Guidelines for Life-Cycle Assessment: A "Code of Practice"

EDITION 1

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About this publication

Life-Cycle Assessment is one of the tools used to examine the environmental cradle-to-grave consequences of making and using products or providing services. It is a powerful and complex tool that should be used properly. This publication provides guidelines for carrying out and reporting Life-Cycle Assessment studies in a responsible and consistent manner. It is based on the considered opinion of 50 experts from 13 countries who pooled their knowledge and experience in a 4-day workshop.

In some countries or professions, the words "Code of Practice" imply a formal obligation. SETAC is a professional society established to promote the use of a multi-disciplinary approach to solving problems of the impact of chemicals and technology on the environment. It has no regulatory powers, nor does it have the authority of a standards organization. Hence, the quotation marks around the words "Code of Practice" in the title of this publication. SETAC's authority and the quality of its work depend on the expertise of its members. We hope this publication will be recognised as authoritative on that basis, and that it will serve to enhance the use of Life-Cycle Assessment as a tool for environmental management.

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Preface

In response to an increasing need for guidance in Life-Cycle Assessment (LCA), particularly in Europe where LCA is currently used more than elsewhere, the European and North American organizations of the Society of Environmental Toxicology and Chemistry (SETAC) planned and conducted the LCA "Code of Practice" Workshop in Sesimbra, Portugal. It was the second cooperative effort of the two SETAC LCA Advisory groups and the fifth technical workshop on LCA sponsored by SETAC.

This document will be useful to a wide array of people -- public policy-makers, industry managers, private and public-domain planners, educators, and others. As is stated elsewhere, this document is not intended to be a standard nor to mandate certain practices or procedures. It is intended as guidance. Users should recognize that LCA is a rapidly evolving "discipline," and the information contained herein -- the best available in 1993 -- is likely to be updated in 1994 and beyond.

Contributions by the organizations listed in Appendix 4 are greatly appreciated, as is the hard work of Claudine Ruttens and Linda Longsworth in planning the workshop and on-site support, and that of Mirjam van Poelje in preparing the camera-ready copy. The Editors thank Richard Denison, Environmental Defense Fund, who helped plan the workshop and edit this document.

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August 1993
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INTRODUCTION

The heightened awareness and concern over the environmental impacts associated with the provision of goods and services to society has renewed the interest in the development and application of methods to better comprehend and reduce the negative consequences of human activities on the environment. In recent years, the idea that methods and techniques must encourage a comprehensive evaluation of all "upstream" and "downstream" effects of the activity or product under examination has gained acceptance. The life-cycle concept, also called "cradle-to-grave", has influenced and shaped many approaches and techniques to calculate, assess, and improve the environmental performance of products and production systems.

One of the most recognized and internationally accepted methods for examining environmental performance is Life-Cycle Assessment (LCA). Work to develop broad consensus on the conduct of LCA was initiated in 1990 by the Society of Environmental Toxicology and Chemistry (SETAC). A series of workshops convening representatives of the international LCA community has produced documents reflecting consensus and current thinking on the practice of LCA (Table 1). Developing international consensus on harmonized methods has been a goal of the SETAC LCA effort from the outset.
LCA is an emerging tool with significant potential for appropriate use (as well as misuse), and it is important that global development and application be done consistently. Because of widespread interest in the application of this method and the desire to promote the conduct of scientifically sound LCAs and the proper use of their results, SETAC sponsored the development and publication of these guidelines for the practice of Life-Cycle Assessments. This 'Code of Practice' is not a standard for conducting LCA; this first edition of the document seeks to provide guidance on process and methodological aspects of conducting LCAs reflecting the current situation to emphasize that:

(1) LCA is a complex, multi-dimensional tool;

(2) The LCA methodology has yet to be described in full. (Of the three LCA components, only the Life-Cycle Inventory Analysis has been well documented. The Life-Cycle Impact Assessment methodology remains in development, and the Improvement Analysis has yet to be described conceptually);

(3) The state-of-the art in 1993 is Life-Cycle Inventory (LCI) and improvement of environmental performance based on LCI information; and

(4) New issues arise as practitioners continue to gain knowledge and experience on the application of LCA.
This document defines the LCA method and discusses its various possible applications. A description of the overall technical framework is provided and a discussion of key methodological aspects is included within the initial section of the technical framework. The document also provides guidance on the presentation and communication of findings according to various applications of LCAs. This is followed by a discussion on validation of the study results, including a framework and requirements for peer review and conflict resolution.

