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Preface

Why This Book?

This book seeks to address the needs of life-cycle management (LCM), while presenting the current practice in both large and small firms. Furthermore, although LCM is established in several organisations, often integrated into environment, health, and safety (EHS); new product introduction; and design teams, the authors acknowledge that for a great majority of potential practitioners there remains uncertainty as to how to implement environmental management in a cohesive manner. For example, for a non-expert in environmental management (EM), environmental management systems (EMSs), life-cycle assessment (LCA), and environmental performance indicators (EPIs) are often viewed as being the same, despite clear differences (see Glossary). Furthermore, existing voluntary programs, such as the International Organization for Standardization’s (ISO’s) 14040 series, can be both restrictive and, for many, vague and not sufficiently operational. Therefore, for the great majority of firms, where product and site-related environmental issues are treated separately and where the same director or team manages environment and safety, the integration of new environmental concepts is difficult. There is also a debate within many companies and industry associations as to which program should be subscribed to and where the priorities should be set. For small- and medium-sized enterprises (SMEs) in particular, this poses a dilemma. For example, integrated product policy (IPP) is advocated by the European Commission as a public policy explicitly aimed to modify and improve the performance of product systems. Therefore, there is a responsibility of manufacturers, linked to a partnership with authorities and, for many, an unprecedented need, for supply-chain communication and cooperation. When these programs are viewed through a business filter, which seeks to have expedient and validated (eco-)indicators and metrics, one realises the confusion that can exist.

At the outset of the three-year study that preceded this document, the SETAC Europe Working Group on Life-Cycle Management was charged to examine if LCM could be a tool to alleviate the aforementioned difficulties in implementation. Therefore, this book seeks to examine LCM, define the needs for instruments, and itemise, via case studies and benchmarks, the LCM toolbox components that exist and are in practice today. With this contribution, the authors hope to provide support and guidelines for the further implementation of LCM in businesses.

David Hunkeler, Geneva, May 2003
Acknowledgements

This book is the result of 3 years of deliberations by the Society of Environmental Toxicology and Chemistry (SETAC) Europe Working Group (WG) on Life-Cycle Management. The active members of this WG are listed in alphabetical order below. The authors of this book thank all those who presented their material during invited sessions, as well as those who provided input from a distance or as comments from related WGs or SETAC-related activities and conferences. Additionally, the authors greatly appreciate Walter Klöpfer’s willingness to elaborate a detailed review of the early versions of this book. His suggestions helped tremendously to improve critical parts and to shape and expand the final version. Finally, a special thanks is offered to all those who went before us, most particularly Michael Royston, whose book Pollution Prevention Pays seems, in retrospect, decades ahead of its time.

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1 All affiliations were current at time of the working group’s deliberations.
Introduction: Business Perspective
What Life-Cycle Management Should and Should Not Be

There are, at a minimum, 6 audiences for life-cycle management (LCM), each with specific needs. These include:

- multinationals in Organization for Economic Cooperation and Development (OECD) countries,
- small- and medium-sized enterprises (SMEs) (including start-ups) in OECD countries and large firms from developing regions,
- governments (including international governmental organisations),
- nongovernmental organisations (NGOs),
- consulting firms, and
- academics.

This categorisation, arbitrary as all are, requires some explanation. Specifically, while the uses of decision support and management tools differ, clearly, in the competitive and public sectors and between for-profit and non-profit institutions, the authors of this report have also differentiated between the first and second categories based on the risks involved in business decisions. Briefly, while the consequences of suboptimal resource allocation decisions, in the case of this book, in regards to environmental management (EM) affect the short-term bottom line and perhaps midterm profitability of multinationals, they have, generally, sufficient means to redefine environmental programs and their associated investments. The same is not the case with either SMEs from the OECD countries or large firms from developing regions. Both of these have much more restricted access to credit, and the consequences of a large allocation error can lead to serious liquidity problems. In the area of EM, therefore, these firms face similar risks and consequences due to late adoption of EM, exclusion from supply-chain markets that may account for a large fraction of their sales, and higher credit terms due to lack of compliance, even to voluntary international standards. On the other hand, several sustainable market indices, which outperform the Dow-30, show that advantages in terms of enhanced competitiveness are evident in the long term, while share price volatility is reduced, through environmental pro-activism. Therefore, this book presents an approach to and a toolbox for LCM used by multinationals, SMEs, and start-ups alike. It is important to note that environmental decision-making in the public sector has been treated elsewhere (see, e.g., Allen et al. 1997) and will not be the topic of this document. Herein, the authors focus on corporate strategies to implement better environmental practice, recognising the need not to restrict firms to create perfect products, but rather to develop a means, which fits into existing corporate culture, for continuous product improvement from both economic and environmental perspectives.

It is clear that the integration of environmental and economic thinking within firms, often with technological information for product groups, is progressing. However, the Society of Environmental Toxicology and Chemistry (SETAC) Europe Working Group (WG) on LCM saw a risk that LCM, if undefined and unspecific, would offer little to end-users, particularly SMEs, which require clearer guidelines. Therefore, as one
shall see throughout this book and in the recommendations given, LCM maintains its flexibility and generality while being applicable in specific instances to product families and providing clear evaluative means by which a firm can evaluate its progress. This document will demonstrate that LCM, despite some initial confusion related to the terminology, is being practiced in industry today. After the introduction in Chapter 1, the concept is defined in Chapter 2. Chapter 3 provides the key drivers and entry gates within a firm, and Chapter 4 presents benchmarks and cases. The Appendix is intended as a supplement, providing the historic rationalisation of the definition of and the role of supply-chain management (SCM) in LCM.

**Environment as Core Business**

The authors have examined environmental business policy on 2 axes, according to the proactive nature of the firm, as well as the type of focus on the product. Figure 1-1, therefore, categorises firms into those that are compliant, informed, market driven, and sustainable. Many advocate the latter as a long-term competitive advantage. Firms that are listed on sustainability indexes have been shown to have long-term advantages in terms of competitiveness, market penetration, share price evaluation, reduced volatility, and cost reduction, as has been documented in several surveys (see, e.g., Huang and Hunkeler 1996), and will be elaborated upon in this book. Informed firms anticipate the development of future regulations, another quite common motivator, in Europe, North America, and Japan (Hunkeler and Huang 1996). Finally, market-driven firms seek efficiency and address customer and supply-chain environmental concerns and sustainability.

**Strengths–Weaknesses–Opportunities–Threats Analysis of Life-Cycle Management**

Because LCM is still being refined, the working group thought it prudent to carry out a strengths–weaknesses–opportunities–threats (SWOT) analysis. This places LCM within a typical business framework and is consistent with evaluations made in new project planning.

![Figure 1-1 Categorisation of environment as a core business (reprinted with permission from Saur 2001)](attachment:image)
within large firms and business plans in startups. Table 1-1 summarises the key points in the LCM-SWOT analysis.

While SWOT analysis may not be common to environmentalists, it is a current business concept used to judge the suitability of new investments, as well as the positioning of a firm within a sector. For LCM to be adopted in practice, it will have to pass several internal, confidential, SWOT-like analyses. Therefore, Table 1-1 is used as an example, prepared by the working group, of the perceived strengths and significant opportunities of LCM for industrial and consumer-based products. Awareness of the weaknesses that are inherent in any system or toolbox, in this case, as well as the threats is important. As an example of the latter, firms typically introduce programs with the aim of having internal adoption within twelve months. If LCM is to pass such criteria, then it will have to bridge culture gaps with accounting and manufacturing divisions and to communicate a clear vision that can be understood and used by financial, technical, and managerial staff alike.

**Typical Uses of Life-Cycle Management**

Based on presentations from the SETAC WG, which included a majority of representatives from large and small industry, as well as external presentations, a brief, non-exhaustive list of the most common corporate uses for LCM has been established (see Table 1-2). In general, so as to provide access to information for readers who are interested in following up on specific programs, references are given to large firms for which literature or electronic information is easily accessible. Cases related to SMEs are treated in detail in Chapter 4. A majority of firms commented that it was important that LCM not be a new isolated program but rather fit into existing corporate culture. It was also emphasised that it

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Opportunities</th>
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</thead>
<tbody>
<tr>
<td>LCM links monetary and environmental aspects via systematic streamlined approaches.</td>
<td>Firms can use environmental management to increase market share and protect competitive positions.</td>
</tr>
<tr>
<td>LCM provides businesses with indicators for decision-making.</td>
<td>LCM projects often result in direct cost reductions and increased profitability.</td>
</tr>
<tr>
<td>Businesses and corporations can enhance employee motivation and corporate identity.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Weaknesses</th>
<th>Threats</th>
</tr>
</thead>
<tbody>
<tr>
<td>The win-win optimisation of economic and environmental issues may be restricted to selected examples within a firm, the so-called 'low-hanging fruit'.</td>
<td>If the LCM approach is not benchmarked and does not use validated indicators, it risks making incorrect allocation recommendations.</td>
</tr>
<tr>
<td>Supply-chain integration, as part of LCM, could block LCM's acceptance and widespread adoption.</td>
<td>LCM risks becoming obsolete if it tries to be too ambitious and undefined or unspecified. For example, if LCM is a toolbox and set of approaches with guidance for its applicability in certain sectors or for products, it is useable as a management tool. If it aims to address all environmental problems from certification to declaration to evaluation, it is amiss.</td>
</tr>
</tbody>
</table>

Table 1-1 Strengths–weaknesses–opportunities–threats analysis of life-cycle management
## Table 1-2 Typical corporate applications of life-cycle management

<table>
<thead>
<tr>
<th>Corporate uses of LCM</th>
<th>Example firm or industry association</th>
</tr>
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<tbody>
<tr>
<td><strong>Product-based</strong></td>
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<tr>
<td>New product introduction</td>
<td>3M</td>
</tr>
<tr>
<td>Life-cycle engineering or life-cycle design</td>
<td>DaimlerChrysler</td>
</tr>
<tr>
<td>Continuous product improvement</td>
<td>Unilever</td>
</tr>
<tr>
<td>Environmental product declarations</td>
<td>Asea Brown Boverie (ABB)</td>
</tr>
<tr>
<td>Environmentally preferred products creation</td>
<td>Motorola</td>
</tr>
<tr>
<td>Design metrics development</td>
<td>Philips</td>
</tr>
<tr>
<td>Improved recycling infrastructure</td>
<td>Sony</td>
</tr>
<tr>
<td>Eco-efficiency indicator development</td>
<td>Badische Anilin und Soda Fabrik (BASF)</td>
</tr>
<tr>
<td><strong>Firm-based</strong></td>
<td></td>
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<tr>
<td>Strategy</td>
<td>Volkswagen (VW)</td>
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<td>Heigtened awareness</td>
<td>United Technologies</td>
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<tr>
<td>Condensed information for decision maker</td>
<td>Alcan</td>
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<td>Extended producer responsibility</td>
<td>American Chemistry Council</td>
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<tr>
<td>Record keeping</td>
<td>Ciba</td>
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<tr>
<td>Questions for new environmental studies defined</td>
<td>SNF Floerger</td>
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<tr>
<td>What-if analysis</td>
<td>AQUA+TECH</td>
</tr>
<tr>
<td>Financing</td>
<td>World Business Council for Sustainable Development (WBCSD)</td>
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<tr>
<td>Stakeholder communication</td>
<td>Shell</td>
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<td>Liability management</td>
<td>Storebrand Funds</td>
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<td><strong>Market- and legislation-based</strong></td>
<td></td>
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<tr>
<td>Market tendencies</td>
<td>EU Auto Industry (Light and Recyclable Car Project [LIRECAR])</td>
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<td>Green marketing</td>
<td>Japanese Refrigerator Association</td>
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<td>Life-cycle costing</td>
<td>Ford</td>
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<td><strong>Supply chain-based</strong></td>
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<td>Stakeholder communication</td>
<td>AT&amp;T</td>
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<tr>
<td>Basis to improve client cooperation</td>
<td>Packaging Industry (e.g., aluminum)</td>
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<td>Responding to supply-chain queries</td>
<td>Schneider Electric</td>
</tr>
<tr>
<td>Improving supplier environmental awareness</td>
<td>Volvo</td>
</tr>
<tr>
<td>Data sharing and aggregation</td>
<td>EU Plastics Industry (Association of Plastics Manufacturers in Europe [APME])</td>
</tr>
</tbody>
</table>
was necessary to adapt LCM to a firm’s corporate experience.

**Decision Support**

Surveys in the U.S. and Japan have indicated that, for 57% of the multinationals questioned, market and cost are the primary economic drivers for LCM (Huang and Hunkeler 1996; Hunkeler and Huang 1996). Furthermore, more than 40% of firms were engaged in life-cycle costing (LCC), often for the customer’s benefit, to demonstrate that their product lowered total costs. The majority of firms have combined quantitative and qualitative metrics. It was clearly acknowledged, however, that decision-making goes beyond indicators, with the planned (and stopped) deep-sea disposal of the Brent Spar Shell oil platform in 1995 the best-known example. Firms sought to have a decision support tool that was matrix and life-cycle based, flexible, transparent, iterative, and contained an external value system. Some firms commented that they saw LCM as a means to produce environmental balance sheets. Corporations also sought to combine life-cycle thinking, integrating qualitative and quantitative measures, ideally with the ability to incorporate stakeholder concerns.

**Use of Metrics and Indicators**

Ecometrics are stakeholder-dependent values, which are a prerequisite to manage progress. It has been recently advocated (Hunkeler 1999) that limiting the number of ecometrics risks disenfranchisement (exclusion of some interest groups from the process of EM), while aggregation risks invalidation. One must also realise that, at least within a business context, indicators can be redundant. An example of this is the various stock market and economic performance indicators (e.g., housing starts, unemployment rate), which, over the short term, can even go in the opposite direction. Therefore, while specific metrics are susceptible to noise, both in the economic system and in the environment (e.g., fluctuations in global temperature), composite metrics tend to be short term and lack predictive ability. Corporations have expressed a need for indicators that 1) communicate progress, 2) permit continuous improvement, and 3) permit certification to international standards. Overall, 4 categories of environmental metrics have been defined (Hunkeler 1999):

- micro-ecometrics and eco-efficiency indicators,
- macro-ecometrics,
- individual quality-of-life indicators, and
- sustainable development metrics.

The so-called micro-ecometrics can be regional (e.g., dematerialisation), national (e.g., waste minimisation), or global (e.g., energy consumption). However, few metrics evaluate services, with many techniques geared towards technology. As an example, there are several indicators developed within a Design for Environment (DfE) or for a firm, for example, eco-efficiency, though they often lack validation via systematic studies, that is, they lack the life-cycle perspective which distinguishes LCM from EM in general.

Macro-ecometrics are not predictive or barometric and include items such as the average global temperature, atmospheric compositions, sea level, and earth-based measures such as topsoil levels. Finally, the link from micro-ecometrics to macro-ecometrics is possible, though neither has been validated for sustainability. Furthermore, thresholds are needed prior to application. It should also be cautioned that eco-indications do not measure sustainable development unless proven to do so and can be a form of discrimination if those with power (e.g., financial institutions) are unauthorised to act on the public behalf but use such measures as, for example, credit screens.

**Requirements for an Objective Management Index**

Several of the organisations presented in Table 1-2, and hereafter in Chapter 4, have defined 3 basic elements for the reduction of LCM to business indicators (Hunkeler and Biswas 2000). These elements must

1) be based on quantifiable, validated, investigator-independent data.

2) be scalable so that the results can be normalised to be representative. The ability to generalise may be restricted to a given product line, for certain sectors or for whole industries. Nonetheless, some means of cross-comparison is desirable.
3) combine environmental and economic information while being insensitive to technical details.

If these 3 elements are satisfied, the resulting tools could be used to guide LCM practitioners to assess whether sufficient data have been collected, as well as to determine whether costs or impacts have been underestimated.

**Sustainability**

The purpose of this book is to point out that, while LCM may address product, firm-wide, supply chain, and even multinational issues, the link between the LCM toolbox and sustainability is difficult to establish in the short term. Therefore, one of the underlying recommendations of this report is to strive for 'better practice' rather than inactivity due to a lack of definition, within a business and environmental context of 'best practice'. Having said that, the majority of people seem able to agree on 4 common values: 1) quality of life for individuals and families, 2) preservation of the well-being of the population, 3) maintenance of the environment, and 4) intergenerational responsibility, though the ranking varies quite severely (Schmidt and Sullivan 2002). However, one should recognise that sustainability, coded by the United Nations (UN) in 1992 (UN 1992), is a normative value with some stakeholder groups either not particularly subscribing to it or having very different environmental discount factors (Hellweg et al. 2003). These differences are longstanding and can be constitutionally based.

**What Life-Cycle Management is Not**

LCM involves more than arbitrary or non-validated environmental reporting. As a specific example, gate-to-gate material and energy balances on a given facility lack the systemic perspective. Therefore, prior to defining LCM in Chapter 2, the authors and the WG thought it prudent to list some of the areas and applications where LCM is not foreseen to be the most appropriate approach or toolbox. These include:

- an approach to corporate decision-making,
- a tool to estimate direct environmental and economic costs,
- non-deliberate method providing a means for two-way stakeholder communication, or
- a stand-alone program to integrate legislation.

**The Life-Cycle Management Toolbox**

It is important to underline that LCM is not a collection of individual, existing, specific approaches, such as environmental risk assessment (ERA), LCC, or other compatible approaches defined in the Glossary. As a preview to the definition and case related to LCM, Table 1-3 provides a categorisation of the elements that are contained in the LCM programs reviewed by the present WG. The tools listed are either named after the organisation using them or by a specific method, some of which can be found in the Glossary (if they are not self-explanatory). At present, we seek to illustrate the multidisciplinary nature of LCM and the fact that all of the methods seen to date are largely comprehensive and incorporate significant extra-firm based activities. For an analytical overview of components of the LCM toolbox, see Wrisberg et al. (2002). The authors should also emphasise that the present toolbox, while establishing common elements, will certainly evolve.
Table 1-3: Categorisation of concepts and tools that can be elements of life-cycle management

<table>
<thead>
<tr>
<th>Organisation or method</th>
<th>Product life-cycle perspective</th>
<th>Continuous improvement</th>
<th>Integration (environment + economics)</th>
<th>Environmental management</th>
<th>Eco-labelling and communication</th>
<th>Supply-chain management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Environmentally Preferable Purchasing (EPP)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Product-Oriented Environmental Management System (POEMS)</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
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<tr>
<td>Promille</td>
<td>✓</td>
<td>✓</td>
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</tr>
<tr>
<td>ABB-LCM</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Life-cycle engineering (LCE)</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>dk-Toolbox</td>
<td>✓</td>
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</tr>
<tr>
<td>Philips</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>Environmentally Conscious Decision Support System (EcoDS)</td>
<td>✓</td>
<td>✓</td>
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<td>Hartmann</td>
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<td>Ford</td>
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<td>DaimlerChrysler</td>
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<tr>
<td>Environment Canada</td>
<td>✓</td>
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<tr>
<td>Unilever</td>
<td>✓</td>
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<tr>
<td>Chalmers</td>
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<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>entwicklungsbegleitendes Instrument für umwelt-</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
<tr>
<td>und recyclingorientierte Materiallösungen (euroMat)</td>
<td>✓</td>
<td>✓</td>
<td></td>
<td>✓</td>
<td></td>
<td>✓</td>
</tr>
</tbody>
</table>
Definition of Life-Cycle Management

This chapter presents the life-cycle management (LCM) concept and discusses its role for management and business strategy in organisations, multinational corporations, and small- and medium-sized enterprises (SMEs) alike. It also proposes a definition of LCM and describes how LCM is related to established and emerging environmental management and business concepts and tools. The features needed and available in the LCM toolbox, as well as the relationship between LCM and other current tools, such as integrated product policy (IPP), life-cycle assessment (LCA), pollution prevention, and Design for Environment (DfE) are discussed and defined in the Glossary.

The Environment in the 21st Century Business Climate: Motivation and Positioning

Increasing globalisation, revolutions in information technology, rapid process and product innovations, and a volatile marketplace are changing and shaping the present business climate. Decision-making in multinationals is also becoming increasingly complex, with cross-functional groups often charged to make choices rapidly with increasing degrees of uncertainty. The latter is certainly, in part, related to the speed of information, a multinational focus, and increased supply-chain interactions and cooperations. With each new scientific discovery and technological development, there is a concomitant reduction in the comprehensibility of the social, political, economic, technical, and environmental connections. Making decisions intuitively, or on the basis of simple or linear connections, is, therefore, often no longer possible. If one adds to this the growing amount of information available, the number of factors to be considered in decision-making processes increases.

Together with these pressures, existing infrastructures—governmental, supranational, and nongovernmental alike—have an important influence on the degree to which firms deal with and indeed support the conservation of the natural environment. The planet is thought by some to be reaching ecological limits in critical areas, such as ozone layer depletion, species diversity, and climate change. This realisation is beginning to change the way goods, services, information, and funds are exchanged. This emerging business climate will likely require and demand improvements in current ways of working and measuring the impact of interdisciplinary consequences, including those at the technology—environment—economic interface. This is forecasted to lead to significant shifts in how organisations deliver products and services to 'customers'. Firms in many sectors are effectively using management systems and LCAs to understand and improve their operations and products (goods and services). However, in order to make improvements that will significantly reduce the pressure on natural systems and
successfully respond to complexity in decision-making and other characteristics of the emerging business climate, a more comprehensive approach is needed. Specifically, the authors of this report believe that the economy of this century will increase its value added and knowledge content per unit of material and energy content. This will require improvements in resource productivity and innovative new approaches to the production and consumption of products. It will also require one to define indicators or metrics for the measurement of such progress, and the validation of system boundaries and functional units for the analyses. Overall, continued economic development may very well be dependent upon ecological and social sustainability. By making information and incentives part of core decision-making and operations, this level of change is possible and intrinsically advantageous from a business perspective. This chapter discusses LCM as a business strategy for a successful, effective, and sustained response to the challenges of this business climate.

**Environmental Management as a Business Opportunity**

Given the character of the emerging business climate, it is essential to assess and evaluate new products and services for their material and energy efficiency. Business opportunities exist, for instance, for products that require less energy and resources, generate less waste, or contain fewer regulated substances. A sustainable business strategy could realise this parallel for environmental and socioeconomic impacts, as is seen in examples such as the reduction in the transportation burden via localised home offices and the coordination of transportation logistics throughout the supply chain. In such a strategy, decisions regarding societal, economic, and environmental improvement will likely look to the overall performance of a product and a service, not only to the manufacturing or use. Thus, life-cycle considerations, including resource use, transportation, product, component, or material reuse or recycling and disposal, are most effective to assess overall systems. Because a life-cycle perspective can identify the tradeoffs between manufacture, use, and end-of-life requirements, the authors believe it will be essential to integrate this perspective into the decision-making process.

LCM, as will be shown, is a broad concept, which can be integrated into an organisation's objectives. For example, for firms with a strategy aimed at complying with existing regulations, a system that identifies and tracks releases offers the benefit of reducing liabilities and potential fines. Moving further, firms may identify opportunities for cost savings and improved efficiency of resource use. Conscientious consumers and public sectors can lead to increased revenues, an enhanced image, and increasingly, a more favourable position with market analysts. Some companies will identify product or service adjustments that improve customer satisfaction, while others who integrate full system considerations into the core operations will define new technologies and innovative change. Overall, integrating efforts into core operations and decisions often allows a more transparent cost structure and reduces false starts and low-yielding investments. This is seen in the performance of some sustainable mutual funds, whose element of environmental risk screening identifies sets of firms that generally outperform the broad-based and technology-sector stock indicators.

To realise the aforementioned benefits, organisations have begun to address environmental aspects of their operations and products through environmental management systems (EMSs) and life-cycle studies or assessments. While tools such as DfE can achieve improvements and initiate some change, their scopes are limited and they can fall short of enabling an organisation to realise sustained benefits from their efforts. Specifically, the tools and metrics used, unless validated by larger internal or supply-chain coordinated studies can be invalid. Two excellent illustrations of how life-cycle thinking identifies procedures for implementation are given in the automotive cases in Chapter 4. Interactions with the environment do not occur in isolated instances and thus must be considered in decisions at all, or at least most, levels within an organisation. For example, while EMSs draw a picture of the organisation, they do not generally provide the systems perspective needed for informed decision-making. Therefore, in LCM and its tools, the key unit is the product, throughout many organisations, rather than the firm or the physical limits of a facility. This company-oriented, procedural approach to improving a firm's environmental performance also lacks detailed techniques that will support decision-making. On the other hand, quantitative information gained from an LCA
of the impacts from an existing product is not generally viewed by the business community as an integrated part of how an organisation operates or makes decisions. Such assessments lack interaction with management systems, links to strategy, and aspects of continuous improvement, as discussed in the case study in Chapter 4 referring to 3M's procedures.

While LCA studies can provide a more complete view than EMSs, they are usually based on retrospective data, which may be out of line with future-oriented decision-making. Decisions that do centre on information from an LCA, such as the resource efficiency and environmental compatibility of the product studied, in turn do not comprehensively link information on economic requirements or social aspects with environmental improvement, including our existing and possible future social systems. Thus, firms relying on an EMS or LCA to inform their improvement efforts will likely lack several key elements for success.

Clearly, there is no single program or technique capable of an overall answer with respect to environmental decision-making and choices about improving operations, products, and services. However, for an organisation to respond to the decision-making challenges of this business climate in an economically and environmentally sustainable manner, it will probably have to go beyond environmental management (EM), at the minimum, for some products. An approach that identifies economically viable and environmentally compatible solutions is, therefore, needed.

Defining Life-Cycle Management: First Approach

LCM addresses the needs discussed in the previous section and is normally integrated into an existing or new business strategy, rather than being a stand-alone program. It is most effectively implemented as a direct cost in production, design, or marketing via product teams, rather than grouped as on overhead issue (indirect cost) in an environmental health and safety (EHS) department.

The LCM concept can be considered as a system or framework for improving organisations and their respective goods and services. Decisions taken at all levels of an organisation will influence the overall impact a product has throughout its life cycle. Therefore, the framework is integrated at all levels of the organisation, effectively in marketing, purchasing, research and development, product design, strategic planning, corporate reporting, and management. To reach these levels, LCM will have to remain flexible. In terms of implementing LCM, concepts, programs, and techniques (tools) are all required. A life-cycle framework addresses improvement to technological, economic, environmental, and occasionally, social aspects of an organisation and the goods and services it provides. Overall, the framework is for improvement that is continuous and based on a full system or life-cycle perspective. Therefore, the LCM concept is an integrated system for improving operations, products, and services that ensures information and decisions from a life-cycle perspective and, quite often, is seen to improve decision-making by placing better information in front of decision-makers.

LCM has recently been discussed and defined by many organisations, academia, and government bodies (Christiansen et al. 2001; Udo de Haes et al. 2002; UNEP 2002). Integration in the organisation is surely the key, common defining element. It is also widely agreed that an LCM approach is an approach for decision-making in organisations and not to be used as a public policy or allocation tool, for which other methods are much better suited. The approach ensures that information for decisions comes from the whole or a significant part of the operation, product, or service, which clearly requires interaction along the supply-produce-use-dispose chain. Clearly, a key to LCM is to establish validated methods for determining which function within a firm should be involved for a given product type, market, or supply-chain structure. To carry this out, the majority of descriptions of LCM discuss concepts, methods, and specific tools that are all needed.

Prerequisites for success in an organisation

As organisations are rediscovering, there are several factors, of which one or more are required, for progress and success in improving products and operations. Success is most likely in firms that recognise that environment in a sustainability context goes beyond compliance. A full systemic, or life-cycle, perspective is essential to understand all impacts associated with operations and product systems and their interrelations in order to control and manage
them. Another factor for success is the availability of competence and champions in the organisation, as is best seen in organisations such as Texas Instruments. The list includes pioneers, such as 3M’s former president who initiated the Pollution Prevention Pays (3P) program in 1975 (Royston 1979), and advocates, such as AT&T’s Braden Allenby. Also included in the list is commitment from top management and its continuous support.

A Strategy to Adopt Life-Cycle Management

Organisations use LCM frameworks to explicitly identify, document, and communicate their existing business strategy and, secondly, to chart a course from this strategy toward a more sustainable firm. An operational definition for making sustainability accessible in this way might be the ‘integration of life-cycle environment, health, safety, resource productivity, and social responsibility into core business practices to achieve business benefits’. In the following section, examples of how firms spin LCM into functional programs are categorised.

Broader definitions of the environment

To render sustainability accessible, the definition of ‘environment’ must be broader than compliance with laws and regulations. Over the past 3 decades, organisations have implemented programs to prevent pollution, which have resulted in substantial savings and increased operational efficiency. The most obvious benefits include reduced liabilities and fines for companies that continually operate beyond compliance with the governing regulations. Many examples clearly illustrate the cost savings associated directly with reductions in environmental releases. Generally, for each unit of pollution emitted, there were costs to purchase it as raw material, costs to process it, costs to expel it as waste, and perhaps further costs to treat or store the waste. These programs are ongoing, and in some cases, organisations expand them to reduce or avoid costs associated with environmental impacts (external cost). It is critical that the strategy is explicitly described, agreed to, and communicated to all employees and stakeholders. If so, an organisation using the flexible framework of an LCM strategy should reap the specific business benefits discussed herein (DeSimone and Popoff 1997).

Reflecting on the ‘vision’ and related behaviours

Adopting an LCM approach to move towards a more sustainable business strategy could have several implications, though only two are frequently cited. First, the overall vision, policy, and strategy may need to be modified. For instance, as one moves from a compliant strategy towards a sustainability strategy, issues are further integrated into existing decision-making processes. As an example, decisions on capital investments, optimisation of existing products, or development of new products will each require considerations, such as the downstream environmental effects and the upstream social implications. Second, the behaviour of the organisation, its management, its employees, and its shareholders must all alter to reflect this new vision and direction.

Mutual opportunities along the product chain

A broader definition of environment should now apply to the supply chain or life cycle of goods or services provided by the organisation. Opportunities exist for economising resource consumption, saving energy, avoiding costs for redemption and abatement, enhancing image, and generating revenue along the supply chain where partnerships and business alliances are growing. Thus, LCM enables firms to gain and maintain competitive advantages and cost savings through cooperation with business partners. A sustainable strategy enables essential dialogue within the value creation chain, with authorities and with stakeholders. As a result, all related actors along the chain both contribute to and benefit from this approach. For example, if a supplier and a producer cooperate to identify and reduce the hazardous chemicals in a supplied component, the results are increased customer safety, reduced handling and disposal costs, and improved overall environmental

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[1] One must keep definitions of business sustainability as a subset of larger environmental goals. The facts that only 2 of the 10 largest firms in 1900 were multinationals a century later and only 3 remained in existence provide an important impetus for government-industry coordination and cooperation.
performance. The supplier and the producer may also have established a deeper cooperative relationship and both have a clearer picture of their opportunities in the product chain. Slightly more elusive benefits have included the potential to identify mutual synergies among firms along the supply-produce-use-dispose chain and to discover breakthrough technologies. Examples of this are increasingly common, particularly in supply chains, which are dominated by multinationals, or with strong trade associations.

Life-cycle management (LCM) extends actions beyond the organisation, so that firms in the supply chain are linked and able to make comprehensive, product-oriented environmental improvements.

Enhancing existing structures and procedures in the firm

The existing structures and procedures in the organisation can be enhanced within an LCM concept or approach. On a second level, the specific environmental work already in place in the organisation, such as EMS or isolated environmental redesign initiatives, can be better conceptualised and structured within an LCM approach. Therefore, LCM provides relative, streamlined comparisons of alternative choices and outputs with results in a concise form suitable for mid- and top-level corporate decision-makers. LCM permits key information to be readily integrated into operational decision-making to ensure consideration of issues beyond immediate financial concerns and beyond the organisation's gateways. More specifically, LCM is easily integrated with existing corporate structures, such as total quality management (TQM). In the interest of integration, the uptake and implementation of LCM into TQM, for example, should be managed by existing teams and not by new or isolated 'environment' teams.

Improving products and services, from an environmental perspective, is associated with the use of several 'environmental improvement' concepts and tools such as LCA (life cycle assessment), product stewardship, supply chain EM (environmental management), or DfE (design for environment). The complete LCM toolbox, as it stands today, was discussed in Chapter 1. The intent of each tool is to help ensure that future decisions will not result in unintended and adverse consequences to the environment. Looking beyond only environmental improvement, it is understood that a primary goal of tools in general is to promote more informed decisions. However, environmental assessment and decision-making tools are most often developed in the academic sector and are often not tailored to the individual needs of private and public organisations. As a result, they do not align with or support a firm's immediate decision-making needs. It is, therefore, necessary to bridge the gap between the tools available and the decision support needs in public policy-making and in the private sector.

Executive surveys in the private sector have concluded that it is of utmost importance to realise a reliable and fast-responding system for decision support, as informed decisions are to be made in organisational planning and in the design and research and development framework (Huang and Hunkeler, 1996). To define, demonstrate, and enhance the value of integrating environment in organisational decisions, firms need help to understand the different levels of tools, such as strategic and tactical tools, and also to understand how and by whom these tools are developed. Ultimately, success will likely, or more expediently, be achieved with tool development that is better integrated with the way decisions are made, resulting in management tools that help to simplify complex interactions and present knowledge to decision-makers in a useful way. With an LCM approach, organisations may modify existing tools, techniques, and decision processes to help them effectively link the performance of their organisation (e.g., customer satisfaction) with environmental performance. Once this occurs, the shift from development into practice will be clear.

As industry moves toward comprehensive environmental, product-related programs, it requires the availability, validation, benchmarking, and documentation of EM metrics for given products, sites, and sectors. The international standardisation of EM is documented by the ISO 14000 series, and a number of product- and organisation-related EM tools are treated within this series and could be considered a preliminary list for an LCM toolbox. However, a number of questions remain because they are not treated by the standards (Finkbeiner et al., 1998). For example, which of the tools should be applied to which EM problem? Furthermore, what are the synergies and antagonisms between these tools? LCM addresses these questions through its justification of simplification.
via validation. Specifically, as a management concept, LCM normalises itself against other practices and uses these conclusions to streamline subsequent decision processes. Businesses that link LCM with traditional product teams seem able to make 'better informed' decisions from an environmental and economic perspective. LCM also seeks to identify the correct ranking of alternatives, using metrics and tools that provide such, with an effort that can be justified, both financially and temporally vis-à-vis the competition. LCM is, therefore, a business concept for EM, which is required in the absence of environmentally justifiable tax schemes, and is required, to a large extent, only because the latter does not exist.

**Enhancing core competencies of the firm**

Another major element for making sustainability accessible is the transformation of an organisation's core competencies to include competencies related to environmental, social, and economic considerations. For example, improving the capabilities of the environmental professional to use financial management techniques like net present value (NPV) or economic value added (EVA) may enhance how they represent environmental initiatives in a fashion to make them comparable to other capital investment decisions. Internally, benefits of a sustainability strategy include a more transparent cost structure and the ability to avoid false starts and wrong investments.

Improving the environmental performance alone is not the intention of the LCM approach. Value for the business and its stakeholders is at least as important, and competencies that support this core goal need to be enhanced. Indeed, surveys of entrepreneurs, carried out in 2001 (Royston and Hunkeler forthcoming), have noted that customer, investor, and employee satisfaction are the 3 key functions a board and the president of a company address. As new issues impact these functions, as the environment has, managers adapt. The same respondents believe that other factors, seeming critical, such as marketing, pricing, and shareholder value, are subsets of the aforementioned 'satisfactions'. Improvement to operations, products, and services that satisfy both ecological and economic demand is the intent of LCM. One balance between the ecological impacts and the economical aspects is called 'eco-efficiency' (EE) and can be used as the yardstick to position environmental challenges for industry, provided that the indicators used in EE are validated on the basis of systemic studies. Methods based on LCA or risk assessment can be used to assess the ecology parameter. Life-cycle value (LCV), life-cycle costing (LCC), or cost of ownership (COO) can be used to assess the economy parameter (e.g., see Rebitzer 2002). Human factors are an essential additional ingredient, and there is movement in many scientific and industry-wide organisations to include social parameters within their comprehensive studies.

**Advantages of leadership**

One can see a certain competition for leadership with respect to sustainable goods and services. Companies implementing these programs first benefit from increased resource and energy productivity, as well as the additional revenues and image gains, as is always the case when a pioneer creates or satisfies a demand. The rate of implementation seems also to be driven by the specific nature of each business sector, with visible consumer goods as well as the materials sectors leading the way.

If LCM and its tools do not lead to a competitive edge and link to business benefits such as those described previously, they are unlikely to replace EM or move from an indirect expense in an EHS division to a direct cost reducer in production. This implies that the added value has to be clear in terms of environmental care, TQM, cost savings options, or market share improvement and brand imaging. Ultimately, firms can become successful leaders when they link environmental issues with 'brand image', as, for example, was the case with Philips and its low mercury lamp or United Technologies with its green engine.

**Conclusion: What is Life-Cycle Management?**

While the Appendix provides a perspective on the evolution of the deliberations of the SETAC LCM working group (WG), the following definition was accepted at the conclusion of the 3-year study:

- LCM is a practical and integrated approach to minimise the environmental burdens associated with a product over its life cycle. It is a concept that may be useful in moving towards sustainable
development and a means of linking environmental improvement with economic efficiency.

- LCM is applied on a voluntary basis and can be adapted to the specific needs and characteristics of individual organisations.
- LCM facilitates transparent internal and external communication.
- LCM's toolbox makes use of existing environmental tools and management systems, which may include national or international voluntary standards and validated indicators or metrics.
- LCM supports the business assimilation of IPP, eco-labelling, DfE, green procurement, and other product- or market-related business or government initiatives.
Entry Gates and Drivers

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In this chapter, entry gates to and drivers for life-cycle management (LCM) are presented. The entry gates typically correspond to a function within an organisation, such as manufacturing, research and development (R&D), marketing, or environmental health and safety (EHS), while the drivers identify which of these units—top management, finance, and legal included—have initiated, funded, and provided the continued support for LCM policies or projects. The chapter illustrates that, regardless of the entry gate selected and the LCM drivers that are in place in a given organisation, it is possible to install a coherent LCM implementation strategy whose results, economic and environmental alike, can be validated. Chapter 4 includes examples where strategy implementations are demonstrated. These cases complement the toolbox that was presented in Chapter 1.

Entry Gates

Several entry gates into LCM, corresponding to corporate functions, such as manufacturing, finance, legal affairs, or top management, have been documented. Traditionally, the focus of environmental activities within a private firm has been on the potential impacts from production, while the indirect environmental effects attributable to other functions, such as purchasing, sales, or marketing, have generally been ignored. LCM focuses on the total potential environmental impacts from products throughout an organisation or its supply chain. This includes, at the minimum cursory analyses, all departments in the organisation, including management, product development, logistics, customer relations, and transportation, in addition to those named above. The following list summarises the possible entry gates in an organisation in descending order of occurrence:

- EHS
- R&D
- Top management
- Production
- Procurement
- Sales and marketing

The relations between various functions within a firm and the dialogue along the supply chain are elements of LCM (Schmidt K et al. 2000). It should be noted that, while EHS still dominates as an entry gate, several firms in the vanguard, such as 3M and Dow, have had their programs initiated by chief executive officers (CEOs). Furthermore, with the acceptance of the ISO 9000 and 14000 standards, production and procurement are increasing over the past 5 years as entry gates within organisations and are providing an impetus for firms to refine their LCM programs and communication.

In the ‘Entry Gate’ and ‘Driver’ sections of this chapter, there will be an emphasis on the management of the organisations, research and development, procurement (supply chain), production and distribution, and sales and marketing because these are the most typical departments that initiate,
Life-Cycle Management

fund, and motivate LCM. It will be shown that the aforementioned environmental activities embrace the strategic, tactical, and operational levels.

**Management**

As stated in systems such as ISO 9000 and ISO 14000, it is the top management that ultimately has to ensure that specific policies are put into practice in certain areas. It is also the management that defines the policies of the organisation in regards to issues such as environmental management (EM) and that, in some countries, bears the ultimate legal responsibility for the decisions. Depending on the corporate culture and the nature of communication, LCM can be driven by top-down or bottom-up approaches. When the management seeks to implement LCM, it has a key role to play in the internal justification of resource allocation to this new function. It is also, generally, the intermediate managers who decide if LCM teams are created anew or integrated into existing structures, most frequently new product introduction or R&D teams. When LCM is introduced within an organisation, a common step is to survey the information routes. An organigram of the firm and its co-operative partners, including suppliers and customers, can be a very useful tool in communicating the advantages of life-cycle and supply chain considerations to issues as diverse as pricing, product development, and legislative compliance (e.g., take-back). LCM as an approach is associated with brand enhancement and possibly a leadership position. Corporate reporting can, therefore, be an important entry gate in this respect.

**Research and development**

In R&D departments, including design and engineering, many decisions concerning a product or its modification are taken under intense time pressure. These can include key issues that have long-term implications, such as the energy consumption during use or production, the choice of materials used for the products, and the amount of waste that will be produced during production or after use of the products. Clearly, a large fraction of the future economic and environmental costs, as well as the environmental possibilities concerning a product's end-of-life options, are fixed during design. The integration of environmental aspects into product development and design (ISO 2002) is, however, not the only important issue. Designers can also be an entry gate into LCM, if they identify alternative goals or develop gray lists of materials or checklists. Most often, a vision as general as 'we are interested in producing greener, economically viable, products' leads developers, during their quick design cycles, to observe elements that contribute to the life-cycle burdens (Hunkeler and Vanakari 2000). Therefore, the role of continued communication is that it provides a faster feedback loop between those who drive LCM and those who practice it. Examples of the integration of environmental aspects into product development are quality function deployment (QFD) (Ryding 1995) and toolboxes such as environmental development of industrial products and processes (EDIP) (Wenzel et al. 1997).

**Procurement**

The activities of the purchasing department influence the environmental performance for the product from the organisation later in its life cycle, if for no other reason than pricing. In LCM, life-cycle assessment (LCA), and systematic studies in general, 2 key issues are the definitions of system boundaries and of the functional unit. The latter is critical in assessment because consumers purchase, or lease, utility. Therefore, price influences consumption and the substitution of alternative products and services. Purchasing influences the direct costs and the product planning and, as such, is a key element in evaluating the system-wide, or per unit, environmental burdens and costs, because purchasing contributes to the ultimate product density in the marketplace. If one realises that life-cycle costs and impacts, for a given inventory, scale with each other in many instances (Hunkeler and Biswas 2000), the pricing influences the overall and per-unit environmental burdens. Purchasing departments are also critical in implementing the conclusions of LCM such as banned material lists (black and gray lists). The departments can be the entry gate via their awareness of what purchasing departments in competitors or supply chain partners are doing.

**Supply chain**

An organisation's procurement policies and procedures are common and effective gates by which LCM can develop in the firm. Working with suppliers and supply chain issues is rapidly increasing as an important strategic consideration. Traditionally, enterprises manage suppliers in order to optimise the supply chain;
track flows of information, materials, and funds; manage the logistics of supply and distribution; minimise cycle times and costs; and integrate processes and functions along the supply chain (Seuring 2001). An LCM framework is set up for continuous improvement and is based on a full system or life-cycle perspective; thus, supply-chain management (SCM) practices are an entry gate for LCM. Most importantly, existing SCM practices clearly will be enhanced by such an approach.

Firms are requiring suppliers to divulge information about the goods they supply, such as materials and substances used and systems for tracking and management of environmental impacts. As a supplier firm receives these requirements, they in turn pass requests along their supply chain. An organisation that is unsure of how or where to begin can use an effective procurement policy to learn and benefit from the efforts of other firms in the chain. Alternatively, firms who are leading can improve the performance of up- and downstream suppliers by collaborating on programs, tools, and efforts. Thus, the understanding of environmental impacts through the supply chain can extend into other parts of the organisation to begin a more comprehensive and integrated LCM approach. This comprehensive approach might also serve to align the improvement progress of the chain, and ensure the exchange of usefully formatted information.

'Producers are decreasing the number of suppliers they deal with and establishing collaborative relationships (Garcia 1999) and risk-sharing with those that remain' (Hall 2001). This is particularly true in established industries such as the automotive sector and in aerospace, where a contraction in the number of manufacturers has been observed over the past 2 decades.