Key subjects which have yet to be debated or which require further research, a section on terminology, and a list of useful reference documents conclude the document.

This document is not a detailed methodological reference. Rather, it lays out general principles and a framework for the conduct, review, presentation, and use of LCA findings. As such, it is intended as guidance for all individuals who commission, carry-out, review, or use the results of a LCA, and should be used to enhance the quality transparency, and credibility of such studies. As knowledge of and consensus on the practice of LCAs evolve, this document is likely to be amended or others added to reflect new scientific thinking and practical experience on the subject.
WHAT IS LIFE-CYCLE ASSESSMENT?

Life-Cycle Assessment is a process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment; to assess the impact of those energy and material uses and releases to the environment; and to identify and evaluate opportunities to affect environmental improvements. The assessment includes the entire life-cycle of the product, process, or activity, encompassing extracting and processing raw materials; manufacturing; transportation and distribution; use, re-use, maintenance; recycling, and final disposal (SETAC 1991).

Life-Cycle Assessment (LCA) addresses environmental impacts of the system under study in the areas of ecological health human health and resource depletion. It does not address economic considerations or social effects. Additionally, like all other scientific models, LCA is a simplification of the physical system and cannot claim to provide an absolute and complete representation of every environmental interaction.

The prime objectives of carrying out a LCA are:

(1) to provide as complete a picture as possible of the interactions of an activity with the environment;
(2) to contribute to the understanding of the overall and interdependent nature of the environmental consequences of human activities; and

(3) to provide decision-makers with information which defines the environmental effects of these activities and identifies opportunities for environmental improvements.

Additionally, the systematic procedures for LCA facilitate constructive dialogue among different sectors in society concerned with environmental quality. The concept of LCA is also an important influence on a range of techniques and thought processes that guide decision-making and the selection of options for design and improvement.

The LCA methodological framework recommended by SETAC (1991, 1992, and 1993) comprises goal definition and scoping, inventory analysis, impact assessment and improvement assessment. In the Life-Cycle Inventory (LCI), data on inputs and outputs system being studied are compiled and presented. This part of LCA methodology is well developed. Much useful information is provided by the results of the LCI and most studies conducted to date go no further. However, the quality of data used in LCIs is an important concern due to the wide variety of sources and broad scope of the studies. For this reason, SETAC sponsored a workshop on LCA data quality which resulted in an agreement that data quality assessment should be an integral part of any life-cycle study. As only one component of the broader methodology, Life-Cycle Inventories alone cannot be described as LCAs.

In its complete application, LCA considers the environmental impacts along a product's life from raw materials acquisition to production, use, and disposal. Impacts to consider include resource depletion, human health, and ecological health. Work has not been completed and agreements have not been recorded on a methodology for impact assessment, in which the results of the inventory are transposed into measures of environmental impacts.
Although improvement assessments based on LCI information are being conducted, formal systematic procedures for improvement assessment are not yet established. Table 2 summarizes the state of development of the LCA methodology at the present time. The methodological framework for LCA is explained in detail in Chapter 3, and needs for further research are discussed in Chapter 8.

Table 2. The state of development of LCA methodology

<table>
<thead>
<tr>
<th>LCA Components or Phases</th>
<th>State-of-the-Art of Written Documents</th>
</tr>
</thead>
<tbody>
<tr>
<td>Goal Definition and Scoping</td>
<td>Defined.</td>
</tr>
<tr>
<td>Inventory Analysis</td>
<td>Defined and understood; needs some further work.</td>
</tr>
<tr>
<td>Impact Assessment:</td>
<td>Defined; needs further work.</td>
</tr>
<tr>
<td>- Classification</td>
<td>Conceptually defined and partly developed.</td>
</tr>
<tr>
<td>- Characterization</td>
<td>Conceptually defined; different methods and approaches currently being used.</td>
</tr>
<tr>
<td>- Valuation</td>
<td>Not yet documented.</td>
</tr>
<tr>
<td>Improvement Assessment</td>
<td></td>
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</tbody>
</table>
A study described as life-cycle assessment should cover the entire life-cycle as described above. The methodology is often applied in studies of a more restricted nature, for example, to study one particular environmental parameter such as energy throughout the whole life-cycle or, alternatively, to examine the environmental impacts arising from only selected stages of the life-cycle. It should be emphasized that, while much useful information can be obtained from such studies, they cannot, by definition, be described as LCAs or LCIs, if they are so restricted in scope.