'The complexity of the product chain is likely to decrease (Garcia 1999) as this trend progresses' (Hall 2001). Despite decreasing complexity, firms are outsourcing the assembly and sub-assembly of components, the supply of full systems and the design of components and whole systems, more as a rule than an exception (Hall 2001). Therefore, there are 2 key reasons for a firm to build solid, interactive relationships with suppliers (Hall 2001):

1) To ensure that an externally designed component system meets all requirements, a firm must effectively interact with its suppliers.

2) As firms search for the most effective and efficient point to make improvements along different stages of the product life cycle, they will inevitably have to act at points beyond their internal operations. Effective relationships are forecasted to be essential to finding the best points at which to act and to developing efficient actions.

**Production and distribution**

Traditionally, production and distribution are considered to be core elements in private organisations in virtually all areas. LCM challenges such structures to determine how they contribute directly to life-cycle costs and environmental burdens, rather than assign an indirect impact or cost, as has been the tendency with calculations in the past, which assigned an environmental overhead. The shift of the environment expenses to direct costs, as is the case in multinational conglomerates such as United Technologies, implies the need to transfer product, market, and supply chain information in a reliable manner throughout the organisation. Therefore, when production is an entry gate, it requires partnering from management, and likely information technology (IT) departments, to coordinate information exchange while ensuring confidentiality. For this reason, many firms have separate programs for internal LCM and external environmental reporting.

**Sales and marketing**

Marketing activities are a key entry gate for an LCM approach to develop in the firm. Experience shows that it is common for a firm's marketing division to externally communicate initiatives for improving environmental performance in a way that exceeds what is actually in practice. This internally generated external pressure has been an unintended but interesting driver that presses firms to implement the programs and tools that they have outlined on paper. While firms responding to consumer and society group pressures may find a competitive advantage from their efforts, such as improved brand image and a perceived leadership position, a firm can also be more deliberate. Marketing is traditionally a 2-way activity, important for gathering information from consumers and potential consumers. Thus, integrating environmental improvement considerations into marketing perspectives and efforts expands the
potential to identify and pursue new markets and niche demands.

Environment, health, and safety
It is clear from the preceding discussion that the environmental department does not need to be the entry point for LCM. While the maturity of environmental awareness and efforts for improvement will differ at each of these ‘gates’, an LCM approach should clearly demonstrate the economic rationale, foster awareness, encourage efforts, and support their integration with the key functions and decisions at each ‘entry gate’.

The management link between the entry gate and the driver
The research and development department of an unnamed multinational had, based on internal environmental goals, decided to phase out a grey-listed substance. This target was transmitted to the sales and marketing team, though the purchasing department was not informed sufficiently early and signed a 5-year supply agreement (Schmidt K et al. 2000). This case illustrates the need for continual reinforcement of new objectives, independent of where the program enters a firm. Top management, if not the sole driver, has a complimentary role in supporting new programs such as LCM.

Drivers
Drivers can include a large number of actions, efforts, or demands, which are considered in the following section. The presented drivers are meant to be illustrative rather than exhaustive. Indeed, one will see examples in the Chapter 4 case studies where some firms have unique drivers for LCM, which can include specific product- or site-related issues, strategic visions, as well as reorganisations mandated on certain units. The drivers are categorised, arbitrarily, as internal and external drivers, in reference to a company. As a precondition, all drivers are addressed to the business management. As such, all the drivers will have an influence on the strategy. This choice reflects several surveys (see, e.g., Huang and Hunkeler 1996) that indicate that LCM is becoming more interdisciplinary within a firm. Furthermore, the involvement of top management, finance, and legal departments generally coincides with the extensiveness of the LCM activities. Firms with top-down support of environmental programs, communicated publicly, repeatedly, and internally, also have higher environmental ratings from banks and mutual funds and less variance in the stock price. Clearly, the drivers will affect different entry gates depending on their nature.

External environmental drivers
Global drivers
Several international environmentally, ethically, or socially relevant conventions and accords have been approved and ratified by countries worldwide, although the continued adoption of such agreements has been limited (e.g., the Kyoto Protocol). Other agreements have included targets to reduce or eliminate environmental impacts from the use of energy and chemical substances, or to ensure a minimum standard of human rights. The latter can include variables such as access to clean water and sanitary installations, denied to approximately 1.5 billion people on the globe (Hunkeler 2003). The best example of the former is the Montreal Protocol, which in 1990 phased out chlorinated fluorocarbons (CFCs). Nobel Laureate Mario Molina, who presented the mechanism for ozone depletion, has observed that these atmospheric compositions have changed favourably since, and sees this as the first example that human action can influence global variables.

Based on the aforementioned agreements, which reflect political preferences, the most relevant areas for LCM are individually discussed in the succeeding subsections. This list does not include normative judgments on what should be done but rather reflects the common topics of discussion in the United Nations, G8, and as a part of the North–South dialogue. Many of these conventions and accords will likely act as drivers to design, over extended periods and for visible products, though their incorporation into production seems to require the participation of multinationals from a given industry, such as automotive, electronics, energy, or water, at the table. The following subsections itemise some global drivers, which do not normally dominate a firm’s motivation for LCM, though selected items (e.g., global warming potential [GWP]) are high in terms of organisational awareness.

Ozone-depleting substances
The United Nations Environment Programme (UNEP) has been addressing ozone depletion since 1977 (UNEP 2003a). Under the auspices of
UNEP, the governments of the world arrived at the Vienna Convention on the Protection of the Ozone Layer in 1985 (UNEP 2001). Through this convention, governments committed themselves to protect the ozone layer and to co-operate with each other in scientific research to improve understanding of the atmospheric processes (UNEP 2003a).

The Montreal Protocol on Substances that Deplete the Ozone Layer was adopted in 1987 (UNEP 2000). The Protocol aims to reduce and eventually eliminate the emissions of manmade ozone-depleting substances. It has been amended several times, though, as mentioned in the preceding section, it seems to be yielding positive and measurable results.

Greenhouse gases
The United Nations Framework Convention on Climate Change (UNFCCC 2002) is the centrepiece of global efforts to combat global warming. [It was adopted] in 1992 at the Rio Earth Summit, with its ultimate objective as the ‘stabilisation of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous [manmade] interference with the climate system’. The Convention sets out some guiding principles. The precautionary principle says that the lack of full scientific certainty should not be used as an excuse to postpone action when there is a threat of serious or irreversible damage. The principle of the ‘common but differentiated responsibilities’ of states assigns the lead in combating climate change to developed countries. Other principles deal with the special needs of developing countries and the importance of promoting sustainable development (UNFCCC 2002).

Waste
The Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal was adopted in 1989 and came into force on 5 May 1992:

The Convention is the response of the international community to the problems caused by the annual worldwide production of hundreds of millions of tons of wastes. These wastes are hazardous to people or the environment because they are toxic, poisonous, explosive, corrosive, flammable, ecotoxic, or infectious.

[This global environmental treaty] strictly regulates the transboundary movements of hazardous wastes and provides obligations to its parties to ensure that such wastes are managed and disposed of in an environmentally sound manner. (UN 2002a)

Biodiversity
The objectives of the Convention on Biological Diversity are

‘the conservation of biological diversity, the sustainable use of its components and the fair and equitable sharing of the benefits arising out of the use of genetic resources’. The Convention is thus the first global, comprehensive agreement to address all aspects of biological diversity: genetic resources, species, and ecosystems. It recognises, for the first time, that the conservation of biological diversity is ‘a common concern of humankind’ and an integral part of the development process. To achieve its objectives, the Convention, in accordance with the spirit of the Rio Declaration on Environment and Development of 1992 [UN 1992], promotes a renewed partnership among countries. Its provisions on scientific and technical cooperation, access to genetic resources, and the transfer of environmentally sound technologies form the foundations of this partnership. (UN 2002b)

Prior informed consent
In March 1998, 95 governments finalised the Rotterdam Convention on the Prior Informed Consent (PIC) Procedure for Certain Hazardous Chemicals and Pesticides in International Trade (UN 2002c). The Convention represents an important step towards ensuring the protection of citizens and the environment in all countries from the possible dangers resulting from trade in highly dangerous pesticides and chemicals.

Persistent organic pollutants
The UNEP Convention on Persistent Organic Pollutants (POPs) was adopted in Stockholm, Sweden, on 22 May 2001:

The Stockholm Convention is a global treaty to protect human health and the environment from [POPs]. POPs are chemicals that remain intact in the environment for long periods, become widely distributed geographically, accumulate in the fatty tissue of living organisms, and are toxic to humans and wildlife. POPs circulate globally and can cause damage wherever they travel. In implementing the Convention, governments will take measures
to eliminate or reduce the release of POPs into the environment. (UNEP 2002d)

**Forests**

Agenda 21, the Rio Declaration on Environment and Development, and the Statement of Principles for the Sustainable Management of Forests were adopted by more than 178 governments at the United Nations Conference on Environment and Development (UNCED) held in Rio de Janeiro, Brazil, 3 to 14 June 1992 (UN 2003).

**Human rights**

Human rights considerations may also be relevant in LCM because, for instance, slave work and child labour are not sustainable. Several international agreements exist; for instance, on December 10, 1948, the General Assembly of the United Nations adopted and proclaimed the Universal Declaration of Human Rights . . . . Following this historic act, the Assembly called upon all member countries to publicise the text of the Declaration and ‘to cause it to be disseminated, displayed, read and expounded principally in schools and other educational institutions, without distinction based on the political status of countries or territories’. (UN 1948)

The first Convention on the Rights of the Child was adopted and opened for signature, ratification, and accession by the UN General Assembly Resolution 44/25 of 20 November 1989. Two optional protocols were adopted by the UN General Assembly on 25 May 2000 (General Assembly Resolution A/Res/54/263) (UNICEF 2003).

**Market drivers**

Market demands are considered as an effective ‘pull instrument’. The instrument is used in all markets, varying from monetary to service to goods. Since the 1930s, these public demands have been used as a formulated instrument. In terms of opportunity, the market offers significant advantages to firms that are the first to move on these issues, and this is demonstrated in practice and documented in recent literature such as well described examples from Electrolux (Charter 1997) and Xerox (Earl and Clift 1998). Thus, leading companies are linking LCM initiatives to increased market share and enhanced potential to market innovations.

Large consumers, generally multinationals and governments, are not only more responsive to the performance improvements that firms demonstrate, but they are very often demanding such improvements (Erdmenger 2003). Public procurement policies can be very specific about systems for environmental management (EM), materials content of certain products, as well as the sourcing and disposal practices of the firms they buy from. Eco-labelling acts as a driver for improved sustainability in certain product groups or service sectors. It sets performance criteria, and these criteria often define the minimal level consumers will expect. A deliberate and comprehensive LCM system will ease the work needed to achieve product labels as the organisation has operationally defined their efforts toward sustainability.

In the near future, it is likely that environmental product declarations (EPDs) will be a tool in individual private purchasing as well, though the extent and speed with which this will trickle down to the private sector is difficult to estimate. Consumers’ willingness to pay for green products is generally limited to price increases of a few percentage points. However, such a window, which encompasses products with improved life-cycle performance (e.g., higher return on environment [Rebitzer and Hunkeler 2001]) and profitability, is sizable and reaches trillions of dollars per annum.

Without simple cause-effect relationships or the aid of information such as labels, ‘the complexity of environmental issues can pose a problem for customers to express their demands’ (Hall 2001). For example, the range of environmental impacts associated with certain products is complex, and customers are unable to express their environmental preferences in the terms that product designers can respond to. However, individual consumers are exercising their power more and more, making an effective driver for an integrated LCM approach. Consumers may not yet know how to communicate their environmental performance expectations to firms that use traditional approaches to determine ‘customer needs’, but this does not mean that there are no market opportunities here.

Competitor pressure is also a driver for implementing LCM and highlighting the value of such an approach. A firm that does not understand the interactions of their good or service across its life cycle stands to relinquish opportunity for increased markets and innovation to competitors. Beyond their boundaries, suppliers, who may also impose environmental requirements, drive firms from one end of the
product chain by customers, who demand environmentally superior products, and from the other end by suppliers who may also impose environmental requirements. The classic example of this is the automobile industry’s requests to suppliers of adhesives, where chemical compositions are mandated via black and gray lists. As companies integrate environmental considerations into their product development, they ‘realise the necessity to involve actors up (and down) the product chain (Garcia 1999). Thus, companies supplying components and systems and companies dealing with the use and disposal of products find their environmental work driven by other actors in the system’ (Hall 2001). To avoid playing ‘catch up’ with a response-driven approach, firms should use integrated, comprehensive, life-cycle approaches to manage their environmental impacts together with more traditional cost-driven SCM efforts.

Public procurement

Public procurement has increasingly been used as an instrument to promote environmentally conscious purchasing. In some countries, environmentally conscious purchasing has been decided as the preferred means of procurement, including the U.S. government’s legislation, under the Clinton–Gore administration, for green procurement in the public sector and life-cycle considerations in defence. One outcome of this was a dramatic increase in the use of non-virgin and non-dyed papers. Furthermore, some countries, states, or municipalities have decided to prefer products that are environmentally labelled, for example, with the EU flower or the German Blue Angel.

Private procurement

Private procurement can occur at the personal or institutional level. The public sector as well as consumer organisations have purposely stimulated the political awareness of consumers to make environmentally conscious purchases. The consumers have been advised to buy environmentally labelled products and less energy-consuming equipment and thereby stimulate the development and selling of these products. An example of this is product testing by ‘Stiftung Warentest’ in Germany, which also includes environmental considerations (Stiftung Warentest 2002). This trend has also been stimulated at the institutional level. In Japan, consumers can see life-cycle burdens of various alternatives, principally energy use and disposal options and consequences, on-line during purchasing. Furthermore, many high-profile and short-life services, including portable music players, are designed to include the most likely end-of-life scenario, which can include often inadvertent environmental disposal, even to water sources, when they are thrown into a lake or river by the end-user. Therefore, while there is no evidence that private procurement is a major driver, its influence is rising. We cite, as examples, European consumers balking at genetically modified corn, which ultimately contributed to the fractioning of an established multinational, Monsanto. In addition to Monsanto’s product failure, consumer pressure against multinational lobbying to abandon the Kyoto Protocol has led Shell and BP-Amoco to withdraw from the oil industry group calling for the withdrawal from Kyoto.

Society

A public demanding accountability drives firms to improve stakeholder relations and their reputation with nongovernmental organisations (NGOs) and pressure groups. In terms of technical improvement, ‘consumer demands are one of the main forces steering companies to integrate the consideration of environmental impacts into their operations (Tulenheimo and Thun 1995). Consumers are supporting schemes that pressure manufacturers to design products with less environmental impact, and for some products, they are actively pressing manufacturers for products that are more “environmentally friendly”. In order to maintain or enhance the image of their brand, firms are driven to improve the environmental performance of their products, services, and operations’ (Hall 2001).

The influence of consumers on product design is not new, nor is it specific to environmental issues (Hall 2001). Taking the automobile as an example, Thomas Gale, at the time with Chrysler, stated that when ‘dealing with a vehicle architecture of the future, the question of what our customers really want is of paramount concern’ (Anonymous 2000). ‘Design strategies to focus on customer orientation and satisfaction may span “all areas and corporate divisions and remain a constant presence”’ (Hall 2001). Volkswagen has also stated, as part of a 5-firm EC-sponsored automobile study (LIRECAR project) that their designs must be sustainable to be competitive. Environment is not just a key element but, it seems, is viewed as a feature that, if ignored, could threaten the viability of the firm itself.
Consumers are also employees, and thus, implementation of an LCM approach toward improved sustainability will also be driven internally in an organisation. Employees are expecting better information on how the firm's overall performance is connected to environmental performance. Meeting these expectations, firms can improve employee satisfaction and productivity.

**Legislation**

Several years ago, experts were stating that 'bringing environmental issues into the core operations of organisations would require government policy and regulation' (Hall 2001). Today, existing regulations target substances of concern (e.g., EU 2003a) and pending regulations target specific products and increase policy emphasis on the sustainability of services and product service systems. In this context, perhaps the most well known is the EU directive on end-of-life vehicles (EU 2000) and the directive on waste of electric and electronic equipment (EU 2003b) along with similar policy initiatives at the national level. Also widely studied is the Duales System Deutschland (DSD or system of 'der Grüne Punkt') for packaging materials. Each of these intends to drive product (or packaging) improvement by making the producer responsible for the product at the end of its intended use. The focus is on producers because they have the greatest knowledge and ability for adapting product design to meet the legislated requirements (Hall 2001).

The existing legislative framework also acts as a strong driver for firms to consider the environmental impacts of their operations, products, and services. Liability for exceeding local air quality emission limits, for example, will result in fines and possibly licensing restrictions and costs. More so, retrospective liability for past and unintended pollution of groundwater, for example, is an effective driver. The threat of retrospective liability makes a clear case for a proactive LCM approach to understand all aspects of the organisation and ensure life-cycle information is available for decision-making at all levels.

Only recently a new management approach for the private and public sector, including a new communication approach, has been introduced: Integrated product policy (IPP) (EC 2001). IPP aims at better understanding the environmental and economic impacts of products, replacing the more traditional approach of an isolated only-environmental and end-of-pipe approach, focussing on single environmental media. IPP also offers new opportunities in product positioning and eco-efficient products. The whole value-creation chain is involved, and overall advantages over all life-cycle stages of a product can be achieved. However, IPP does not only offer opportunities in this direction; by embracing the whole sustainability target, including not only environment but also economic and social aspects, IPP believes it can also offer a good communication platform to policy-makers and other related stakeholders. IPP may become a new platform for policy-making and communication, at least in Europe where it has pan-national support.

**Financial sector**

A 'lack of awareness, information, and expertise in the market has served to conceal the economic advantages of environmental improvements' (Hall 2001), such as redesigning a product to eliminate a toxic substance, recovering a material for reuse, or reducing fuel consumption. In organisations, 'costs are often overlooked or incorrectly allocated as overhead, which is a barrier to realising the financial advantages of designing for better environmental performance. Thus, there is a perceived disincentive for companies to go beyond compliance to reduce the impact of their products' (Hall 2001). Rebitzer (2002) discussed the implications of life-cycle costing models with respect to improved system perspectives and the possibility to identify business solutions along the value creation chain, if proper data exist and adequate interpretation techniques are available. This lack of information and expertise for properly allocating cost is clearly and quickly changing, as the costs that society has been bearing are re-directed back to the firms where they originate.

The activities of investors, insurance companies, banks, and ranking institutions are increasingly driving firms toward sustainability, as has been briefly discussed in preceding sections. Traditionally, investors look for funds with calculated risks and some level of predictability. As characteristics of the business climate are changing, firms that do not have a comprehensive approach to understand their environmental and social impacts on the system in which they operate are increasingly a high-risk investment. Using the same logic, insurance companies charge higher rates to companies that, for one or the other reason, appear to be greater risks in terms of their environmental or social performance.
The opportunity now exists for firms to secure or lower their insurance rates by actively demonstrating their approach to tracking, managing, and preventing their environmental (and social) impacts. Banks are also integrating sustainability performance criteria into procedures for loan and credit approval. Furthermore, the Dow Jones has a sustainability index, established by Sustainability Asset Management (SAM) (SAM 2002), which uses criteria to assess, rank, and publish the sustainability of practices in various firms. For entrepreneurs, the situation is more dramatic, with visits from financial institutes usually consisting of a team of MBAs (Master of Business Administration) and environmental auditors. The latter view the inherent abilities of the directors, the site, the firm’s policies, and the studies it has sponsored. Chapter 4 will demonstrate that the risks of not incorporating EM, and the cost of compliance, are largest for Northern small- and medium-sized enterprises (SMEs) and Southern nationals. Specific cases will illustrate that the additional cost of compliance with financial sector-based environmental values places LCM at the strategic front, specifically for manufacturing-based start-ups.

### Internal drivers

#### Management

While there are several entry gates to LCM, early experience demonstrates that organisations, multinationals, and SMEs alike require top management support and involvement as a key success factor. These institutional elements can play at least as important a role as technical factors in reducing hazardous substance content of products, as can be seen in the case of product design. Design processes ‘occur “within the broader corporate management structure” and a formal EM system with a policy, goals, performance measures, and strategic plan that support’ (Hall 2001) environmental improvements will be a driver for successful integration of environmental performance concerns. For an organisation using specific tools, their effectiveness will also ride on the firm itself. ‘Tools are valuable because they support good management processes’ (Simon et al. 1998) and ‘simply having tools available to designers is not sufficient to integrate environmental considerations’ into core practices (Hall 2001). LCM offers a framework for management to organise and align the various tools in a way that exploits the synergies and interrelations among them.

Moving toward more sustainable business practices is becoming, or seen to be, a necessary condition for securing long-term business success. The attitudes and expectations of society and markets, together with requirements from legislators and the financial community, are effective drivers for an LCM approach to achieve more sustainable business practices. Because LCM engages all divisions of an organisation and extends perspectives beyond the firm’s gates, it addresses these drivers in a proactive manner, tackling each as an opportunity for added value and business excellence.

#### Miscellaneous internal drivers

To complete the portfolio of internal drivers, one must look at specific factors that depend on the firm and its organisation structure as well as its product lines. While this list would be too long and perhaps useless to detail, the authors find it important to mention non-management-related internal drivers, which have been reported in the case studies of this book (see Chapter 4). These include 1) measures to reduce production costs, 2) policies to ensure that new product designs have long-term viability, and 3) champions in environmental management systems (EMSS) or EHS, who strive to extend their impact in the organisation.
Applications in Life-Cycle Management

Applications of life-cycle management (LCM) will be highlighted in this chapter, using 8 case studies, all condensed into the same format. The examples will be organised by the entry gate within a firm, with subcategorisations according to the drivers within the enterprise for implementing and continuing LCM. Cases will be presented for large firms, small- and medium-sized enterprises (SMEs) and their supply-chain interactions, highlighting specific products and approaches (for various tools, see Table 1-3 in Chapter 1). However, it is important to point out that applications go beyond case studies and references to historical trends, and the need for and definition of (Chapter 2) LCM will be addressed as well.