LCA is only one of several techniques for environmental management. It complements other techniques such as environmental impact assessment, hazard identification, risk assessment, technology assessment, waste audits and waste minimization assessment of processes, design for the environment, product stewardship, and management systems standards. All such techniques and management tools should be used only where appropriate.
3.1 General Considerations

It is not possible to define rigid methodological rules for all aspects of LCA because the technique is still in development. Moreover, no system of industrial activity can be studied feasibly without introducing simplifications to keep the analysis to manageable proportions. The appropriate ways of making such simplifications or, conversely, the appropriate level of detail to be achieved, will be heavily dependent on the purposes of each individual study. Assessments of the relative importance of environmental impacts inevitably involve value judgements which, by their nature, cannot be expressed in universally acceptable rules or criteria.

The purpose of this technical framework chapter is to encourage as consistent an approach for carrying out LCAs as possible, given the uncertainties mentioned above, and to recommend practices which should ensure that LCAs are carried out and reported in a transparent manner (i.e., clear to the reader, explaining what was done and how) that enables a reviewer to verify the results and gain a good understanding of the applicability, validity, and limitations of the study.
3.2 Overall Structure

LCAs are composed of several interrelated components: goal definition and scoping, inventory analysis, impact assessment, and improvement assessment. Figure 1 shows the inter-relationship of these components in carrying out an LCA. The meaning and uses of these terms, and others in the context of the recommended framework, are explained in the following paragraphs.

For over 20 years, life-cycle related studies have focused on the quantification of energy and materials used and wastes released into the environment along the entire life-cycle of a product, package, material, process, or activity. For this reason, the life-cycle inventory methodology is better understood and practices are well developed. The incorporation of the impact assessment, improvement assessment, and goal definition and scoping into the technical framework for life-cycle assessment has taken place in recent years.

The goal definition and scoping component is an integral part of the technical framework. Steps are required at an early stage in the study by those conducting or commissioning the study to gain a clear understanding of the purpose, to specify the system(s) to be studied, and to determine the relevant requirements for peer review and communication of results. The purpose, scope, and intended application influence the direction and depth of the study, as well as requirements for reporting and peer review.

The impact assessment component was added to the technical framework (Figure 1) because it is important to place the inventory input and output data and information into perspective. Without an assessment of the impacts of environmental releases and consumption
of resources, it is difficult to understand the environmental relevance of the system's inputs and outputs or the benefits from achieving improvements in the system. However, this component is currently still in the developmental stage.

Figure 1. Technical Framework for Life-Cycle Assessment (Modified from SETAC 1991, 1992, and 1993)

Similarly, the improvement assessment was incorporated into the technical framework for three main reasons:

(1) to place emphasis on using LCA to reduce the environmental impacts associated with the system under study;

(2) to ensure that the goal of an LCA was not to use LCA solely to justify the status-quo; and
(3) to recognize that all systems have some level of environmental impacts, which possibly can be reduced.

Although each component serves an important function in providing information to achieve these objectives, it is important to realize that it may not be necessary to complete both the inventory and impact assessment components before opportunities for environmental improvement can be identified. For example, the inventory analysis alone may be used to identify opportunities for reducing energy and material use and environmental releases.

3.3 Goal Definition and Scoping

The first component of an LCA is the Goal Definition and Scoping. This component consists of defining the study purpose and its scope, establishing the functional unit, and establishing a procedure for quality assurance of the study. The data and information required to support inventory, impact assessment, and/or improvement assessment should be identified during Goal Definition and Scoping. For example, if an impact assessment is to be performed, then the impact categories to be assessed should be identified at this stage, and data collection should be compatible with the scope of the impact assessment. Additional information on issues associated with Goal Definition and Scoping are presented and discussed in Section 3.4.

3.3.1 Purpose

At the start of an LCA, it is important to clearly define the study purpose. The study purpose should include a clear and unambiguous statement of the reason for carrying out the LCA, and the intended use of the results. The purpose should be specified in terms of what decision is to be based on the findings, and what information is required, at what level of detail, and for what purpose. A key consideration is whether the results of LCA will be used for
applications internal to a company to improve the environmental performance of the system, or whether the results will be used externally, for example, to influence public policy.

3.3.2 Scope

The scope of a study defines the system, boundaries, data requirements, assumptions, and limitations. The scope should be defined in sufficient detail to ensure that the breadth and depth of analysis are compatible with and sufficient to address the stated purpose. All boundaries, methodology, data categories, and assumptions should be clearly stated, comprehensible, and visible. These include geographic extent (local, national, regional, continental, or global), and time (product life, time horizon of processes, and impacts).

It is also important to consider and include an estimate of the variability associated with the data, in addition to the average value. In some studies, product and/or facility-specific data are necessary, while in other studies average data are appropriate or acceptable.

Further modifications of the study scope may be required after the first evaluation of the different components during which key issues (e.g., most important processes, most relevant types of impacts, and most feasible options for improvement) are identified. Additionally, it is important to realize that throughout an LCA there may be refinements to the scope because of additional information encountered.

3.3.3 Functional Unit

One of the most important elements in a life-cycle study is a clear statement of the specification of the system's function and, derived from that, the functional unit for the study. This is a key step for avoiding ambiguity in the statement of purpose and for clarifying the basis for the scope. The functional unit is the measure of performance which the system delivers. This has to be clearly defined, measurable,
and relevant to input and output data. Examples of functional units are "unit surface area covered by paint for a defined period of time," "the packaging used to deliver a given volume of beverage," or "the amount of detergents necessary for a standard household wash." In comparative studies, it is essential that the systems are compared on the basis of equivalent function.

### 3.3.4 Data-Quality Assessment

Data quality in LCA is defined as the degree of confidence in individual input and output data, in the data set as a whole, and ultimately in decisions based upon using the data. Data-quality assessment (as described in Chapter 4) is an integral part of LCAs. As discussed in Chapter 7, peer review also plays an important role in assessing the quality of a LCA study. Specific data-quality goals should be clearly established during this Goal Definition and Scoping stage.

### 3.4 Inventory Analysis

The principles of Life-Cycle Inventory (LCI) analysis described below apply to any activities that involve the direct or indirect use of energy or materials. Although most of the methodological aspects of LCI, use industrial production operations (which have been the main subject of studies in this area), the principles described apply to any physical system of activities.

#### 3.4.1 Defining Systems and System Boundaries

Any product or service needs to be represented as a system in the inventory analysis methodology. A system is defined as a collection of materially and energetically connected operations (e.g., manufacturing process, transport process, or fuel extraction process)
which performs some defined function. The system is separated from its surroundings by a system boundary. The whole region outside the boundary is known as the system environment.

Any system can be represented, as shown in Figure 2, where the collection of operations is enclosed within the box. The outline of the box denotes the system boundary and separates the system from its surroundings -- the system environment. The system environment is the source of all inputs to the system and the sink for all outputs from the system. The inventory analysis is a quantitative description of all flows of materials and energy across the system boundary either into or out of the system itself.

![Figure 2. Schematic Representation of a Simple System (SETAC 1991)](image)

The system should be defined, not only in terms of its function, but also in relation to other pertinent factors such as sources of inputs, any specific aspects of the internal processing route, geographical considerations, and time-frames. Sources of data for inventory calculation must be consistent with these factors. (Many of the apparent discrepancies between LCA studies reported in the literature arise because systems are not properly specified on a comparable basis or because different systems are being compared.)

In order to compile the inputs to and outputs from a system, the system must be broken down into a series of inter-linked operations or sub-systems, each of which will be taking, as input, the output from an "upstream" operation and processing it into an output which is then the
input for the next operation "downstream." The degree of sub-division of the total system into individual operations is frequently determined by the availability of data and the requirements set forth in the goal and scope of the study.