Table 4-1 summarises the case studies treated herein according to industry sector. Interestingly, the applications summarised, which are representative of the previous work carried out in firms, are heavily skewed to old-economy-type enterprises. With the exception of the provision of textiles as a service, whose high margins and focus on customer needs can be linked to new economy tendencies, though it is certainly not a e-commerce case, the majority of applications are in the raw materials and manufacturing sectors. This is likely due to pressures that date from the outset of the environmental movements in Western countries in the 1970s. Therefore, automobile, chemical, and pharmaceutical industries and manufacturers, all of which have subscribed strongly to ISO standards, are complemented by high-tech sectors (e.g., coatings) and consumer and electronic goods, whose high visibility and packaging is another common, historic driver for LCM. One of the cases also documents a federal initiative by the U.S. Environmental Protection Agency (USEPA) that has motivated LCM practices.

Table 4-1 represents products in the broadest definition (see Glossary) and includes services provided by individual firms and coordinated supply-chain efforts. The tools discussed include Design for Environment (DfE), life-cycle engineering (LCE), and environmentally conscious decision-making (EcoDS). In general, the cases involve a combination of impact assessment and life-cycle costing (LCC), with most firms noting follow-up to the initial incentive, independent of its driver. This implies a corporate belief that LCM can be applied to a variety of industrial needs and not just the 'low-hanging fruit', as has been a frequent criticism of less management-oriented life-cycle approaches.

This section summarises the 8 cases according to the principal entry gate.

Management and Strategic Issues

The applications discussed herein focus on proactive organisational mandates for LCM. They include examples of the integration of LCM within environmental management systems (EMSSs) and product-oriented strategies, as well as supply-chain management. The Danish 'Promille' Project (Schmidt K et al. 2000), consisting of 10 individual cases, and product-oriented environmental management systems (POEMS) (Brezet
Table 4-1 Categorisation of life-cycle management cases

<table>
<thead>
<tr>
<th>Raw materials and manufacturing</th>
<th>Consumer goods</th>
<th>Electronics</th>
<th>High technology</th>
<th>‘New economy’</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Automobile</td>
<td>• Illumination</td>
<td>• Electrical subsystems</td>
<td>• Coatings</td>
<td>• Textile service</td>
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<tr>
<td>• Plastics</td>
<td></td>
<td>• Aerospace</td>
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<td>• Water treatment</td>
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and Rocha 2001), which are not highlighted in this book, are other examples. If Promille can be considered the application, then POEMS presents the underlying concepts related to product-oriented EMS.

**Research and Development and Design**

The principal drivers involved in the implementation of LCM in design and development are engineers who are faced with ambiguous constraints for new products. While LCM is often integrated into existing product teams, an advantage many firms realise rather than creating parallel structures, designers spend vastly different times considering environmental information. This, as will be shown, is related to the product's visibility, its durability, the length of the design cycle, and the state of competition. Some of the applications discuss firm- or product-specific eco-indicators (or ecometrics), many of which have been validated by life-cycle-based approaches. The designers use a balance of opportunity- and cost-estimation to create new products, many of which pass through internal environmental committees prior to any public claim of improved 'greenness' being issued. This indicates the industry's commitment to peer review (e.g., automobile and manufacturing sectors where significant environmental burden is observed outside the gate of the firm) and the use of established methodologies. The desire for harmonisation of methodologies along the supply chain is a recurring theme among many of the cases.

**Supply Chain and Procurement**

Purchasing-based drivers focus on business-to-business (B2B) synergies and cost reduction. Applications discuss the involvement of stakeholders and social elements in addition to costing. Several of the cases point to SMEs' concerns on being integrated into several supply chains, dominated by multinationals, wherein each requires environmental disclosures and reporting in a different format according to various methodologies. Therefore, multinationals seem to have realised that SMEs require an LCM system that, while independent from their own, can be certified or, to a large extent, standardised. Another case discusses the indirect benefits to start-ups of an LCM policy, including a tangible reduction in their interest payments, given banks' interests in including environmental management (EM) as part of the credit screen.

**Production and Distribution**

Production-based drivers focus on large firms and public projects. One of the first LCM approaches, '3M LCM', is highlighted. More broadly speaking, 3M is significant in regards to its historic commitment to LCM precursors such as pollution prevention and its high level of innovation. If LCM can be implemented in an organisation with more than 40,000 products and 600 new developments per year, all of which are assessed, is this not a good confirmation of the shareholder benefit and strategic advantage of considering environmental issues in manufacturing and distribution? The applications also cite indicator development, including those by the World Business Council for Sustainable Development. References to extensive tabulations of validated metrics, used by several firms, are also provided.

**Sales and Marketing**

When marketing drives LCM activities, firms focus on eco-labelling and reporting, with a focus
on end-of-life issues, specifically disposal. Applications of combined labelling, from Scandinavia, and the use of LCM in environmental product declarations (EPDs) have also been studied in the past (see the example of Volvo [Rowledge et al. 1999]). Surveys have indicated that sales and legal issues lag in terms of their corporate integration into LCM (Huang and Hunkeler 1996). This indication may be due to the lack of inclusion into product development teams for the latter or different incentive structures for the employees in the former. In any case, while a minority of applications and firms drive their environmental activity from the marketing division, their incorporation into discussions within the organisation is increasing, as the same surveys have also noted. Clearly, sale is a driver, which applies more so to larger firms, at least in regards to LCM, with SMEs focussing on market, cash flow, and credit motives. Although not explicitly discussed within one of the cases in the next section, with the exception of a brief note in the start-up discussion, the role of sales and marketing as an entry gate is increasing rapidly and is already the norm in some countries (e.g., Switzerland).

**Management and Strategic Issues**

This section examines applications of LCM from an organisational perspective with a particular focus on EMS in old-economy-type industries. As such, the chapter begins with a case study from the automotive sector wherein the principal corporate driver involves the formulation of priorities and how systematic processes, specifically LCM, can provide competitive advantages and opportunities. A second case involves an SME where auto manufacture supply-chain pressure and a proactive management stance in regard to the environment lead to new products in a mature industry. LCC and cost effectiveness are discussed for metal manufacturing, while the need for in-house training is presented for the plastics industry. The cases in this section highlight a proactive industry focus, in regards to internal (cost) and external (legislation) factors.

**Case 1: Bringing the life-cycle perspective into environmental management systems**

(Matthias Finkbeiner)

<table>
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<th>Summary</th>
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<td>This LCM case study illustrates how life-cycle assessment (LCA) can be used to support an existing EMS. The case study revealed that the environmental improvement strategies of an SME in the field of paint production—based on an EMS/production view—were inefficient. The use of LCA confirmed that the improvements in the field of waste or water management do not lead to a significant reduction of the overall environmental burden, because the raw materials (binders, pigments, etc.) they purchase account for by far the largest share of it. As a consequence, the purchase and choice of raw materials was defined as a new focus to improve the environmental performance.</td>
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**Definition**

*Why?* The company of this case study is a 300-employee Germany-based SME founded in 1926. The core business is the production of paint for industrial applications. This includes solvent-borne, waterborne, and powder-based coatings. The annual product output of approximately 7000 types of paint totals about 12,000 metric tonnes. More than 800 different raw materials enter about 500 production steps. The company recognised the potential to differentiate itself by offering environmentally preferable products and started powder coat production as early as the 1970s. The company identified worker safety and environment as key management guidelines. The company has some major clients, especially for powdered coatings, that place high importance on the environmental profile of their suppliers. The firm began implementing an EMS in 1995 and obtained certification according to the European eco-management and audit scheme (EMAS) in 1996.

*What?* For the company, LCM consisted of a product-oriented extension or optimisation of the existing EMS. Basically, LCA was used to complement the EMS. From a theoretical
Life-Cycle Management

viewpoint, LCA and EMS provide answers to quite different questions. While LCAs study products over the whole life cycle, EMSs aim at the continual improvement of organisations. For an academic discussion of LCA and EMS, it is important to relate to these different aims. However, from a practical and less structured viewpoint of the main users of both tools, that is, companies, they might be seen to serve the same purpose in providing answers to the question of how the environmental performance of a company and its products can be improved.

LCA was used for weak-point analysis in order to define targets and programs. LCA was chosen as a tool because of its systems perspective and product orientation.

How? The company joined a multi-client project, which was led by a university as the LCA consultant. This multi-client project was partly funded by the regional government to promote the use of LCA in SMEs. As case studies, the company selected typical paint products, for which exemplary LCAs were performed together with the university. Information and data were obtained from internal process and EMS data, contact with their up- and downstream supply chains, and from the university that had carried out LCAs previously. Based on the LCA results, optimisation strategies were defined and implemented into the EMS.

Who? The environmental manager of the firm carried out the operational work. He had support from the technical managers of the product lines powder coat, waterborne coatings, and solvent-borne coatings. The director of the company attended the kick-off and final presentation meetings.

Entry Gate and Drivers

Entry gate

The entry gate of LCM into the company was the environmental manager. After the successful implementation of the EMS and harvesting the 'low-hanging fruits' based on corporate ecobalances, he was looking for new approaches and tools to continually improve the environmental performance. A partly government-sponsored LCA project provided the opportunity to experiment with and apply a life-cycle-based tool at an affordable budget.

Drivers

Product

The company generates the major share of revenue with 'environmentally sound' paint products, that is, powder coats and waterborne coatings. It is the product that largely determines the corporate image.

Organisation

There is an efficient EMS organisation in place. However, product issues play only a marginal role, and responsibilities for the environmental performance of the products are not clearly defined.

External pressure

Products, processes, and the plant are heavily regulated. As part of the chemical industry and a major industrial plant in a small town, management faced the need to cooperate with (critical) stakeholders.

Supply chain

There were no supply-chain pressures or initiatives from the raw material suppliers. However, on the customer side, there were in some cases strong preferences to deliver environmentally sound products.

Implementation

Companies, in particular SMEs, cannot devote a large effort to an academic analysis of what type of tool could be used for a particular problem. In addition, they will not use all of the EM tools. Most of them will try to establish one common approach to achieve sound EM. Both LCA and EMSs are valuable tools for improving the environmental performance of organisations. Due to the company-oriented, procedural approach of EMS and the product-oriented, analytical concept of LCA, they are methodologically not compatible, even if at first sight similar system elements like the input-output analysis of material and energy flows are compared. The integration of the analytical EMS element corporate ecobalance (CEB) into LCA might be theoretically possible, but practical relevance is questionable due to different system boundaries and different reference units, parameters, and data. A promising solution might be a company- or situation-dependent combination of LCA and EMS in an ideal sense in an orthogonal manner. A sensible and comprehensive combination of complementary elements might increase the
efficiency of EM efforts towards ecological and economical sustainability.

The company began their LCA activities on a project basis. As a starting point, the main interface between LCA and EMS, which is obviously the evaluation of the potential environmental impacts associated with the respective economic activities, was analyzed. From a practical and economical point of view, it is desirable that CEB data could be used for LCAs, that is, LCAs could be compiled by aggregating several 'gate to gate' energy and material balances of companies and vice versa. At first glance, there is no reason why this should not be feasible. However, in many LCAs and CEBs, the parameters and data used are somewhat different. Specifically, the parameters that are relevant for an LCA are flows that cross the border between technosphere and ecosphere. They are referred to as 'elementary flows' and 'product flows'. As a consequence of the life-cycle concept, the elementary flows consist of resources on the input side and emissions on the output side only. All intermediate products are followed back to their origin, that is, the intermediate flows are completely within the technosphere and therefore are inputs and outputs of processes but not of the final life-cycle inventory (LCI). In EMS, the flows that enter and leave an organisation are relevant. Therefore, intermediates are found in the input–output scheme of CEBs. CEBs require data on the full magnitude of the processes.

Another difference in the parameters studied between LCAs and CEBs is the stock. In a classical LCA, all processes are assumed to operate at a steady-state level and at regular operation conditions. Only the allocated net inputs and outputs are used to calculate the LCI. In a CEB, the stocks of materials and the consumption due to nonregular operations are considered. Because the storage of chemicals has considerable environmental risk potential, CEBs deliver more information on that aspect than do LCAs. In the case study of the company, it was revealed that, apart from the parameters themselves, the data to quantify the parameters have a different type, too. This can be demonstrated by Figure 4-1 and Figure 4-2, which show CEB and LCA results for the primary energy demand of the production (compounding) of 1 kg of paint.

As mentioned earlier, CEB and LCA theoretically answer different questions. However, the studied paint producer used the respective information for the same purpose of optimising the production process.

The LCA results for 2 types of paint (LCA paint A, LCA paint B) were compiled according to ISO 14040 methodology, including intermediate and raw material production (ISO 1997). For the CEB results, 1 kg paint was employed as an EMS indicator. This measures the specific energy demand per kg paint by dividing the energy demand of the CEB by the amount of paint produced. All the raw data are from the same company.

Figure 4-1 examines the results of the compounding step in detail. The primary energy demand for compounding according to the CEB is higher than both of the LCA results. This can be explained by the different data types used to quantify the respective parameters. For the LCAs, paint-specific energy data of steady-state operation are used. The CEB data represent the overall energy demand. The main difference is the energy consumption for business sectors like administration or research and development (R&D) or room heating, both of which are included in the CEB but not accounted for in an LCA. To neglect these data within an LCA is a convention, in principle, not inherent to the tool. However, to include this information in an LCA would lead to significant allocation problems because these activities relate typically to the whole product spectrum rather than to an individual product.

Figure 4-2 shows the LCA results for the complete life cycle divided into the life-cycle stages (raw materials, transport, and compounding) as well as the CEB result (compounding step only). It is expected that by adding the energy demand of further life-cycle stages, the result of the LCA is higher than the CEB. It is revealed that by far the largest share of the environmental burden is produced outside the factory gates of the paint producer (i.e., the CEB results which only account for the compounding step describe 5% to 15% of the potential environmental burden). Therefore, a large optimisation potential for the paint producer is the choice for the raw materials. This information is obtained only by LCA.

An advantage of the LCA results is that different types of paint can be compared. In the examples of Figure 4-1, the energy demands for paint A and paint B differ by a factor of 3. The CEB yields only an average energy demand for an average kg of paint.

The main conclusion of the company was that its strategies, targets, and programs to improve the environmental performance of its organisa-
Figure 4-1 Gate-to-gate energy demand for the compounding of different paints, calculated with the life-cycle assessment (LCA) and with the corporate ecobalance (CEB) method (adapted from Finkbeiner et al. 1998 and used with permission from Matthias Finkbeiner)

Figure 4-2 Cradle-to-gate energy demand for the compounding of different paints (LCA paint A and B), compared to corporate ecobalance (CEB) results (adapted from Finkbeiner et al. 1998 and used with permission from Matthias Finkbeiner)
tion had to be redefined. According to its EMS and CEB, the company placed a large emphasis on production issues, for example, reduction of waste and water or energy consumption. The LCM approach to complement the company's EMS with LCA revealed that these areas are responsible for only a minor share of the total environmental burden. The major fraction consisted of the raw materials (e.g., binders, pigments) it purchased. As a result, the purchase and choice of raw materials was defined as a new focus to improve the environmental performance.

Tools
The methodologies and tools consisted of a relatively standard EMS and LCA approach. The added value was obtained by combining these 2 tools. From the EMS perspective, LCA as a complementary tool could assist in a number of ways. Specifically, LCA can

- complement the organisation-oriented, procedural EMS tool by investigating main or environmentally relevant products,
- assist in prioritising the objectives of an EMS,
- assist in achieving the objectives of an EMS by a detailed weak-point analysis of the production process,
- help to add objective and scientific elements to environmental performance evaluation (EPE),
- reveal what share of the overall environmental burden of an organisation is produced 'inside the gates' and 'outside the gates',
- consider the use phase of products, which often is the life-cycle stage with the highest relevance,
- assist in DfE,
- assist supplier audits and choice of materials, and
- assist in investment decisions.

For the LCA part, one of the commercial LCA software tools was used.

Case 2: Small- and medium-size enterprises: The role of top management
(David Hunkeler)

Summary
This LCM case study illustrates how the redefinition of an environmental problem identified technical solutions that satisfy economic and design constraints. An SME, with sales of $50 million per year, had growing waste disposal costs due to a non-recyclable material of which only two-thirds was available for use in the final product. By considering life-cycle impacts and costs, predominantly in the extraction, manufacturing, and use phases, a reuse strategy was identified, which created new products of low weight that could be employed in the auto sector. The SME was able to work within the imposed constraints of its upstream suppliers and identify alternatives that reduced raw material and disposal costs, while providing innovative solutions to their clients. The project was commissioned by the firm's president, with all reporting made to the executive, who took the final decisions based on recommendations.

Definition
Why? American National Rubber (ANR) is a mid-sized firm with its main offices and production facilities in Kentucky, USA. They supply thermoset polymer parts to the automotive industry. These 'stuffers' consist of a foamed rubber, which is manufactured in molds, cut horizontally into strips, with the sheets subsequently punched into final products. These lightweight materials are customised to a given vehicle to absorb vibrations and sounds, which are identified after the design. As such, stuffer parts represent an add-on to vehicle quality in the final manufacturing stage. Their efficacy and light weight are the principal design considerations. In 1995, when the study was commissioned by ANR's president, Tom Maxwell, internal and
supply-chain drivers were moving this SME to seek means to improve the life-cycle burden of their services. ANR, with sales of $50 million per year, was paying $200 thousand for waste disposal, predominantly of by-products of the cutting process, which could not be recycled given the thermosetting nature of the material. This amount was increasing annually and becoming a long-term concern to management. The auto industry also was seeking products with higher recycled contents, penalising manufacturers of virgin parts such as ANR. Additionally, some of the (at the time ‘Big Three’) U.S. auto manufacturers had implemented, in 1995, a policy to reduce the number of suppliers, with conditions related to selection including the economic and life-cycle considerations of the product. These 2 considerations prompted ANR to seek, via an internal consultant, a university or research centre that could examine the recycling-related issues of ANR’s manufacturing and product.

What? For ANR, LCM consisted of an evaluation of manufacturing and use stages of the product life cycle. The issue of weight versus recyclability was and still remains a key issue in automobile designs. Although raw material extraction was not considered, per se, in the charge to consultants, it became an essential issue in the problem solution, as will be summarised herein.

How? This LCM can be categorised as a streamlined LCC exercise. Information was obtained from ANR’s internal data, as well as upstream contacts with the automobile manufacturers, principally DaimlerChrysler, as well as intermediate supply-chain links to the automaker, such as United Technologies Automotive. An evaluation of the impacts during the manufacturing, use, and disposal stages was carried out.

Who? The LCM was commissioned by ANR’s president, who was seeking to reduce the annual disposal costs, or at least limit their future increases, while providing a product to their clients which satisfied design constraints (low weight and recycled components). ANR also believed that a proactive environmental policy could help it remain a direct distributor to the automobile industry, which was cutting the number of suppliers by a factor of 5 to streamline its internal accounting and organisation-related issues.

Entry Gate and Drivers

Entry gate
The LCM was carried out over a period of 4 months in order to identify alternatives to using virgin stuffer parts to control excess automobile vibration and noise, particularly in the rear of new model designs. ANR’s president had approached Vanderbilt University’s (Tennessee, USA) Center for Technology Management, via an internal management consultant, to develop new technologies that satisfied ANR’s supply-chain-imposed environmental and economic decision support criteria. The design and assessment team co-authored a report with the consultant, which was presented to the president along with a demonstration of the technology developed. Top management had, in advance, supported the LCM initiative within the firm and paid for the development costs.

Drivers

Product
ANR sold an established product in a competitive market with a moderate margin. Given the supply-chain pressures, affordable eco-designs would be seriously considered. The product development was key to the sustained economic activity of the firm, which was threatened with a loss of more than one-third of its market share should new policies from the auto manufacturers, which limited suppliers, force ANR out of the market.

ANR’s process generated hundreds of thousands of kilograms of waste thermoset during a year. This nonrecyclable material and its disposal cost were the target of design innovations that could recover costs. Interestingly, ANR was aware of the $200 thousand in end-of-life costs it was incurring per annum, though it had not considered the value of unused raw material in its disposal option, which amounted to 15% of sales or $7 million per year.

Organisation
Potential risk of market share loss, a proactive policy with respect to product design, and the economics associated with waste disposal were factors contributing to management support of the LCM.

External pressure
The principal drivers to instigate this LCM were internal from top management and from those
Applications of life-cycle management implied by upstream supply-chain negotiations. ANR was in full environmental compliance and no external pressures were evident, though there was concern for future liability if stricter environmental waste disposal-related policies were implemented within the state.

Supply chain
The automobile manufacturers desired to reduce the life-cycle burden of their products by lowering weight and increasing reused material content, particularly in the plastics area because the steel was already extensively recycled. Internal designers had not identified solutions that could lower weight while incorporating material reuse, with all alternatives implying economically unjustifiable reprocessing costs and significantly higher foamed product densities.

Other
Given the cyclical nature of the automobile industry, the SME needed to identify low-cost alternatives in terms of fixed capital investment. Any viable alternative would be produced within existing production facilities and require a payback period of 3, and ideally less than 2, years.

Implementation
The alternatives investigated included landfilling and sale of the material to carpet manufacturers as a material for carpet backing. In this case, several of the impact categories could be eliminated because of the low quantity of the waste produced and the simplified nature of the product. For example, radiation, air emissions, waterborne pollutants, and energy consumption are of minor importance in this case compared to solid waste disposal. For this particular enterprise, the problem reverts to a classical waste minimisation evaluation. One alternative identified was the recycling of the thermoset by incorporating a portion of used material in a virgin product. Another alternative involved grinding up the scrap and binding it with an adhesive to make new parts. These options proved to be viable because approximately 65% of the polymer can currently be made into useful products on the first pass through the manufacturing cycle. In this case, the firm reasonably elected to focus their inventory on the solid waste problem from receiving door to grave and the long-term impacts of disposal versus reprocessing.

The new design evaluation focussed on problem redefinition. The main economic benefit for the firm was the reduction in unused raw materials. Given that the material could not be reprocessed, the reuse of the scrap material was evaluated. Specifically, scrap foam was ground into various sizes and heat-treated with a family of different adhesives, both organic and water-soluble latexes. Overall, high molar-mass rubber latex was found to be optimal, providing a flexible product, which is essential in applications, with good mechanical properties, water resistance, as well as a reasonable density and low cost. The pilot testing of the eco-design alternative, referred to internally as 'grind-and-bind', was delivered to ANR's president with a recommendation to scale up the batch remanufacturing of millions of pounds per year. Large equipment presses, heated and with controlled pressure, were also recommended.