It is important to identify key ancillary input data for the system under study. Decision rules as highlighted by SETAC (1991) should be clear and stated in the LCA report. Inputs to ancillary data selected should be traced back to the extraction of raw materials from the earth, and outputs from all of the subsystems should be followed to the release into the environment (e.g., a landfill or incinerator should be included in the system). All transport operations should be included within the system.

3.4.2 Process Flow-Charts

The best way to represent the components of a system is to develop a flow-chart showing how the subsystems are interlinked. Some care is needed in the construction of the flow-charts. Figure 3, for example, shows a simple linear sequence of operations that might be used to represent a subsystem employed to produce and deliver electricity. While indicating the general form of the system, it is an oversimplification of reality.

![Electricity Production Flow-Chart](image)

**Figure 3.** Electricity Production from Coal Represented as a Simple Linear Sequence

Figure 4 is closer to actual practice and illustrates how a simple linear system should be replaced by a more complex network of flows. Figure 4 is still a simplification but it demonstrates the essential point that all human activities are fully interdependent and any change in one will
necessarily affect the others, to some degree. Such interdependence for energies and other parameters can be handled by iterative calculations to a pre-determined level of precision.

Figure 4. Electricity Production Represented as a Simple Network

The flow-chart representative of most industrial system consists of three main groups of operations: the main production sequence, the production of ancillary materials, and the fuel production industries. The main production sequence is usually the easiest to identify. For example, for a system that is defined as the use of polyethylene bottles to package milk, the main operations that would need to be included in the main production sequence are shown in Figure 5. For simplicity, some of the transportation operations that are needed within production sequences are not shown. This does not mean that such operations can be ignored; the inputs to and outputs from transportation operations are important.
Figure 5. Main Sequence of Operations in the Production and use of a Polyethylene Bottle

The identification of the ancillary materials such as pallets, labels, bags, glues, etc. is usually collected along with the data for the unit operations in the main production sequence. In a complete LCI, the production sequence for each of these ancillary materials should also be traced back to the extraction of raw materials from the earth, in the same way as for the bottle system shown in Figure 5. Thus, the analysis of even simple systems frequently demands data from a wide variety of different industries, some of which are remote from the main production sequence.

3.4.3 Data

Data Collection

Once a system has been subdivided into its component subsystems, the data are gathered. Detailed data, in the form of inputs (materials and energy) and outputs (products and releases to the air, water, and land),
are required. When available, these data should be obtained (depending upon the study purpose) from companies operating the specific processes.

Where specific process data are not available, other sources must be identified. Potential sources are:

- process designers;
- engineering calculations based on process chemistry and technology;
- estimations from similar operations;
- published sources and commercially available databases; and
- market-place patterns of usage of products.

Data for the performance of each subsystem should normally be based on a statistically relevant period that is long enough to smooth out any atypical behavior such as machine breakdowns or process upsets. One year is a common timeframe.

The basis of all data, their source and geographic and temporal relevance, should be well documented. Averaging and weighting techniques should be reported when multiple data sources are selected. Quality of the data should be consistent with the purpose and scope of the LCI.

Data are presented in a standardized format, e.g., by normalizing, with respect to a given unit of output for each subsystem unit operation. Each subsystem should be mass-and energy-balanced.

**Calculation Procedures**

The calculation of the inventory of the overall system is a two-stage process. First, the output from the operation corresponding to the functional unit is set to unity and the materials inputs for all of the subsystem operations are used to calculate the mass balance linking all of the subsystem operations in the extended system from the point of
extraction of raw materials from the earth to waste management operations. When this total mass-balance has been completed, it will quantify the outputs from each of the unit operations (subsystems). Second, the contributions from each subsystem to the overall system are then calculated by multiplying all of the normalized data by the mass output. A description of the overall system is the sum of the contributions from each of the subsystems.

Inventory Tables

In reporting LCI data, it is important not to lose information because of the way data are presented. Essentially, this means that the level of detail (in terms of inputs and outputs) that has been used throughout the collection of data is maintained in reporting.

For the most important subprocesses, the data should, to the extent possible, be presented as an average (or other measure of central tendency) and range (low and high value) or some measure of the variability around the average.

Data Variability, Uncertainties, and Sensitivity Analysis

All LCIs have data variability, data uncertainties, and data gaps. These issues should be discussed in the context of the goals of the study. Sensitivity analysis should be carried out to test the effects on the results and possible limitations on the conclusions. In some cases, this may lead to a decision to collect more data. The extent of variability and uncertainty, along with specific data gaps, should be reported in the study.

Deliberate Omissions

Exclusion of minor subsystems from the LCI is necessary to keep pre-calculation to manageable proportions. This is usually the case for
capital equipment, minor components of products, or minor ancillary materials. Such exclusion should be logical, consistent with the goal and scope of the study, explained fully, and justified.

3.4.4 Allocation Procedures

In many subsystems, more than one useful output or product is produced. The treatment of pollutants from several subsystems may take place in a single-unit operation. A system may have an open-loop recycling element. Consequently, it is necessary to have a consistent way to identify those inputs and outputs attributed to the product system that are the subject of the study. For example, the actual releases to the air, water, and land are allocated to the product of interest, in many instances on a mass basis, or other physical criteria. Where physical characteristic allocation methods may not apply, other methods (e.g., theoretical thermodynamics, economics, etc.) are being used.

Coproducts

Unit processes within the system being studied may yield two or more saleable products, only one of which is used for further processing within the system. For example, if chlorine is an input to an operation in the system, the upstream chlorine manufacturing operation will also produce an equivalent amount of caustic soda. If the other product(s) leaves the system for beneficial use in other systems (i.e. not treated as a "waste" released to the environment from the system under study), allowance must be made for their share of all the upstream inputs and outputs to and from the system. This is the problem of co-product allocation.

The objective of co-product allocation is to use an allocation parameter that reflects, as realistically as possible, the physical behavior of the system itself. The most common practice is to allocate on the basis of mass. Although the precise method of allocation may vary from one system to another, the choice of allocation basis should be related
directly to the chemistry and physics of the process. For example, when limestone rock is subjected to milling, there are two products, granulated limestone and limestone powder. Inputs to the mill and outputs can be allocated between the two products on the basis of their relative mass.

**Waste treatment processes**

In many cases where multiple products are produced in the same subsystem or plant, the air emission controls, wastewater treatment, and solid wastes may be treated in common facilities. Thus, an allocation is necessary that separates the combined waste streams back to the output products of interest in the LCI. This allocation follows in the same manner as the actual releases to the air, water, and land are allocated to the product of interest, generally on a mass basis, or other physical criteria. Thus, the emissions associated with a waste treatment process are allocated so that the product under study carries only its own share of burdens to the environment.

**Recycling**

Any recycling option is simply another set of subsystems within the main system. Closed-loop recycling returns material to the original process. Open-loop recycling refers to a product or component going from one system to another for use as a raw material in producing a different product, e.g., a PET bottle used to produce carpet fibers. In this case, the two systems that are performing different functions are linked together because they share some common inputs and outputs.

The proper method to analyze these linked systems (particularly when a few systems are involved) is to study the inputs and outputs from the total linked system. However, in the case when complex linked systems are involved (e.g., oil refining where 20 products may be processed), this may not be practical. To study one of the systems in isolation, arbitrary allocation decisions have to be made.
The appropriate allocation method will depend on the scope and purpose of the study. However, it is important to:

(1) use a logical allocation approach, consistent with the study goal; and

(2) explicitly explain the approach used in the final report.

3.4.5 Treatment of Energy

For the purpose of inventory calculation, operations involved in generating (and converting) the energy are part of the system and contribute to the inventory as does any other subsystem. The sources should be noted and energy should be reported in energy units (e.g., MJ), but the associated raw material consumption also may be accounted for in mass units.

The materials inputs to any processing operation are frequently referred to as feedstocks. It is important, however, to distinguish between inorganic and organic feedstocks. Inorganic or mineral feedstocks are relatively easy to account for because, during processing, their mass carries through into either the final product or the waste output. It is therefore a relatively simple matter to carry out a mass balance to ensure that none of the materials have been "lost" during processing.