Tools
The methodology consisted of a preliminary impact assessment where key stages, stressors, and impacts were identified by the design team. The potential financial costs and liabilities were available internally.

The methodology is part of the LCM toolbox identified within this book (see Table 1-3). EcoDS, an environmentally conscious decision support system, has a product life-cycle perspective, integrates economic and environmental aspects, includes supply-chain coordination, and applies to design. It is applied as an LCM system in several Global Fortune 500 firms, including 3M (Huang and Hunkeler 1996; Hunkeler and Huang 1996). Recent work uses this case, and others, to demonstrate how semi-quantitative environmental information can be incorporated into specific indicators. Concepts that involve normalisation, such as 'Return on Environment', provide decision-makers with the ability to compare LCM studies against those carried out on other products (Hunkeler and Biswas 2000).

Research and Development and Design
This section focuses on product development in multinationals. The cases have been selected to demonstrate how, for established and related industries, the drivers and procedures for LCM can differ. The LCE approach, now employed in several hundred firms worldwide, is illustrated in Case 3. This case focuses on the engineers
who seek to make environment a vital element in automobile design and development, as well as the key tradeoffs that exist. The second case in this section focuses on the key life-cycle debate between closing the materials recycle loop and low-weight vehicles in the key use stage. The use phase is also the focus on product development in the energy sector, where downstream clients observe the majority of environmental impacts.

**Case 3: Automotive manufacturer: Environment in design**

(Wulf-Peter Schmidt)

**Summary**

This LCM case study illustrates how environmental aspects are implemented in the product development of automobiles. By considering these aspects, the usage of sustainable materials could be increased and vehicle emissions could be drastically lowered. In doing so, life-cycle impacts and costs, predominantly in the use phase as well as during the end-of-life phase, could be decreased. In addition to the product development phase, examples of LCM are given also for the manufacturing, use, and recycling phases. The following case is an example from one automotive manufacturer. Many of the reported LCM-related activities and programs are standard practice in the automotive industry, and many other manufacturers undertake similar or other LCM actions.

**Definition**

**Why?** The firm in question is a global organization with a total of 112 plants, including joint ventures and equity-owned facilities, with headquarters located in Cologne, Germany. In Europe, the small- and medium-sized vehicles are being developed and produced.

In the past, there has been the need to provide people the opportunity to satisfy their mobility needs in an affordable way. This has been one precondition of an outstanding economic and social development in the world. Looking at the environmental side of this success story, William Clay Ford, Jr., the chairman, declared his vision that this mobility has to be achieved in a sustainable way: ‘Ford once provided the world with mobility by making it affordable. In the 21st century, we want to continue to provide the world with mobility by making it sustainable’ (Ford 2000).

**What?** Following the LCM guidelines listed in previous chapters, senior management visions have been translated in various actions in several areas (Schmidt 2000), including the following:

1) **Research and Design**

   Half of the research conducted in the firm's worldwide scientific laboratories concerns environmental issues including fuel cell vehicles. There are also tendencies to link old and new economies by combining physical mobility with communication or Internet technology. In the product development and design process, environmental aspects are included as described in more detail under ‘How’.

2) **Supply Chain and Procurement**

   In the automotive industry, there is a trend toward full-service suppliers who have complete design responsibility in fulfilling the targets (e.g., weight, recyclability, recycled and renewable content, restriction of substances). This implies that a full-service supplier can decide the way these objectives are fulfilled. In order to support the supplier in meeting the environmental requirements, a DfE training program was initiated. This program is open to all suppliers and employees. Additionally, a close cooperation between the automotive manufacturer and its supply chain delivers key product- and component-based information. Annual environmental awards are presented to outstanding environmental achievements of suppliers.

3) **Production and Distribution**

   Worldwide, all manufacturing facilities have been certified according to the ISO 14001 standard since 1998. The firm also participates in the education of dealers and includes environmental aspects in dealership contracts.

4) **Sales and Marketing, Consumer**

   Consumers are informed about environmental aspects of the products (e.g., environmental and safety information label) and environmentally conscious handling of the products (e.g., the offering of an Eco-Driving course in Germany in coop-
Design for Environment, research
(Fuel cells, alternative fuel vehicle [AFV], etc.), supplier cooperation

Environmental management (ISO 14001/EMAS),
ensuring environmental demands to suppliers

Life-cycle chain management = Life-cycle assessment

Ecodriving, cleaner dealership, telematic,
service approaches, link mobility/communication,
environmental customer information, etc.

Figure 4-3 Life-cycle-related activities at one of the world’s largest automobile manufacturers

5) End-of-Life

Figure 4-3 illustrates the integration of DfE, EMS, and recycling initiatives within the company’s integrated product (IPP) and life-cycle policies.

How? This particular study concentrated on the aspect of how environmental consequences are integrated into product development. The following aspects are important.

At the outset of the design development for any new vehicle, the product development system requires the specification of environmental objectives, such as fuel economy, vehicle emissions, and recycling. Recycling objectives include such areas as overall vehicle recyclability, the use of recycled materials in specific components, and the identification of polymeric compounds as well as restriction of certain substances and materials. These objectives are given, depending on the type of product development (all-new or minor freshening), several years before production starts. These objectives are then systematically verified and confirmed during the entire design development process. DfE training (Beyer and Schmidt 1999) transfers the necessary know-how into the engineering community. In Europe, there are, for example, vehicle-specific recycling teams where representatives from all modules of a vehicle are reporting their actual status for recyclability, recycled content, and other recycling-related information. In addition, Environmental Failure Mode Effect Analysis, LCAs, and other tools are applied to check the environmental performance of important vehicle parts. Cross-car line and cross-functional teams as the European Recycling Action Teams and cross-car line design recommendations are supporting vehicle-specific efforts.

At the end of the development phase, before mass production starts, prototypes are dismantled to evaluate the actual status of the vehicle and to derive recommendations. These actions are used to provide information for immediate changes or for succeeding product developments.

Who? The integration of environmental actions into product development was carried out by various departments, including environmental departments (e.g., recycling department), product development departments (e.g., vehicle integration), as well as vehicle-specific teams (e.g., teams with supplier engineers from all vehicle modules). Cross-functional teams (e.g.,
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European Recycling action team of materials, environmental, purchasing, and engineering department are also employed.

Entry Gate and Drivers

Entry gate
The specific approach of integrating environmental aspects into product development, developed over a time period of several years, is a mixture of top-down and bottom-up approaches.

Drivers

Product
The automobile sector is a highly competitive market. Offering products that aim to lead, from an environmental perspective, may provide not only an additional competitive edge but also a pre-condition for long-term (sustainable) business success.

Organisation
Strong internal personalities as well as a number of enthusiastic employees and non-senior managers have been drivers for implementing these ideas, both top-down as well as bottom-up.

External pressure
The principal drivers to instigate LCM were internal. However, there is also an increasing external pressure from governments (e.g., European directive on end-of-life-vehicles [EU 2000], emissions legislation), customers (fuel economy concerns, tax incentives for lower emissions), and nongovernmental organisations (NGOs).

Supply chain
The automotive industry is highly interlinked with suppliers. Full-service suppliers are deciding on the means (materials and processes) to fulfill company specifications. Therefore, the integration of environmental aspects into product development has been possible only by cooperating closely with suppliers.

Other
Given the cyclical nature of the automobile industry, as well as the long development times, the automotive manufacturer has to make sure that there is a long-term need for the found design solutions and that they are still competitive in the future.

Implementation
There are several examples of implemented environmental ideas in mass production, including the use of significant amounts of sustainable materials such as recycled polymers (more than 19 500 metric tonnes in Europe) and renewable fibres (more than 27 000 metric tonnes in Europe) that have replaced virgin or nonrenewable materials. For these materials, different alternatives have been evaluated (see 'Tools', below). Examples include housings for air-conditioning systems made of recycled polypropylene bottle caps, engine covers made of recycled polyamide, wheelhouse linings made of recycled polypropylene, sound damping or insulation materials made of recycled textile waste or scrap and recycled bitumen, a fan wheel and frame made of recycled carpets and packaging tapes, air filter housings made of recycled car battery housings, door mirrors made of various types of recycled housings, and a radiator grille made of recycled bumper material. By using recycled materials, without cutting back the vehicle's safety and quality standards, a market for recycling products could be established, thus lowering end-of-life vehicle costs.

The dismantling rate (amount of non-metals that can be taken out of the vehicle before the shredder within 30 minutes) could be increased. This decreases life-cycle costs in end-of-life vehicle treatment. Other associated positive aspects are the significantly improved situation in vehicle emissions. For example, fifty 1997 Kas are producing the same amount of emissions (e.g., NOx, CO) as one 1976 Fiesta. The European automotive industry has a voluntary agreement to reduce CO2 levels in the vehicle fleet by 25%. Providing vehicles that have lower taxation, due to lower emission levels, and improving fuel economy could reduce the cost of ownership for the customers.

Tools
There is a wide range of LCM methodologies used internally in implementing the aforementioned programs (Gottselig and Schmidt 2000). This includes environment failure-mode-and-effect analyses (FMEAs), Environment Multi-Criteria Requirement Matrix, simplified LCA, LCC, as well as general DfE guidelines, component-specific DfE advice, and the dismantling of vehicles. An example of a comprehensive tool that facilitates LCA and LCC in materials selection is the euroMat methodology and software prototype (Concurrent Engineering Design Tool
Applications of life-cycle management for the Selection of Environmentally Sound and Recyclable Materials. euroMat has been developed in cooperation with this automobile manufacturer (BMBF 2001; Technical University Berlin 2002). Also, the euroMat methodology was applied to a front subframe module of the new middle-class vehicle (Schmidt W-P et al. 2000; Rebitzer et al. 2001). In the context of LCM tools, one has to note that organisational aspects, described under the subsection ‘How?’ (p 37) are equally important for the successful implementation of LCM.

Another key element is the Environmental Life-Cycle Chain Management (Schmidt 2001), that is, all life-cycle stakeholders, have certain roles and responsibilities to improve the environmental performance along the life cycle of the product (see Table 4-2). A pre-condition for this concept is an open and constructive communication between all life-cycle stakeholders including material and part producer, logistic operations, dealer, customer, researcher, NGOs, and end-of-life operators.

Case 4: From compliance to proactive life-cycle management with a materials perspective
(Gerald Rebitzer)

**Definition**

**Why?** MAN Technologie AG (MAN) is a Germany-based multinational in the aerospace sector. The products of MAN include the production of freshwater and wastewater tanks for Airbus airplanes as well as modules for the European Ariane space carrier program. For these products, MAN uses its knowledge and technologies in the area of lightweight fibre-reinforced composites, because weight is a priority in the design of these products. Essentially, the business concept of MAN is focussed on providing components for aerospace vehicles, which meet the mechanical and other use-oriented requirements with minimal weight. Generally speaking, less weight for aerospace components also reduces the costs and environmental impacts in the use phase, and is therefore a technologically and economically very significant design parameter, which influences the price of the product paid to MAN by its customers.

In 1997, MAN’s strategy dictated a move beyond regulatory compliance, initiated through EM activities in manufacturing. The development of more fuel-efficient commercial aircrafts and, therefore, of lighter components had been at the centre of MAN’s attention for more than 3 decades and was therefore a core focus in the drive for improved products. However, MAN also anticipated future recycling regulations in the aircraft industry, similar to the European directive for the recycling of automobiles (see EU 2000). Another issue concerned work environmental issues because the manufacturing processes for fibre-reinforced thermosets, the main materials used, involve solvents and other potentially toxic materials.

In order to become a proactive environmental player in the aerospace industry, where product-related environmental issues have been focussed mostly on engine emissions and fuel efficiency in the past, and to explore new business opportunities, MAN Technologie joined a multidisciplinary project on materials selection in product development. This project, euroMat, included technology-based selection of materials and manufacturing processes as well as a comprehensive assessment of feasible materials in regards to environmental impacts, life-cycle costs, and work environment (Fleischer et al. 2000; BMBF 2001). The study was lead by the Technical University Berlin and included the freshwater tank of the Airbus A 320 (see Figure 4-4), which is manufactured by MAN, as a case
<table>
<thead>
<tr>
<th>Stage</th>
<th>Role of industry (manufacturers and suppliers)</th>
<th>Role of the consumer (users and end-users)</th>
<th>Role of companies in disposal and recycling</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upstream in the life-cycle</strong></td>
<td>• Influencing the environmental performance processes of suppliers directly, banning the usage of certain targeted substances in the supply chain (lists of restricted substances are used by most companies in particular in the electronics and automotive industry) • Creating a green supply market by demanding competitive, environmentally favourable materials, technology, and design solutions that provide a better environmental performance • Establishing an environmental information flow</td>
<td>• Buying materials, technology, and design solutions that provide significantly better environmental performance, even if they are more expensive • Giving feedback to manufacturers as to what (environmental) issues have priority for them</td>
<td>• Providing information to end-users about where to leave products at the end of their life</td>
</tr>
<tr>
<td><strong>Own life-cycle stage</strong></td>
<td>• Improving own environmental performance of manufacturing (cleaner production, waste, and energy management, ISO 14001, etc.) • Choosing materials and design options (use of recycled or renewable materials, use of materials that are supported by DfE tools) • Educating staff and cooperating with suppliers in environmental aspects • Innovating and improving the product</td>
<td>• Following recommendations on how to use the product in an environmentally responsible way (e.g., eco-driving) • Switching off standby devices to avoid unnecessary environmental impacts • Looking for further usage or functions of products as well as use cascades (e.g., old computer processors for other purposes) • Intelligent combinations of products (intermodality using the different mobility and communication opportunities)</td>
<td>• Improving environmental performance (cleaner production, waste and energy management, ISO 14001, improved yield, etc.) • Ensuring high quality and competitiveness of recycled materials or products (same or lower price, same or higher quality compared to virgin materials or products)</td>
</tr>
<tr>
<td><strong>Downstream in the life-cycle</strong></td>
<td>• Educating dealers and including environmental aspects in dealership contracts • Informing and training customers about environmental aspects of the products and environmentally conscious use of the products (e.g., dosing recommendations to measure out washing agents) • Enabling and providing information for product dismantling and recycling and recovery (International Dismantling Information System [IDIS], International Material Data System of the Automotive Industry [IMDS])</td>
<td>• Directing products and materials to the appropriate collection, disposal, or recycling facilities</td>
<td>• Communicating to manufacturers how to improve design for recycling or dismantling</td>
</tr>
</tbody>
</table>
study (for a detailed report of this case study, see Lichtenvort et al. 2001).

What? The expansion of the EM to include a life-cycle perspective was used as a means to provide design feedback. Specifically, the complete life cycle of several material alternatives for the aircraft freshwater tank (see Figure 4-4) were studied and the assessments were put in relation to technical requirements, which, of course, could not be compromised by environmental considerations. The results are used in future product designs. In addition, the euroMat project aimed at developing a software prototype for materials selection in DfE, which would be available for all project partners, including—apart from Technical University Berlin and MAN Technologie—4 other companies and 5 research institutes (Rebitzer and Fleischer 2001).

How? The project began with the definition of the technological requirements and included a comprehensive search for alternative materials as well as extensive research on the material currently used, which is carbon fibre-reinforced epoxy (EP). Furthermore, the manufacturing processes at MAN Technologie and alternative processes were studied in detail. Data for the use phase were obtained by MAN's customer, the Airbus consortium. For the end-of-life phase, scenarios had to be developed because, to date, there have not been significant amounts of airplanes disposed of by airlines. For the manufacturing stage, internal data of MAN Technologie were collected and compiled through an additional materials- and substance-flow analysis (Worm 1999), which had the goal of allocating the materials and substances used in component manufacturing to the specific product and process. Upstream processes were researched in LCA databases, in the literature, and through contacting material suppliers.

Who? The LCM study was carried out by the Technical University Berlin in cooperation with the head of manufacturing at MAN and the other research institutes involved (C.A.U. GmbH, Fraunhofer Institutes ICT and IPT, and Technical University Cottbus). Funding for this study was in part provided by MAN and in part by the German Ministry for Research and Education.

Entry Gate and Drivers

Entry gate
The idea for the LCM was created during a DfE workshop, which provoked the manufacturing department of MAN to fund a study. In addition, the so-called production and product-integrated environmental protection has been a main theme of the German Ministry for Research and Education, which secured the funding for the complete project.

Drivers
Product
MAN sells a high-tech product in an evolving and innovative, though also highly conservative, market. Therefore, product quality and safety have absolute priority, while innovation remains a key factor. The development and continuous improvement of products and manufacturing processes, which are highly interlinked for fibre-reinforced components, are essential elements of the core business of MAN. Because the aircraft industry is highly innovative and alternative materials are constantly explored,
MAN sought to examine whether advancements in other materials (e.g., lightweight steel constructions) could lead to competitive alternatives to the used fibre-reinforced tank.

Due to the materials used and the processes employed, MAN produced significant amounts of hazardous waste, which could not be directly allocated to the products. Therefore, a methodology was needed to define the resource and waste requirements for each product as a basis for internal process improvements.

MAN wished to be prepared for questions regarding environmental issues by its existing and potential customers. In particular, the influence of MAN's activities on the impacts of the complete life cycle of aircrafts was of interest. Within this, the recycling of aircraft components was another focus. MAN was interested in the question of how relevant the recycling phase would be for its products.

Organisation

The holding company MAN AG, which MAN Technologie is a part of, has committed itself to a proactive role in life-cycle-oriented EM. Within this frame, MAN Technologie has devoted itself to be a modern and sustainable firm and has made voluntary agreements with the state government of Bavaria, Germany. Therefore, the LCM was supported and commissioned by top management (head of manufacturing) and carried out in direct cooperation with the manufacturing and product development divisions. EM personnel of MAN were involved to a lesser extent because the interrelated areas of product development and manufacturing were in the focus.

External pressure

The principal drivers to instigate this LCM were internal, from the head of manufacturing. MAN was in full environmental compliance and no external pressures were evident, though there was concern for future demands by its customers and possibly evolving recycling regulations (see 'Definition', p 39).

Supply chain

Because materials selection was the focus of the LCM, the materials supply chain was an eminent part of the project. The upstream impacts and comparative costs were included to get a comprehensive picture of the life cycle of the product.

Other

Because product-oriented environmental protection is a major issue of policy measures and publicly supported research and development activities in Germany, funding was available to allow the assessment of a bigger, holistic picture. This allowed for the involvement of external know-how of several research organisations in the fields of engineering materials, manufacturing, recycling, environmental assessment, LCC, work environment, and environmental risk assessment (ERA).

Implementation

Based on a technological profile of requirements, potentially feasible materials were selected through an iterative process. Apart from carbon fibre-reinforced EP, with which a tank weight of 14.2 kg is realised, 3 potentially interesting material solutions with different weights resulted (Lichtenvort et al. 2001):

- polyethylene (PE) fibre-reinforced EP (about 11.5 kg),
- boron fibre-reinforced EP (about 15.1 kg), and
- steel (about 16.5 kg).

Results of the environmental assessment are shown in Figure 4-5. One can see clearly that the global warming potential (GWP) is dominated by the use phase, which correlates to the weight of the component. The comparison of the material alternatives in regards to other impact categories such as acidification, nutrification potential and resource consumption lead to the same general ranking. These impact categories have been previously validated as an indicator for activities that are characterised by high energy consumption in the use phase such as air transport (for the correlation of energy consumption and impacts see, e.g., Christiansen 1997).

Comparing the material options on the basis of life-cycle costs led to a ranking identical to that of the environmental assessment (see Figure 4-6).

The LCA results as well as the LCC figures show that only PE fibre-reinforced EP would lead to an improvement and should, therefore, be the

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For steel, it was assumed that the set weight limit (construction constraint) of 16.5 kg can be met.
primary material to be considered for research and development (R&D) activities. This material could also improve the work environmental situation since less toxic materials are involved (Lichtenvort et al. 2001). Another conclusion was that the end-of-life phase is not relevant either from an environmental or an economic point of view. Therefore, one could recommend to keep focussing on weight reduction rather than on recycling issues. Recycling regulations with high standards for materials recycling, as implemented in the European Union for the automotive industry (EU 2000), would probably lead to adverse effects in this sector.

In summary, a win-win situation could be identified, and a promising potential direction for
future development was shown. This can also be explained and demonstrated with the return on environment concept (ROE), which is a double-normalised indicator relating environmental impacts to life-cycle costs (Hunkeler and Biswas 2000; Hunkeler 2001). An ROE calculation for the Airbus freshwater tanks shows the potential benefits and points to the direction of PE-fibre reinforced EP as well (Rebitzer and Hunkeler 2001). In addition, the detailed analysis of the manufacturing processes led to improvement in resource efficiency for the currently used material and raised the awareness of the relevance of the manufacturing processes at MAN in general. For example, the significance of losing epoxy resin material (a liquid that drops off the component) could be demonstrated to the workers in manufacturing. Overall, the increased resource efficiency and better handling of toxic materials resulted in less raw material costs, less hazardous waste (and cost), and an improvement in the work conditions, with the latter probably being the main motivator for the workers' direct involvement.

Tools
Prior to the outset of the project with MAN, the euroMat method for the selection and assessment of materials in DfE had been developed in principle. For a detailed description of the methodology, see Fleischer et al. (1997 and 2000) and BMBF (2001). During the term of the project, the method was refined and validated, adapted to the needs of industry, and implemented as a software prototype. In the following paragraph, a short description of the tool is presented. Further information and an online demonstration version can be found at www.euroMat-online.de.

The tool euroMat is based on sophisticated selection and assessment methods that expand the conventional materials selection process by taking all materials and (theoretical) material combinations into account. It also includes selection and assessment criteria concerning manufacturing issues, environmental and recycling performance, life-cycle costs, work environment, and risk aspects (Rebitzer et al. 2000).

Supply-Chain Issues and Procurement
This section focuses on SMEs in particular with regard to how supply-chain coordination and credit ratings impact on policy. The first SME example was promoted by top management and resulted in a continuing program, wherein new product alternatives could be identified. In the specific case discussed, for an office furniture manufacturer, a total LCC identified alternatives, which would not have been selected from a traditional profitability perspective. A discussion of the implementation of LCM in start-ups concludes the section.

Overall, the cases point out how a systemic management system, which includes supply-chain coordination (i.e., LCM), results in direct cost reductions and rapid payback for smaller firms. Furthermore, SMEs that cannot justify the development of their own LCM approach nor provide information to the diverse LCM protocols required by their downstream customers, can use a credible LCM system based on guidelines and tools, such as those summarised in this book. This includes LCE, EcoDS, and a variety of eco-indicators.

Case 5: Supply-chain influences on SMEs
(David Hunkeler)

Summary
This LCM case study illustrates how a joint economic valuation and environmental assessment could identify new market possibilities that satisfied an SME's investment criteria, while reducing environmental impacts. Specifically, a new product, gray office furniture, which could not be designed based on in-house manufacturing-only evaluations, was created from recycled black paint sludge. The case involved a coordinated supply-chain alternative, which identified worker safety, health and safety impacts, and high disposal costs as the key areas of concern. EcoDS was applied as the LCM tool because it involved the financial and environmental indicators that used the firm's internal data as well as consultant-derived assessed impacts. If traditional profitability tools had evaluated the alternative products, the current technology would not have been replaced. However, by including life-cycle costs, specifically transport, 2 alternatives were identified as being more environmentally benign and cost effective.
Definition

Why? UNARCO, a 330-employee U.S.-based SME involved in the production of metal-based office furniture, was interested in evaluating manufacturing alternatives. These, based on internal or external recycling of an organic solvent used in their painting process, were evaluated as possible replacements to an organic spray paint. The latter involved an 'overspray' that was not transferred to the product and, when collected as a sludge, was transported to disposal. UNARCO identified worker health and safety, process risks, and high disposal costs as the key areas of concern. Management believed that joint financial and environmental assessments could be used to screen 3 alternative process redesigns, all of which would require a capital investment: 1) solvent substitution to a powdered painting process with high recovery, 2) internal recycling of solvent with external disposal of sludge, and 3) internal recycling of solvent, external recycling of sludge.

What? For UNARCO, LCM consisted of an evaluation of manufacturing, transport, and disposal costs and risks, the latter assuming environmental (solid waste, atmospheric emissions) and health aspects (acute and chronic).

How? This LCM can be categorised as a streamlined risk assessment coupled with LCC. Information was obtained from UNARCO’s internal data, contact with their up- and downstream supply chains, and via a university that had carried out LCAs and risk assessments previously. An evaluation of the impacts of transportation and disposal options based on expert feedback was also employed.

Who? The LCM was commissioned by the main plant manager who had recognised the looming obsolescence of an organic solvent-based process and wanted to identify economical alternatives with affordable capital investment to maintain his competitive position in the regional office-furniture market.

Entry Gate and Drivers

Entry gate
The LCM was carried out over a period of 6 months in order identify alternatives to a high-waste painting process involving a volatile, non-recyclable flammable paint. The plant manager had approached Vanderbilt University’s Center for Technology Management to apply methodologies that combined environmental and economic decision-support criteria. The plant manager presented the results of the condensed LCM, in the form of a profit-risk spectrum, to the firm’s director who took the ultimate decision. Top management had, in advance, supported the LCM initiative within the firm, as well as paying for the external consulting costs.

Drivers

Product
UNARCO sold an established product in a low-margin competitive market, implying little room for design innovation.

UNARCO's process involved the use of a volatile organic compound (VOC)-based non-reusable spray paint, which caused concern that their office furniture product could be replaced by a substitute from a different material should storage, handling, or disposal regulations change for xylene.

Organisation
An inefficient process, potential worker health issues, process safety concerns, and mounting disposal costs were factors contributing to management support of the LCM.

External pressure
Both the product and process were within regulations, though concern over more strict guidelines, worker exposure, and a possible spillage were worrying management.

Supply chain
No supply chain pressures were identified though, through the case, the SME negotiated an opportunity to coordinate its process improvements with a supplier take-back policy. This reduced life-cycle costs, predominantly due to a net reduction in transport distances, concomitant with new product definition (gray office furniture).

2 In the European Commission, an SME is defined as a firm with less than 250 employees, with additional constraints related to turnover and ownership.
other

the sme needed to identify low-cost alternatives in terms of fixed capital investment and operating expenses.

implementation

figure 4-7 summarises the lcm case study, identifying the 3 alternatives (1 to 3 below) relative to the current process. the latter did not involve any solvent or sludge recovery, and the coating inefficiency resulted in unarco disposing of more than half of the non-reusable, flammable, xylene-based paint. with the exception of the powdered coating alternative 1, for which, at the time of the decision (1995), the technology was not sufficiently commercialised to provide a competitive market price, all alternatives resulted in reduced life-cycle impacts while satisfying unarco’s internal investment criteria (10.25%). management chose alternative 3 (internal solvent recycling and external sludge recycling) over alternative 2 (internal recycling of both solvent and sludge) due to its high return and potential to enhance supply-chain relations. this decision was taken upon the recommendation of the production manager, supported by an external report, which was confidential at the time, and carried out by vanderbilt university. alternative 3 involved a capital investment of $35 000 for a distillation column (solvent regeneration), corresponding to a life-cycle net present value of $3.07 million. unarco also coordinated a take-back program with the paint supplier wherein the used black paint sludge was blended with virgin white material to produce a recycled gray paint. this developed into a new market color for office furniture in the late 1990s. furthermore, by encouraging the take-back program, the supplier trucks, which had previously returned to their site empty, now carried back sludge, reducing transport impacts. the mass disposed was also reduced by 90%, further reducing transport risks, which decrease solid waste burdens substantially. interestingly, figure 4-7 identifies alternative 3 as the ideal (low cost) only from a life-cycle cost perspective, with the status quo preferred from a manufacturing-only view (data not shown). however, the latter would have missed new market opportunities identified via the systems perspective or ecods process.

tools

the methodology consisted of a simplified impact assessment in which an expert committee identified key stages and impacts. this vertical screening was followed by data collection in these key areas. the potential financial costs and liabilities were treated and complemented with estimates of the ‘residual’ risks inherent in the various stages. to avoid double counting, im-

![Figure 4-7 A plot of life-cycle costs (with a discount rate of 10.25%) and life-cycle risks for the 3 alternatives evaluated](image-url)
pacts were assessed either qualitatively or monetarily, with the 2 metrics summarised as shown in Figure 4-7.

The methodology is part of the LCM toolbox identified within this book (see Table 1-3).

EcoDS (Hunkeler et al. 1998), an environmentally conscious decision support system, has a product life-cycle perspective, integrates economic and environmental aspects, includes supply-chain coordination, and can be applied to design. It is applied as an LCM system in several Global Fortune 500 firms (Huang and Hunkeler 1996; Hunkeler and Huang 1996).

The manufacturing, transport, and disposal stages were evaluated along with the human health, ecological health and resource depletion impacts and solid waste and air emissions as impact categories (Biswas et al. 1998). ‘Residual risk’ was identified in this case as those impacts that could not be accounted for based on financial impacts. The preferred alternatives would be located at low costs and low ‘residual risks’.

Learnings

This LCM case was part of a continuous top management commitment to use cost and environmental assessment in decision-making. This specific case was reevaluated, in conjunction with external consultants, after one year. The firm continues to implement joint environmental and economic assessments for strategic decisions. For an SME, LCM can be considered akin to a technological advantage.

Case 6: Start-Ups: Environmental management and credit risk
(David Hunkeler)

Summary

This LCM case study illustrates that firms, prior to incorporation, can produce shareholder value and long-term durability by incorporating life-cycle thinking into the design and construction of facilities, marketing efforts, and relationships with stakeholders, particularly municipalities. It demonstrates the bottom-line benefits of a zero-discharge facility, the reduction in the cost of credit associated with life-cycle thinking, the creation of shareholder value via certification, and the use of LCC as a marketing tool to take customers away from multinationals.

Definition

Why? AQUA+TECH Specialties S.A. is a producer and retailer of flocculants for water clarification. Their first facility in Orbe, Switzerland, approximately 70 km northeast of Geneva, had a capacity of 3000 tons per year of emulsion-based product.1 The firm, which was incorporated in November 1997, began the installation of its factory in April 1998. Production was initiated in October 1999, with sales beginning 2 months later. The company of 11 people has received 3 state and federal prizes for technological innovation and entrepreneurship, respectively in 1997 and 1999, totalling half a million dollars. It was also voted the environmental firm of the year in 2002 by the Wall Street Journal Europe (WSJE), as well as awarded WSJE’s bronze medal for business innovation. In 1993, AQUA+TECH received the Certificate of the Swiss Economic Award. The firm also received the Label of Excellence from the Swiss Commission for the Innovation of Technology and the Prize of Honor from the Lausanne-based Foundation for the Innovation of Technology. Their CEO is also a past winner, in 1999, of the de Vigier Prize for young entrepreneurs. One aspect addressed in the technological innovation, in addition to the newly patented processes and

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1 In June 2002, the firm moved the facility to a larger chemical plant in La Plaine, Geneva, occupying a part of a former facility of Akzo Nobel with 2 other SMEs.
products, was that a small firm could economically design, build, and operate a zero-discharge facility.

What? LCM for this start-up consisted of 3 pillars: 1) the construction of a facility that reduced environmental burdens and expenses, essentially to zero; 2) the demonstration that forward environmental thinking could provide improved credit terms; and 3) the implementation of an EMS with subsequent certification to ISO 14000. The zero-discharge facility's design was part of the initial business plan. It was based on the belief that the demonstration of environmental excellence, in the comprehension and implementation of evolving international norms, adopted early in the start-up process and prior to negotiation with potential investors and creditors, would make the firm more competitive and attractive. As production began to generate revenue and the firm moved toward operation-based profitability, certification became a priority. Following the achievement of break-even operations, the firm also commissioned a comparative LCA and LCC study of the chemicals used in water treatment.

How? This LCM can be categorised as a DfE study, though the technological details in this case refer to a facility rather than a product. Zero-discharge as a policy also can be categorised as an extreme of waste minimisation. The understanding of EM-related issues comes from a belief of the co-founders, who moved from the United States, that the inherent business risks associated with a poor business decision are larger for SMEs and large firms in developing regions. The cost of miscalculations can be the disappearance of the firm, rather than several quarters of poor profitability. Therefore, it was decided that life-cycle planning should be a part of the strategic decision-making process and involve financial, technical, marketing, and administrative staff. Because bottom-line performance and share price stability have been shown to be linked, for multinationals, to environmental performance, LCM was viewed as one supplemental tool to help AQUA+TECH pass the 5-year threshold that bankrupts more than 90% of start-ups. Approximately 15% of AQUA+TECH's interest payments are based on environmental valuations from life-cycle experts commissioned from financial institutes. This fraction of the interest can be reduced to zero if appropriate programs, and competency, are in place.

The second aspect of the firm's policy is clearly related to compliance and risk avoidance. The recently commissioned life-cycle analysis and costing study is intended to be used as a marketing tool because AQUA+TECH's clients, which produce clean water, need to ensure that their total life-cycle cost in purchasing a new chemical is reduced. Out-of-gate burdens for AQUA+TECH's customers include the cost of transporting of by-products (sludge) to incineration or farms, sometimes out of the country, and the energy costs associated with water and by-product processing, largely in drying. As a point of reference, a 1% reduction in the water content of the by-product saves a municipality approximately $2 per capita per annum, providing a strong emphasis for coordinated life-cycle thinking. AQUA+TECH's AlpineFloc product line typically reduces chemical consumption by 30%, while increasing the dry content of by-products by 2%. The latter passes on life-cycle savings to clients via transport reductions. Therefore, AQUA+TECH supplies, to customers and resellers alike, a software that can calculate their life-cycle costs based on various chemical consumption scenarios.

Who? The zero-discharge facility was designed by the co-founder and Director of Technology, with the LCA study and certification commissioned by the CEO. Both followed extensive internal and board discussions, with the latter authorising the environment as only the secondary activity for the firm, which like all start-ups, must focus on core competencies.

Entry Gate and Drivers

Entry gate

Top management, as well as the technical direction of the firm, were the entry gates for the LCM programs.

Drivers

Product

Flocculants are high-molecular-weight polymers used as soluble filters to remove solids from aqueous suspensions. They offer dramatic reductions in energy consumption relative to mechanical filtration, with dosages in the 5 to 500 ppm range yielding near-potable water as a product. One application of this is in water purification in municipal and industrial waste water treatment plants. The primary benefit of a higher-efficiency flocculant can be in reduced
chemical consumption and cost as well in lowering the transportation burden of by-products which the water treatment works must assume.

Organisation

The firm viewed the life-cycle benefits associated with high-efficiency flocculants, and the associated LCA and LCC studies, as a marketing advantage. The facility was designed to reduce future costs and audits and to eliminate the high potential expenditures associated with waste disposal. Certification was thought, in the short term, to be a means to obtain less expensive credit and, in the long term, to be necessary for competitiveness.

External pressure

Other than compliance-related issues, the only external pressure came from financial institutes that would routinely send an economist as well as a university-trained expert in LCA to visit the facility. This included the bank’s first visit to assess the feasibility and potential liabilities and risks associated with the start-up. Therefore, a proactive LCM policy was seen as a way to improve long-term profitability concomitant with a reduction in liabilities.

Supply chain

In the water treatment industry, the client is faced with high costs associated with end-of-life-related issues. While there is no direct pressure on the various suppliers, which include European and American multinationals, to reduce these expenditures, transport cost reduction is a sales feature that can improve business. It also provides image to firms, which resell AQUA+TECH’s products in other markets. Furthermore, from the perspective of the production facility, the establishment of a closed loop system for water, within the factory, adds approximately 4% directly to the bottom line in terms of profitability. This is due to the elimination of water discharge, which is treated as a hazardous waste and billed at $0.50 per litre.

Other

Start-ups typically have capital limitations. Therefore, their cost of having to redesign or reinstall a facility could be catastrophic and lead to the destabilisation or collapse of the firm. The need for careful planning that will not have to be corrected is a driver with particular relevance to SMEs.

Implementation

A zero-discharge facility was constructed for approximately $800,000. The plant in Orbe, which is large by pilot standards, has the tenth-rated capacity for flocculants in Europe. Being in the vanguard with a top-performing product, as well as having an established quality control program and environmentally sound facility, has enabled AQUA+TECH to extend marketing efforts via resellers. This includes firms in Europe (Austria and Germany), Africa (Israel and South Africa), Asia (China), and Latin America (Argentina and Cuba), with a joint venture in the treatment of animal wastes with an established manufacturer in the United States. AQUA+TECH has followed general business practice and always, with its environmental decisions, sought to protect the interests and maximise the return for shareholders.

The demonstration of the understanding of the life-cycle implications of the product, technology, process, and facility was made clear during presentations to banks, where external LCA consultants were brought in to represent AQUA+TECH. Certification is being carried out in conjunction with a Swiss firm with experience in ISO 14000 audits, with the LCA and LCC work in conjunction with a university.

Tools

A detailed life-cycle impact assessment (LCIA), based on inventory data of single processes, was used to estimate key burdens (Rebitzer et al. 2002). The same inventory was costed (Rebitzer et al. 2003) to permit the development of aggregated cost and environmental indicators such as return on environment (Hunkeler and Biswas 2000). Overall, the study was used to identify key metrics that the firm could use in future planning decisions and during discussions with customers and resellers. The LCA was also used to give AQUA+TECH a means to influence local and statewide politics. The firm commissioned the LCM experts to calculate the environmental and economic break-even points for water treatment. Specifically, AQUA+TECH was interested to know the number of person equivalents in a given area for which there was more environmental harm to treat the water, due to associated electrical generation-related burdens and transport costs, compared to discharging the water directly into a river or lake.

Another example of the use of life-cycle cost calculations to demonstrate the downstream
savings to customers is shown in Figure 4-8. Such graphs are presented to customers to demonstrate that the product savings are not just related to reduced consumption, or price per kilogram, but also to burdens such as electricity consumption and reduced transportation costs in by-products.

In addition to these product-related activities, EM certification is carried out in conjunction with a small Swiss environmental consulting firm and follows ISO 14000 guidelines.

The firm has turned their strategy for environmental excellence, its knowledge of the evolving regulatory process, and its leadership position among Swiss SMEs into 2 indirect benefits. AQUA+TECH is routinely asked to consult other firms in developing LCM, and it has recently been nominated to the presidency of a new association of SMEs, the Swiss Water Treatment Association (SWATER). SWATER is a conglomerate of Swiss firms with technology related to water treatment that plans to enter the Chinese market.

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**Case 7: Green procurement**  
*Konrad Saur*

**Summary**

Purchasing functions and supplier management are well-recognised areas of focus for firms improving the performance of their products and moving toward more sustainable strategies. To illustrate how purchasing can be structured to foster this improvement, this case describes 5 principles of the USEPA's Environmentally Preferable Purchasing initiative. Drawing from experience with various firms, discussion of the case is expanded to examine the full business benefits of effective purchasing programs. Overall, it becomes clear that purchasing is not only an effective entry gate for LCM, but key elements of EPP can promote integrated, comprehensive and continuous improvement, which is one of the main drivers for LCM.

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1 AQUA+TECH has, for the last 2 years, been ranked in the top 100 SMEs in Switzerland by a Geneva-based business magazine *PME*. Its policy of Selective Multinationality holds that an SME can be international from the outset if it selects key and emerging markets where it can impose itself as the leading producer or reseller. In particular, because water is a political issue, AQUA+TECH focuses on regions where clean water is viewed as a priority or a prerequisite for attracting new business.
4: Applications of life-cycle management

Definition
The USEPA defines environmentally preferable procurement (also eco-purchasing) as the purchasing of products and services that are environmentally preferable. Products and services are considered environmentally preferable if they have 'lesser or reduced effects on human health and the environment when compared to competing products and services with the same purpose' (USEPA 1999b; OFEE 2003).

Why?
Under the aforementioned initiative, each U.S. government agency is charged to develop policy to promote environmentally preferable purchasing (EPP). Under Executive Order 13101 (OFEE 2003), agencies are required among other things to identify and purchase recycled products and environmentally preferable products and services. This covers the acquisition of raw materials, production and manufacturing, packaging, distribution, and operation as well as maintenance, re-use, and disposal (USEPA 2002). As a measure of the initiative, agencies are being encouraged to conduct pilot tests to evaluate the USEPA's guidance document entitled 'Final Guidance on Environmentally Preferable Purchasing' (USEPA 1999a).

What?
The USEPA (1999a) outlines 5 guiding principles for EPP:

1) Environment + Price + Product Efficacy = Environmentally Preferable Purchasing:
   Environmental considerations should become part of the normal purchasing practice, consistent with traditional factors of product safety, price, performance, and availability.

2) Pollution Prevention: Consideration of environmental preferable should begin early in the acquisition process and be rooted in the ethic of pollution prevention, which strives to eliminate or reduce, up front, potential risk to human health and the environment.

3) Life-Cycle Perspective / Multiple Attributes: A product or service's environmental preferable is a function of multiple attributes from a life-cycle perspective.

4) Comparison of Environmental Impacts: Determining environmental preferable may involve comparing environmental impacts. In comparing environmental impacts, federal agencies should consider the reversibility and geographic scale of the environmental impacts, the degree of difference among competing products or services, and the overriding importance of protecting human health.

5) Environmental Performance Information: Comprehensive, accurate, and meaningful information about environmental performance of products or services is necessary in order to determine environmental preferable.

How? Eco-purchasing encourages the evaluation of multiple impacts of a product throughout its life. Thus, the producer begins to understand the impacts a product or service will have and to communicate with suppliers. Suppliers must in turn provide their knowledge and perspective on the impacts the supplied components will have and must communicate with producers. This understanding and life-cycle information is gathered for a number of environmental attributes, including material toxicity, energy and water efficiency, waste minimisation, recycled content, greenhouse gas emissions, and transport. Other positive attributes include the potential for disassembly of the product, its durability, reusability, and remanufacturability, as well as the possibility for take-back and the incorporation of biomaterials.

Who?
By examining the attributes of the way the USEPA prioritises products, it seems clear that manufacturers, suppliers, and sub-suppliers must be included in the gathering and exchange of information. Furthermore, this list of attributes illustrates that, without a life-cycle perspective incorporating actors beyond the firm's gates, it would be impossible to make the most optimal performance improvements.

Entry Gate and Drivers

Entry gate
The purchasing function itself is an entry gate for LCM in a firm, as has been discussed in Chapter 3 ('Procurement', p 18) Eco-purchasing efforts may very well link to and support other improvement initiatives in the firm by generating understanding of the products and building alliances and interactive relationships along the product chain.

Drivers
The U.S. government's purchasing initiative addresses drivers from the public, from businesses themselves, and from leading activities internationally. For this case description, it is perhaps
more relevant to examine the specific drivers and related benefits for those who implement EPP, or the like.

From a business perspective, EPP has 2 motivators:

1) to reduce adverse environmental impacts and
2) to reduce the total costs of ownership for purchased products and services.

Figure 4-9 clearly illustrates the cost-effectiveness of purchasing that takes the complete life cycle of a product into account. Costs associated with use include training, reporting, handling labor, and storage facility costs, while those associated with disposal can include costs of solid and hazardous waste disposal, water treatment, transport, storage, and monitoring.

Surveys by the author’s former firm (PE Product Engineering) and others have noted that firms engage in green procurement for several reasons, including:

- reduction in cost over the life of the purchased product,
- improvement in productivity,
- cost reduction due to a lowering of the environmental impacts associated with waste and end-of-life product stages,
- improved health and safety conditions that reduce incidents and liability,
- improvement of company’s image, and
- support of existing EMSs.

Thus, through implementation of eco-purchasing, one begins to see the direct supporting link to an LCM approach. LCM seems to improve decision-making, according to its advocates, by putting ‘better information in front of decision makers’. Specifically, many multinationals recognise that purchasing is a key element in product quality and improvement, with the benefits of the former increased if it is integrated within the firm. Green procurement, with its guideline-based approach, is also an ideal tool to introduce social concerns into the firm’s life-cycle perspective more easily than with either a cost- or impact-based quantification.

When changing and improving purchasing functions, one should focus on the following:

- Integration – becoming a part of existing procedures, not an add-on task to procurers
- Contribution – fostering cost-effective purchasing, not adding time and cost burden
- Cooperation – generating understanding of what is to be achieved and gaining acceptance through transparent 2-way communication, not causing defensive responses, secrecy, and mistrust.

**Implementation**

The implementation of eco-purchasing requires a management system that incorporates the environmental aspects of manufacturing, product design, use, and operations to identify adverse impacts, associate them with hidden costs, and

If only acquisition or purchasing costs are considered, Product A seems to be the better choice.

In the long run, Product B is more cost effective.

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Figure 4-9 Discrepancy between initial and total cost of a purchased product
Applications of life-cycle management
devise measures to reduce both. It is, initially, important to establish what should be achieved by changing the purchasing procedures to incorporate an eco-purchasing perspective and thus set a clear strategy. The 'cookbook' for implementing green procurement might follow the following steps.

Step 1: Request information from suppliers:
For instance, the firm could inquire about its suppliers' overall environmental initiatives as well as what issues the suppliers perceive to be important and how they are approached. The definition of specific environmental metrics for suppliers' product or material is important to identify, as is the supplier's vision of their component or material within the complete product system. Requirements for this type of information can be incorporated directly in requests for proposals. The goal is to ask for the information at the earliest stages of procurement and obtain it in a nonconfidential disclosure so that it can be disseminated throughout the supply chain.

Step 2: Include the requirements identified in Step 1 in the technical quality and performance requirements for the supplied product or service. These may already exist in the technical requirements for the firm's internal engineering and design product specifications.

Many firms also send their supplier forms or questionnaires with these specific questions related to environmental performance and continuous improvement efforts. According to the types of responses, firms may categorise different suppliers, focusing guidance and assistance on those that respond below a certain level. The logic behind this is that high-performing suppliers require less guidance, will cost less in terms of interaction, and may in fact contribute to furthering the firm's internal improvement efforts.

Changing and improving purchasing functions to foster product improvement will require more specific measures or indicators, as was discussed in Chapter 1 ('Use of Metrics and Indicators', p 5). Specifically, the commonly employed metrics, such as percentage of recycled content, energy efficiency, or cadmium reduction, often lack verification in specific cases. The metrics, in addition to the use in monitoring progress towards goals, can be effective in linking the procurement to LCC initiatives.

Tools
EPP is a program driven by the overall concept to improve. Various tools can be used to implement the program and achieve its aims of improving environmental performance of products and services while simultaneously reducing overall costs. As is very often the case in LCM, green procurement seems to fit in better within an organisation if it uses established product teams. Labels also offer a well-established indicator of product performance and improvement. The key to success seems to rest in the identification of those labels that support the firm's strategy, which must be backed by top management and routinely communicated.

Production and Distribution
This section focuses on large firms, specifically those with a diverse set of products and extensive new product introduction. Broad product lines and rapid product introduction both, if not managed well, could present significant costs to a firm engaging in systematic studies. Specifically, a product entry gate-driven LCM approach is discussed with respect to the high tech industry, whereas indicators are evaluated from an external reporting perspective. The 3M-LCM approach is an excellent example where continued top management commitment has led to decades of savings and cost avoidance. This includes their historical Pollution Prevention Pays programs and ambitious waste-minimisation goals for their decade-long targets program.

Case 8: Product entry-gate driven LCMS in multinationals
(David Hunkeler)

Summary
This LCM case study summarises the methodologies employed by Fortune 500 firms in regards to their need to integrate economic, technical, and environmental information into a pre-existing decision framework. The needs for corporate LCM as well as for common entry gates and drivers are summarised. The typical features and uses of corporate LCMS, including pro-forma income statements and environmental balance sheets are documented based on extensive surveys and consulting experience.
Definition

Why? Surveys of Fortune 500 firms in North America (Huang and Hunkeler 1996) and Asia (Hunkeler and Huang 1996) indicated that a growing number of top executives were finding the need to incorporate environmental information in decision-making. While cross-disciplinary teams were favoured, the retraining of existing corporate cultures required time. Only through continuous top management involvement, such as in 3M's Pollution Prevention Pays program, the thesis of which was originally put forward in the 1970s by Michael Royston (Royston 1979), would continual improvement lead to reductions in environmental burdens. The corporate commitment to reduction in life-cycle burdens, via eco-efficiency, began modestly at the Rio Summit (DeSimone and Popoff 1997) and followed through due to the leading efforts of the World Business Council for Sustainable Development. Former chairmen of the latter began in 1996 to advocate LCM (Schmidheiny and Zorraquin 1996), though the details would be worked out within specific organisations over the coming years.

What? The aforementioned Fortune 500 firm saw a need for 6 elements in what we would now term LCM. Specifically, LCM must

1) heighten awareness in the organisation,
2) condense complicated information for the ultimate decision-maker,
3) fit into existing corporate cultures,
4) use a firm's cumulative experience,
5) combine life-cycle 'thinking' with qualitative and quantitative evaluations of alternatives, and
6) provide a means to incorporate stakeholder concerns.

They also sought a tool that could enable them to heighten awareness early in the design stage (to minimise environmental burdens and maximise savings) as well as to open new markets via a proactive strategy. The LCM tool should also satisfy current needs and enable those responsible to answer to supply-chain demands (Huang and Hunkeler 1996).

How? From a corporate perspective, LCM has evolved into a flexible, transparent, iterative matrix-based toolbox that facilitates the inclusion of internal and external value systems. It is used for internal decision-making regarding development, principally by the pre-existing product teams, as well as externally to provide inventory and 'screened' assessment data to clients and suppliers, some of which, including Volvo, demand inventory data and screen purchases based on a firm's 'greenness' relative to competitors. Aspects desired in an LCM include

1) subjectivity;
2) defaults, which permit a firm to rapidly (in one afternoon) create an LCM case based on existing products, services, or markets;
3) cost estimation while avoiding life-cycle jargon, which is unfamiliar to the majority of managers and designers;
4) uncertainty estimates; and
5) the ability to use an LCM, or its associated software tool, to perform what-if analyses.

Who? Fortune 500 firms envisioned using LCM for new product introduction, in supply-chain management (SCM), to establish environmental marketing claims, in strategic planning, and in green design.

Entry Gate and Drivers

Entry gate

The entry gate for LCMs in large firms is generally one of 3 divisions: manufacturing; top management; and environmental, health, and safety (EHS). The former is clearly related to established industries, including those based on raw materials (plastics and metals), durable goods (refrigerators and automobiles), or consumer products with high visibility (electronics, highly packaged products). Under such circumstances, supply-chain pressures require a diverse set of life-cycle–related information. Several firms, including 3M, have decided to implement streamlined LCM procedures they can perform over their entire product suite. For innovative multinationals, with upwards of 50,000 products and 500 new introductions per year, this daunting task requires continuous top management buy-in and reinforcement. It also needs consensus building, internal and external education and communication programs, as well as the ability to train LCM facilitators and coordinate LCM case studies and workshops between internal experts and external consultants. In the latter, EHS takes a key role, though several firms, including United Technologies, have mandated their environmental divisions to move LCM from an overhead to a direct cost, forcing demonstration of efficacy with the manufacturing divisions. Corporate policies have
Applications of life-cycle management

generally been to provide a framework, such as '3M-LCM', while permitting various divisions and geographical sub-units to define the specifics according to their internal needs and supply-chain pressures.

Drivers

The corporate drivers for LCM are, in respective order of importance (Huang and Hunkeler 1996; Hunkeler and Huang 1996),

- minimising cost,
- avoiding future liabilities,
- ensuring compliance,
- enhancing image,
- preempting regulatory changes, and
- meeting customer requests.

Corporate LCMS generally contain economic and environmental data from the manufacturing, use, and disposal phases, with approximately 50% of assessments including transport. Because resource extraction is rarely included due to difficulty in obtaining data, the LCMS can be characterised as 'gate to grave' streamlined LCAs.

LCMs, in a multinational setting, include a broad-based risk assessment spanning financial risk (capital and operating costs, short-term financial costs), and liability, as well as long-term issues including human health, environment, resources, and when data are available, social welfare. Clearly, uncertainty increases as one moves from short-term assessments, for which the data are generally available in hours, to longer-term prospects. Therefore, most firms' LCMS include 3 components:

1) LCC, which is performed on individual life-cycle stages (e.g., manufacturing, transport) for which the data are readily available;
2) LCIA, which is generally performed based on incomplete inventory information and existing external, software programs; and
3) qualitative risk and opportunity evaluation, for which various stressors are identified as key for a given life-cycle stage, and a firm evaluates if they are in compliance, requiring further effort or leadership.

Implementation

LCM follows a standard management procedure that requires, at the outset,

- specification of goals,
- definition of the target market, and
- determination of the time and financial resources available.

As was discussed in the preceding section, the 3-step implementation process is often best communicated via a matrix with quantitative cost data orthogonal to impact assessment summaries, while individual cells include qualitative information. Firms generally carry out LCMS in a period of 2 to 4 hours, with the involvement of an 8- to 12-person multidisciplinary team including production, design, marketing, finance, and EHS representatives. They tend to leave the LCM meetings with a summary matrix and brief 2- to 3-page report that can be presented to the decision-makers. This provides a means for recordkeeping and monitoring improvement, which is equally important in a corporate setting as a single absolute assessment.

Tools

LCMs in a Fortune 500 firm generally include pro-forma income statements and environmental balance sheets. There are several tools available on the market, as is summarised in Table 1-3. Additionally, some large firms, including General Motors and AT&T, have developed their own systems. Overall, corporate LCM requires a balance of internal knowledge and reliance on private consultants. Involvement in the development of the methodology, through participation in leading organisations such as the Society of Environmental Toxicology and Chemistry (SETAC) is common. Additionally, several firms are directly included in the establishment of standards such as the ISO 14000 series, which has seen significant corporate buy-in following the success of similar total quality management approaches.
Follow-Up: The Evolving Role of Life-Cycle Management

The 3-year deliberations of the 18-member Society of Environmental Toxicology and Chemistry (SETAC) Working Group (WG) on Life-Cycle Management (LCM), culminated in LCM 2001,1 an international conference attracting 270 participants. The conference in Copenhagen presented the state of LCM as it is in practice and development, as well as debating some of its needs (Hunkeler et al. 2001). The preliminary results of the WG were discussed in several presentations. The 3 years prior to Copenhagen included 9 working group meetings, as well as presentations from 23 firms working in LCM. The final working group meeting defined the following recommendations for those who continue to define and form LCM. Collectively, the working group felt that LCM should

- use existing tools,
- develop benchmarks, and
- expand its case study library.

Additional components to the LCM toolbox will certainly come, though there was a belief that these would be better adopted if they and their indicators were comprehensive in nature; were validated for specific products, sectors, or industries; and were benchmarked and simple. An example of the follow-up in regards to the deliberations of the SETAC WG on LCM is the UNEP-SETAC Life-Cycle Initiative (Fava 2002; Töpfer 2002), which includes 6 LCM-related task forces. SETAC itself has also followed up on the economic dimension of LCA by establishing a new working group on life-cycle costing (LCC), which has about 70 members and began deliberations in December 2002 (Rebitzer and Seuring 2003).

As a general goal, those influencing LCM policy should try to ensure that integrated approaches be based on ‘better’, as opposed to ‘best’, practice. This was seen as a way to aid decision-makers in making good allocation decisions, under time pressure and with imperfect or incomplete information. It is expected that follow-up research, elucidating the 3 aforementioned points, will be carried out under the auspices of the UNEP-SETAC initiative and the SETAC Europe WG on LCC.

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1 First International Conference on Life-Cycle Management, LCM 2001, Copenhagen, Denmark, 27 to 29 August 2001.
APPENDIX A

Perspectives on and Evolution of Life-Cycle Management

Life-cycle management (LCM) is certainly more widespread than it was in the Spring of 1998 when the Society of Environmental Toxicology and Chemistry (SETAC) Europe created its LCM Working Group (WG). The external presentations from various firms integrating life-cycle concepts into environmental management (EM) permitted the WG to form hypotheses related to the needs for, and components of, LCM. This appendix presents a historical perspective of the past 4 years, illustrating specific definitions of LCM, while summarising the essentials of the debate, which permitted the WG to coalesce on a framework for LCM. The goal of this section of the report is to duly cite those who contributed to the understanding of LCM as a concept, some of whom were not part of the WG or did not participate in the writing or editing of the book. Additionally, the definitions presented herein provide a breadth of the current practice in LCM and are, therefore, intended to complement the benchmark cases in Chapter 4.

Charge to the Working Group

During the opening meeting of the WG on 15 April 1998, in Bordeaux, France, Allan Astrup Jensen, who served as the Convener and later as the Secretary, introduced a vision for LCM:

LCM is a practical and integrated approach to manage and make decisions related to minimising the environmental burdens associated with a product or service over its life cycle. It is a company-oriented concept, which may be a better way to structure the environmental work (e.g., European eco-management and audit scheme [EMAS]) that firms are presently employing and to make information and data more useful. LCM is also a concept to link the upstream and downstream supply chain towards a comprehensive product-oriented environmental policy.

It is important to note that Jensen, from the outset, alluded to the concept of better practice, rather than best practice. He also referred to the practical nature of the tool and to the fact that LCM is a concept, linking supply-chain issues.

During the first year of discussions, Lars-Gunnar Lindfors introduced the important notion that there are minimum requirements for LCM. Furthermore, Matthias Finkbeiner, then a consultant and now part of the life-cycle group for a multinational company (DaimlerChrysler), proposed the LCM was a toolbox. These were concepts discussed during the first 4 WG meetings, though as is evident from the definition in Chapter 2, the concepts were retained throughout our deliberations. Kim Christiansen, then at an industrial service firm and now a consultant, realised in early 1999 that a goal of the WG would have to be to explain the existing tools, as well as their benefits and limitations, for specific uses and users. Therefore, we concluded that LCM was not necessarily the development of tools but rather their implementation. Clearly, LCM would be broadly based and would require, in addition to environmental information, social, economic, and techno-
logical factors (L.-G. Lindfors, IVL, Sweden, unpublished data). We also introduced, early on, the notion that LCM need not be rigid but must include the aspect of freedom and adaptability (M. Finkbeiner, DaimlerChrysler, Germany, unpublished data).

The following 2 subsections summarise the specific definitions of LCM, provided by firms, consultants, and academics alike, which served to seed the debate and refine the definition. They are presented in the order in which the WG viewed the definitions.

Key Components of Life-Cycle Management

The second WG meeting, as part of the EuroEnvironment conference in Aalborg, Denmark, in September 1998, was the most prolific meeting in terms of presentations regarding LCM. Wulf-Peter Schmidt (Ford, Germany) opened the discussion by defining key components to LCM:

• is based on life-cycle thinking,
• has the goal to optimise the whole life cycle,
• includes all aspects of improvement,
• is seen as a multi-criteria approach,
• includes supply-chain partners,
• includes several functions within the firm (e.g., design, purchasing, manufacturing, research and development [R&D]), and
• is pragmatic.

Mario Tarantini (ENEA, Italy) underlined the need for flexibility and continuous improvement in a practical approach.

Nicoline Wrisberg (CML, The Netherlands) elaborated on the supply-chain concept by suggesting a responsibility of firms within the chain and referring to the Product Stewardship initiative, which came out of the United States. She also noted that procedural tools, eco-audits, and eco-labeling, as well as analytical tools, could support LCM. It was clear, after the preliminary debates, that LCM would not be a methodology but rather a concept. Furthermore, the WG felt that LCM would have a focus much broader than product-specific life-cycle assessments (LCAs). Supply-chain management (SCM) is summarised, briefly, in Appendix B.

Specific Corporate Definitions of Life-Cycle Management

Claus Stig Pedersen presented the Hartmann LCM program and noted that LCM is 'any management activity that focuses on the minimisation of the total environmental impact potentials, and resource consumption, throughout the full life cycle of a product'. He elaborated that any decision-maker performs LCM when he or she bases decisions on an overview of related environmental consequences throughout the entire product chain.

David Hunkeler (AQUA+TECH Specialties, Switzerland) proposed that LCM should consist of a set of pillars:

• environmental management and strategy,
• life-cycle thinking,
• supply-chain dialogue,
• compliance,
• life-cycle costing (LCC),
• values management,
• validation, and
• design.

Hunkeler also added the first considerations of items that were not LCM. These included eco-efficiency and eco-indicators because neither is based on systematic life-cycle validations. From a practical viewpoint, Hunkeler questioned whether the goal of LCM was to provide a correct decision, or ranking of alternatives, with a minimum of effort and cost. He also added that LCM can and should integrate screening indicators or emetrics. Finally, LCM is not sustainable development because the latter requires thresholds and LCM indicates only movements towards sustainability.

Carole Henshaw (Unilever, UK) defined LCM as the process of minimising the environmental burdens of a product or service throughout its life cycle. She noted that this involves a firm adopting life-cycle thinking. Henshaw proposed that detailed investigations could be carried out using LCA and related techniques, and LCM could build on, in part, the conclusions of LCA, at the minimum for specific products and industries. She concluded that LCM is motivating firms to think in a life-cycle way using 'all existing tools and processes'.

Berno Ram and Ab Stevels (Philips Consumer Electronics, The Netherlands) saw LCM as a means to facilitate the exploration of environ-
mental opportunities in the perspective of the product life cycle. They also cautioned as to the need for the methods and tools of LCM to lead to competitive advantages.

Kim Christiansen (Sophus Berendsen, Denmark, now 2-0 LCA consultants, Denmark) noted, 'LCM addresses environmental, economic, technical and social aspects of organisations and products, services or their utility in a life-cycle perspective to achieve continuous environmental improvement'. He noted that LCM should support the voluntary business assimilation of Integrated Product Policy (IPP), Integrated Pollution Prevention and Control, eco-labelling, as well as other national or international regulatory initiatives.

Antonio Giacomucci (ABB Corporate Research, Italy) saw the links between LCA, certification, and environmental management systems (EMSs).

Anders Schmidt (dk-TEKNIK) also contributed significantly, particularly in moderating the role of LCM and ensuring that LCM must be specific, lest it become a relatively useless catchphrase.

### Specific Definitions of Life-Cycle Management from Consultants

Pere Fullana (Randa, Spain) suggested that LCM should use what ISO and SETAC have developed as tools and look for applications in specific management situations. He also realised that if LCM would provide a multi-perspective vision, it would require input from various types of people, both within and outside the organisation.

Gunilla Olund (Chalmers IndustriTeknik, Sweden) noted that LCM may be used as a management tool in order to relate environmental performance with financial performance or competitive advantages within a firm. She also noted the advantages that many companies saw in implementing proactive environmental strategies.

Allan Astrup Jensen (dk-TEKNIK ENERGY & ENVIRONMENT, Denmark) saw LCM as an approach that aims at managing the environmental burdens of activities and decisions when these are set within a chain (system) context. He noted that, in this regard, LCM is placing social requirements on the EMS.

Matthias Finkbeiner (PE Product Engineering, Germany, now DaimlerChrysler, Germany) proposed an LCM approach that integrates or combines LCA and EMS. He noted that both environmental managers and consultants have a strong background with both tools. Finkbeiner concluded by noting that LCM, to be valid as a sustainability indicator, requires the appropriate functional unit. However, it does not have to be, nor should it claim to be, a perfect method. Finkbeiner concluded that LCM should be a practical, voluntary, comprehensive approach toward product- and organisation-related tools wherein at least some of these tools consider a life-cycle perspective.

Konrad Saur (PE Product Engineering, Germany, now Five Winds International, Germany) presented the life-cycle engineering (LCE) approach as a means to evaluate alternative designs and processes. This consists of 3 dimensions: LCA, life-cycle costing (LCC), and total quality management (TQM). Saur recommended that a preliminary assessment of a product's environmental profile be carried out in the design phase. LCE can also impact on materials selection, client and authority dialogue, and weak-point analysis. Saur noted that there is no single program or technique capable of delivering an overall answer in regards to environmental decision-making, leaving an open window for LCM. He made a plea to integrate LCM into existing decision-making structures. Saur concluded by citing a 1995 definition of LCM as a streamlined LCA tool for decision-making, which includes LCC.

Lars-Gunnar Lindfors (IVL, Sweden) noted that we do not know nor does anyone else know what sustainability is, and this places restrictions on environmental improvement. Therefore, we need tools and information that permit business managers to discuss sustainability and environmental improvement.

### Specific Definitions of Life-Cycle Management from Academics

Christiane Maillere (EMPA, Switzerland) saw LCM as an evolved LCA. LCM would, according to Maillere, require attention to both the environment and decision criteria in the early
stage of the assessment of a product or service. The need for systems thinking was also justified.

Andreas Windsperger (Institute for Industrial Ecology, Austria) noted that LCM needed to generalise the LCA concept to satisfy the demand of managers. He suggested an investigation of common decision methodologies, with their characterisation. An overall aim was to see which existing methodologies could best integrate the life-cycle concept.

Juha-Matti Katajajuuri (VTT, Finland) noted that LCM was not a tool, but perhaps a toolbox. Supporting elements in this toolbox could include LCA, total cost accounting (TCA), cost-benefit analysis (CBA), environmental impact assessment (EIA), and environmental risk assessment (ERA). He also noted that LCM comprises ecological, economic, technical, and ethical issues.

### Some Final Words on Life-Cycle Management

The aforementioned presentations have been condensed by the first author of this document and, therefore, do not and could not within the limitations of a book, reflect the full debate carried out over the 3-year term of the WG. If some of the presentations are redundant, this illustrates the consolidation of opinion and the extent to which a widespread agreement was obtained on the key concepts related to LCM. The WG summarised its first concept for LCM during the same meeting where Konrad Saur was elected Chairman; Allan Astrup Jensen, Secretary; and Pere Fullana and Antonio Giacomucci, Convenors. This first definition was as follows:

"LCM is a practical and integrated approach to minimise the environmental burdens associated with a product or service over its life cycle. It is a concept that may be useful in ensuring a sustainable development. It is also a way of linking environmental improvements with economic efficiency."

This definition seems to condense the most important elements of the discussions and presentations. The efforts of the WG are obvious when one views the minutes from the Bordeaux meeting on April 15, 1998, which concluded with the following notion:

"LCM evaluates, according to various financial, environmental, health, and safety related metrics, the impacts of a product or service throughout its life cycle. While comprehensive in scope, it can be vertically streamlined. That is to say, LCM can be performed based on a preliminary impact assessment which identifies key stressors, impacts, and LC stages while omitting others. LCM is not intended to provide a quantitative LCA. Rather, it provides a relative comparison of alternatives and outputs the results in a concise form suitable for mid- and top-level corporate decision makers. LCM can and should be integrated with 'Screening Indicators' or 'Ecometrics'. Furthermore, while LCM can be linked to databases, life-cycle inventory is not a required component of LCM. LCM is intended for application in product design, marketing and new product introduction, to respond to supply-chain queries as well as in executive decision-making. LCM should be easily integrated into existing corporate structures, such as TQM and be based on pre-formed product teams rather than new LCM teams.

Clearly these definitions, and the ultimate definition in Chapter 1, were not intended to be cookbooks, but rather indicative. The WG would hope that users of LCM subscribe to the concept in spirit, rather than in letter. As we close, let us recommend that LCM retains its flexibility and breadth, that it sticks to some guiding principles outlined herein, and that it evolves, as its toolbox does, to incorporate new ideas and approaches. If it does not seek to be everything, LCM may well have a durable position within the corporate world. Perhaps we can summarise by noting that we believe we know what LCM is, though we need to fill in its toolbox."
Supply-Chain Management as a Tool Within Life-Cycle Management

Introduction

Increasing globalisation, advances in information technologies, rapid product and process innovation, and volatile marketplace demands characterise the business climate at the outset of the 21st century. Environmental concerns now play an important role in defining this business climate, not as a stagnant character but as a player of increasing profile. This role is reflected in the policies and emerging practices that set the conditions for decision-making in business operations today.

To understand the full system and life cycle of a firm's operations, focus must extend beyond the factory gates, up and down the product chain. It is this aspect that becomes interesting for business, because understanding the full system of the material good or service will identify optimal points to change and improve performance that go far beyond environmental impacts. A key aspect of building this understanding is in communication back along the product chain, to suppliers. Thus, practices to engage and manage suppliers are essential for sound, profitable business operations and for realising the opportunities in today's business climate. This appendix seeks to demonstrate, through brief examples, that supply-chain management (SCM) is neither a competing program with, nor a synonym for, life-cycle management (LCM) but rather one of the tools that LCM requires, generally, for its implementation. For a further overview of the LCM toolbox, consult 'The Life-Cycle Management Toolbox' (p 6) and Table 1-3.

What is Supply-Chain Management?

The following definitions, many of which are relatively historical in the rapidly developing field of environmental management (EM), demonstrate the extent to which SCM is envisioned to be a tool for LCM, particularly in obtaining information and maintaining it as an asset.

- 'How an industry responds to environmental problems may, in fact, be a leading indicator in its overall competitiveness.... Only those companies that innovate successfully will win. A truly competitive industry is more likely to take up a new standard as a challenge and respond to it with innovation....' (Porter and van der Linde 1995).
- Buyers are 'forging stronger relationships, alliances and partnerships throughout the supply chain in an effort to obtain ensured supply, leverage, inventory management and better quality' (Reilly 2001).
- 'SCM offers the firm integrated planning, visualizing, optimization, (and) a material and information flow along the logistical network' (Steinaecker and Kühner 2001).

These definitions serve to illustrate some key points. First, SCM is not a new concept to business. Secondly, it is a practice of well-recognised and widespread value. According to the definition of environmental SCM, practices that focus on the environmental aspects of the product chain will decrease...
the adverse impact of products or services across their life cycle. Going further, these 2 ideas can be tied together to support the claim that integrating environmental considerations into existing SCM practices contributes to a win-win situation of increasing economic returns and reducing environmental impacts.

**The Supply Chain as an Asset**

As Case 7 in Chapter 4 (p 50) demonstrated, SCM offers several advantages as a firm implements its LCM policies, including

- reducing the tolerances related to environmental product attributes,
- extending producer responsibility, and
- accessing information and maintaining it as an asset within the firm.

The last point is best seen in Figure B-1, which describes the loss of environmental information within an organisation as it passes between departments. Therefore, the LCM interdisciplinary product teams may very well be the best means to communicate the value of systemic approaches to product development and stewardship.

**The Advantages of Being Proactive**

Several cases, which will not be duplicated herein, demonstrate that more value can be derived when a company is proactive with SCM activities. These include 3M's Pollution Prevention Pays program, as well as United Technologies' Green Engine. Another example of a firm engaging actively in SCM is BASF, which has cooperated to calculate the costs to handle soaps containing various substances in terms of U.S. legislation, reporting, handling, and worker safety requirements. They have also developed a model that they now can use for other products where the use phase is important. Their supply-chain involvement included using containers and changing the drum size. This resulted in less expensive detergents to the clients and lower manufacturing costs, as was also seen in the UNARCO case (see Case 5 in Chapter 4, p 44).

![Figure B-1 Information losses about the product components as they pass between actors in the supply chain (Reprinted with permission from Jennifer Hall, Copyright IIIEE, 2001)](image-url)
Where possible, the authors of this glossary employ accepted definitions with the most relevant, or in some cases most recent, citations provided. It is intended as a guide through the often ambiguous or redundant nomenclature.

**A**

**ABB**: Asea Brown Boverie (Swedish-Swiss multinational electrical company)

**ABB-LCM**: LCM program of ABB

**ANR**: American National Rubber

**APME**: Association of Plastics Manufacturers in Europe

**B**

**BASF**: Badische Anilin und Soda Fabrik (Germany)

**BMBF**: Bundesministerium für Bildung und Forschung (Federal Ministry for Research and Education [Germany])

**C**

**CBA**: cost-benefit analysis

**CEB**: corporate ecobalance or corporate environmental balance

**CEO**: chief executive officer

**CFC**: chlorinated fluorocarbon

**CfSD**: Centre for Sustainable Design

**CHAINET**: European Network on Chain Analysis for Environmental Decision Support

**Clean(er) Technology**: Concept used in the manufacturing and processing industries for avoiding pollution and waste at the source.

**CML**: Centrum voor Milieukunde (Leiden University Institute of Environmental Science)

**COO**: cost of ownership

**Corporate Ecobalance**: see Corporate Environmental Balance

**Corporate Environmental Balance** (CEB; Corporate Ecobalance): A methodological framework to compile the gate-to-gate material and energy flows of a corporate facility or a corporation as a whole as it is usually applied in the context of establishing or updating an Environmental Management System.

**D**

**Design and Development**: 'Set of processes that transforms requirements into specified characteristics or into the specification of a product, process or system. ... The terms "Design" and "development" are sometimes used synonymously and sometimes used to define different stages of the overall design and development process' (ISO 2000e).

**Design for Environment** (DfE; Eco-Design; Green Design): A general term for a number of methods for incorporating environmental...
factors into the design process. The use of the concept, in various forms often expressed as 'DfX', conforms to the design of products and therefore to industrial applications.

DfE: see Design for Environment.
DVR: Deutscher Verkehrssicherheitsrat (German Traffic Safety Council)

E

EC: European Commission
ECDM: see Environmentally Conscious Design and Manufacturing.

Eco-Design: see Design for Environment.
EcoDS: see Environmentally Conscious Decision Support System.

Eco-Efficiency (EE) 'is achieved by the delivery of competitively-priced goods and services [the products, the authors, etc.] that satisfy human needs and bring quality of life, while progressively reducing ecological impacts and resource intensity throughout the life cycle to a level at least in line with the earth's estimated carrying capacity. In short, it is concerned with creating more value with less impact' (WBCSD 2003).

Eco-Indicators: see Environmental Indicators

Eco-labelling: Eco-labelling can be divided in different types of labelling according to ISO 14020 (ISO 2000a), ISO 14021 (ISO 1999a), ISO 14024 (ISO 1999b), and ISO/TR 14025 (ISO 2000b). ISO defines 3 different types of labelling: Type I, Type II and Type III: Type III is also called 'Environmental Product Declaration'.

Type I labels are voluntary schemes. In order to be granted the label, applicants have to fulfill a pre-established set of criteria based on life-cycle considerations for the product group. Compliance with the criteria is controlled by a third party. Type II labels are also called 'environmental self-claims'. These are single-issue labels that a manufacturer can place on his product. There is no third-party verification of the correctness of the claim.

Eco-Purchasing: see Environmentally Preferable Purchasing

EDIP: environmental development of industrial products and processes
EE: see eco-efficiency
EEA: European Environmental Agency

EHS: environment, health, and safety
EM: see Environmental Management.

EMPA: Eidgenössische Materialprüfungs- und Forschungsanstalt (Swiss Federal Laboratories for Materials Testing and Research)

EMAS: see European Eco-Management and Audit Scheme.

EMS: see Environmental Management Systems

ENEA: Ente per le Nuove Tecnologie l'Energia e l'Ambiente (Italian National Agency for New Technologies, Energy and the Environment)

Environment: The ‘surroundings in which an organization operates, including air, water, land, natural resources, flora, fauna, humans, and their interrelation’ (ISO 1996).

Environmental Accounting (EA): Can support national income accounting, financial accounting, or internal business managerial accounting. The prime use is as a managerial accounting tool for internal business decisions. The environmental costs may be private costs (impacts a company's bottom line) as well as societal costs to individuals, society, or environment (USEPA 1995).

Environmental Auditing: Systematic, documented verification process of objectively obtaining and evaluating audit evidence to determine whether specified environmental activities, events, conditions, management systems, or information about these matters conform with audit criteria, and communicating the results of this process to the client (ISO 1996).

Environmentally Conscious Decision Support System (EcoDS): A software-based decision support tool for a cost–risk evaluation of environmentally conscious alternatives. It uses Streamlined Life-Cycle Assessment and Life-Cycle Costing and includes a preliminary screening of the potentially most relevant life-cycle stages and impacts. Three metrics are employed for comparison between alternatives: cost, impact assessment, and a qualitative measure of the potential business opportunity, or risk, for a given stage–impact pair (Hunkeler et al. 1998).

Environmentally Conscious Design and Manufacturing (ECDM): Evolved out of environmental issues in manufacturing. Its goal is to cover design and operation of processes after or concurrent to product design. If carried out concurrently to the design of a product, it is strongly interlinked to Design for Environment.
Environmental Impact Assessment (EIA): The process of identifying and evaluating the consequences of one economic activity on the environment and, when appropriate, mitigating those consequences. EIA is used as an aid to public decision-making on larger projects, such as the construction of a highway, power plant, or industrial production sites (CHAINET 2003).

Environmental Impact: 'Any change to the environment, whether adverse or beneficial, wholly or partially resulting from an organization's activities, products or services' (ISO 1996).

Environmental Indicators (Ecometrics; Eco-Indicators): A number of selected parameters on which periodically measures can be made in order to follow the development of the general environmental state. These can be specific to a given product, industry, or stage (micro-ecometrics); linked to global impacts (macro-ecometrics); or aggregated (Hunkeler 1999). The normalisation of indicators is contentious because the denominator can change the relative ranking between alternatives. Prior to use in Sustainable Development, indicators must be verified via a systematic, product-specific valuation, generally involving life-cycle considerations.

Environmental Management (EM): A management strategy that encompasses '...organizational structure, planning activities, responsibilities, practices, procedures, processes and resources for developing, implementing, achieving, reviewing and maintaining the environmental policy' (ISO 1996).

Environmental Management System (EMS) (ISO 14000 and EMAS): A corporate management system including an environmental policy and goals for the activities of the company. The EMS commits the company to continuous improvements of the environmental performance (ISO 1996). In the case of EMAS, there is an obligation to publish a periodic report on the company's activities, environmental policy, and environmental performance.

Environmental Metrics: see Environmental Indicators.

Environmental Performance Evaluation (EPE): Internal tool that can provide management with reliable, objective, and verifiable information to determine the extent to which the organisation is meeting its environmental objectives. It makes use of Environmental Performance Indicators (EPIs). Some of these EPIs can be used as external Ecometrics/Eco-indicators, if validated.

Environmental Performance Indicator (EPI): see Environmental Performance Evaluation.

Environmental Product Declaration (EPD): Declaration of a product's performance with regard to different environmental parameters (e.g., use of resources, emissions, content of chemical substances) during the product's life cycle, either cradle-to-grave or cradle-to-port (type III labelling).

Environmental Reporting: A means of communication, for example, annually, of the environmental aspects of the activities of an organisation (WICE 1994).

Environmental Risk Assessment (ERA): The procedure in which the risks posed by inherent hazards involved in processes or situations are estimated either quantitatively or qualitatively. Risk assessments are carried out to examine the effects of an agent on humans (health risk assessment) and ecosystems (ERA). ERA is the examination of risks resulting from technology that threaten ecosystems, animals, and people. It includes human health risk assessments, ecological or eco-toxicological risk assessments, and specific industrial applications of risk assessment that examine endpoints in people, biota, or ecosystems (Fairman et al. 1999).

Environmentally Preferable Purchasing (EPP; Eco-Purchasing): Selecting products or services that have a lesser or reduced effect on human health and the environment compared with competing products or services that serve the same purpose (USEPA 1999b).

EPD: see Environmental Product Declaration.

EPE: see Environmental Performance Evaluation.

EPI: see Environmental Performance Evaluation.

EPP: see Environmentally Preferable Purchasing.

ERA: see Environmental Risk Assessment.

EU: European Union

eyroMat: entwicklungsbegleitendes Instrument für umwelt- und recyclingorientierte Materiallösungen (Concurrent Engineering Design Tool for the Selection of Environmentally Sound and Recyclable Materials)

European Eco-Management and Audit Scheme (EMAS): A voluntary programme, which became effective in 1995 and enables organisations
within the EU and the European Economic Area to seek certification for their EMS.

EVA: economic value added

**F**

FMEA: failure-mode-and-effect analysis

Full Cost Accounting: see Total Cost Accounting.


**G**

Green Accounting: An enterprise-based account on the use of resources and energy, of emissions and the production of waste. The green account can be published in the enterprise’s annual report. The green account can either be mandatory or voluntary for the firm.

Green and Sustainable Chemistry: Improvements in the Eco-Efficiency of chemical processes, products, and services to achieve a sustainable, cleaner, and healthier environment and a competitive advantage (Jensen 2001).

Green Design: see Design for Environment

Green Procurement: A concept for reducing the environmental burden by buying products with a reduced Environmental Impact compared to similar products. In order to help public and private procurers, guidelines for green procurements can be developed.

GWP: global warming potential

**I**

IDIS: International Dismantling Information System

IIIEE: International Institute for Industrial Environmental Economics (at Lund University, Sweden)

IMDS: International Material Data System of the Automotive Industry

Industrial Ecology: Multidisciplinary study of industrial systems and economic activities, and their links to fundamental natural systems. It provides the theoretical basis and objective understanding upon which reasoned improvement of current practices can be based (Allenby 1999).

Integrated Pollution Prevention: see Pollution Prevention.

Integrated Product Policy (IPP): ‘An environmental policy toolbox currently being discussed within the EU. Its aim is to green markets through an integrated use of policy tools to green consumption (demand side) and to green Product Development (supply side). As a policy concept, IPP aims to take a life-cycle perspective (‘cradle-to-grave’), include all relevant stakeholder viewpoints and consider (in the case of products) the Product Development process from idea generation to product management and reverse logistics …’ (CfSD 2000).

IPP: see Integrated Product Policy.

ISO: International Organization for Standardization

IT: information technology

IVL: Institutet för Vatten- och Luftvårdsförskning (Swedish Environmental Research Institute)

**L**

LCA: see Life-Cycle Assessment.

LCC: see Life-Cycle Costing.

LCE: see Life-Cycle Engineering.

LCI: Life-Cycle Inventory.

LCIA: see Life-Cycle Impact Assessment.

LCM: see Life-Cycle Management.

LCV: Life-Cycle Value


Life-Cycle Costing (LCC): ‘Life-cycle cost refers to all costs associated with the system as applied to the defined life cycle’ (Blanchard and Fabrycky 1998).

Life-Cycle Engineering (LCE): An engineering concept that takes the complete life cycle of products and processes from research and development, production, and use to end-of-life into account. It is generally associated with technical modifications that prolong, or improve, the life or use phase of a product or its compo-
Glossary of terms and abbreviations

Material Flow: Accounting in physical units (usually in terms of tonnes) comprising the extraction, production, transformation, consumption, recycling, and disposal of materials (e.g., substances, raw materials, base materials, products, manufactures, wastes, and emissions to air, water and soil) (CHAINET 2003).

Persistence: The ability of a molecule to remain in the environment for a prolonged period of time. Persistent pollutants are those that do not decompose quickly in the environment and can accumulate in biological systems over time.

Pollution Prevention (Integrated Pollution Prevention): An essential alternative to end-of-pipe approaches for dealing with environment-
Life-Cycle Management

tal pollution. It was introduced in 1976 by Dr. Joseph Ling of 3M (Shen 1999) and was first implemented in 3M's Pollution Prevention Pays Program (Royston 1979). Pollution prevention is based on technological and management advances that reduce environmental releases and the consumption of resources through integrated approaches. These include modifications in production processes, substitution of materials, recycling activities, etc. (Royston 1979).

POP: see Persistent Organic Pollutant.

Product Development: The 'process of taking a product idea from planning to market launch and review of the product in which business strategies, marketing considerations, research methods and design aspects are used to take a product to a point of practical use. It includes improvements or modifications to existing products or processes' (ISO 2002).

Product Line Analysis (PLA): Prospective planning tool developed in Germany studying Environmental Impacts of a particular service to society. Based on Functional Units. Similar to LCA but includes environmental, economic, and social aspects.

Product-Oriented Environmental Management Systems (POEMS): Environmental management that not only focuses on plants or production sites of a firm but also accounts for the life cycle of the products and intermediates that pass through the company's operations (Brezet and Rocha 2001).

Product System: 'Collection of materially and energetically connected unit processes which performs one or more defined functions' (ISO 1997).

Products: Goods and services, or their utility (WCED 1987). A 'product is the result of a process. ... There are 4 generic product categories, as follows: services (e.g., transport); software (e.g., computer program, dictionary); hardware (e.g., engine mechanical part); processed materials (e.g., lubricant)' (ISO 2000e).

Q

QFD: see Quality Function Deployment.

Quality Function Deployment (QFD): A method for the systematic analysis of 'the voice of the customers', and relationships between these quality requirements and the product structure. In the so-called Quality House, all customer requirements are identified and weighted, and the relationships between these requirements and the technical parameters of the total product are analyzed (Hansen et al. 1995).

R

R&D: research and development

Responsible Care: A program created in 1988 by the Chemical Manufacturers Association (CMA), now called International Council of Chemicals Association (ICCA). It is a program adopted by ICCA's members to foster environmentally responsible management of chemicals. Guiding principles and codes of management practices have been established (Shen 1999).

S

SAM: Sustainable Asset Management

SCM: see Supply-Chain Management

SCMC: Supply Chain Management Center

Screening LCA: 'A procedure that identifies some particular characteristic of key issue associated with an LCA, which will normally be the subject of further, more intensive, study' (Christiansen 1997).

SETAC: Society of Environmental Toxicology and Chemistry

Simplified LCA (Streamlined LCA): An LCA obtained through a procedure that reduces the complexity of an LCA and therefore cost, time, and effort involved in the study. This may involve exclusion of certain life-cycle stages, system inputs or outputs, or impact categories, or may involve the use of generic data modules rather than specific data for the system under study' (Christiansen 1997).

SME: small- and medium-sized enterprise

Streamlined LCA: see Simplified LCA.

Substance Flow Analysis (SFA): A mapping of the total use, recycling, and disposal of a specific substance in a defined region. The mapping reveals which materials the substance is a part of. The mapping quantifies use, recycling, and disposal of the substance for the different purposes. Part of Material Flow Analysis.

Supply-Chain Management (SCM): 'Defined as the fulfilment of customer demands by the management of material and information flows
and co-operation along all stages of the supply chain' (SCMC 2003). SCM focuses on globalisation and information management tools that integrate procurement, operations, and logistics from raw materials acquisition to customer satisfaction.

**Sustainable Development:** Development that 'meets the needs of the present without compromising the ability of future generations to meet their own needs' (WCED 1987). Sustainable development addresses economic, environmental, and social aspects.

**SWATER:** Swiss Water Treatment Association

**SWOT:** strengths–weaknesses–opportunities–threats

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**T**

**TCA:** see Total Cost Accounting

**TMR:** see Total Material Requirement

**Total Cost Accounting** (TCA, syn: Full Cost Accounting): A tool for the prospective evaluation of an investment, with particular attention to its environmental component. It combines environmental accounting with traditional accounting and appears to be particularly useful to describe projects for pollution prevention (OECD 1995).

**Total Material Requirement** (TMR): Indicator expressing the total mass of primary materials extracted from nature to support human activities (EEA 2000).

**Total Quality Environmental Management** (TQEM): Environmental management concept that combines the principles of environmental management and Total Quality Management (TQM).

**Total Quality Management** (TQM): A quality management concept with the purpose of ensuring a comprehensive, customer-oriented quality focus. In addition to a company's structure, the management of the people involved internally are main aspects (Becker 2000).

**TQM:** see Total Quality Management

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**U**

**UN:** United Nations

**UNCED:** United Nations Conference on Environment and Development

**UNEP:** United Nations Environment Programme

**UNFCCC:** United Nations Framework Convention on Climate Change

**UNICEF:** United Nations Children's Fund (formerly United Nations International Children's Emergency Fund)

**USEPA:** U.S. Environmental Protection Agency

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**V**

**VOC:** volatile organic compound

**VTT:** Valtion Teknillinen Tutkimuskeskus (Technical Research Centre of Finland)

**VW:** Volkswagen

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**W**

**WBCSD:** World Business Council for Sustainable Development

**WCED:** World Commission on Environment and Development

**WG:** working group

**WICE:** World Industry Council for the Environment

**WSJE:** Wall Street Journal Europe


relative to the USA. *Environ Qual Manag* Autumn 1996:86.


Rebitzer G. 2002. Integrating life-cycle costing and life-cycle assessment for managing...


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The Society of Environmental Toxicology and Chemistry (SETAC), with offices currently in North America and Europe, is a nonprofit, professional society established to provide a forum for individuals and institutions engaged in the study of environmental problems, management and regulation of natural resources, education, research and development, and manufacturing and distribution.

Specific goals of the society are:

- Promote research, education, and training in the environmental sciences.
- Promote the systematic application of all relevant scientific disciplines to the evaluation of chemical hazards.
- Participate in the scientific interpretation of issues concerned with hazard assessment and risk analysis.
- Support the development of ecologically acceptable practices and principles.
- Provide a forum (meetings and publications) for communication among professionals in government, business, academia, and other segments of society involved in the use, protection, and management of our environment.

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