Accounting for organic feedstocks is more complex. Organic materials can be used either as a material input or as a fuel input. When used as a fuel, the material is burned to produce usable energy with the evolution of gaseous emissions, irrecoverably dissipating the available energy. In the case of fossil fuels such as oil and natural gas, this represents a depletion of the available resources. In contrast, when organics are used as materials, the energy associated with much of this input may remain incorporated in the product. The energy content of this material is still available for recovery by burning when the product has fulfilled its primary function.
In describing the resource requirements of any product, it is important that feedstock energy is included, especially if the feedstock is a commodity used as a source of fuel. If the product is eventually burned, then usually a significant proportion of the feedstock energy will be recoverable and will also result in air, water, and solid-waste releases. The fact that the material is often not usefully burned at the end of its life represents a loss of the resources available. Therefore, in the inventory, the resource requirement of a product, including the feedstock energy (which could be recovered eventually), should be included.

Feedstock energy is calculated as the gross calorific value (high heat) of the energy resources removed from the earth’s energy reserves. For fuels, the gross or high-heat value represents the maximum energy that can be derived from a fuel and is therefore a measure of the total energy that is extracted from the earth. Feedstock energy should not be interpreted as the calorific value of the output from a system; rather, it is the calorific value of the inputs. During the life-cycle of the materials, a part of the feedstock energy may be irrecoverably lost during several process operations.

3.5 Impact Assessment

Impact Assessment in LCA is a technical, quantitative, and/or qualitative process to characterize and assess the effects of the environmental burdens identified in the Inventory component. Impact Assessment is presently under development and has, as yet, no commonly agreed-to methodologies. In this section, a structure and recommended terminology for Impact Assessment are presented, and some key issues are discussed.

The Impact Assessment component consists of the following three steps: classification, characterization, and valuation. A conceptual framework, methodologies, and approaches to Impact Assessment are presented by SETAC (1992 and 1993).
3.5.1 Classification

Classification is the step in which the data from the inventory analysis (often referred to as the inventory table) are grouped together into a number of impact categories. This grouping is done in such a way that one entry from the inventory table may well be included in more than one category (e.g., NOx having both an acidifying and an eutrophicating effect).

In the classification step, impacts are to be included in the general protection areas of resource depletion, human health, and ecological health. In defining the specific impact categories, the focus should be on the environmental processes involved, because this will enable one to base the impact assessment as much as possible on scientific knowledge about these processes.

Results of classification may be presented in a matrix (Table 3) which illustrates the relationship of specific impact categories (example only) to the general areas for protection. The relationship between a specific impact category and the various areas of protection is illustrated. Additionally, for a specific impact category, both direct and indirect effects may occur.
Table 3. Relationship Between General Areas for Protection and Specific Impact Categories.

<table>
<thead>
<tr>
<th>Specific Impact Categories (Examples)</th>
<th>General Areas for Protection</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Resources</td>
</tr>
<tr>
<td>Ecol. health</td>
<td></td>
</tr>
<tr>
<td>Resource depletion</td>
<td></td>
</tr>
<tr>
<td>• Depletion of abiotic resources</td>
<td>+</td>
</tr>
<tr>
<td>• Depletion of biotic resources</td>
<td>+</td>
</tr>
<tr>
<td>Pollution</td>
<td></td>
</tr>
<tr>
<td>• Global warming</td>
<td>( + )</td>
</tr>
<tr>
<td>• Ozone depletion</td>
<td>( + )</td>
</tr>
<tr>
<td>• Human toxicity</td>
<td>+</td>
</tr>
<tr>
<td>• Ecotoxicity</td>
<td>( + )</td>
</tr>
<tr>
<td>• Photochemical oxidant formation</td>
<td>+</td>
</tr>
<tr>
<td>• Acidification</td>
<td>( + )</td>
</tr>
<tr>
<td>• Eutrophication</td>
<td>+</td>
</tr>
<tr>
<td>Degradation of ecosystems and landscape</td>
<td></td>
</tr>
<tr>
<td>• Land use</td>
<td>+</td>
</tr>
</tbody>
</table>

+ A direct potential impact.
( + ) An indirect potential impact.

The matrix is based on the results of the Leiden, Netherlands, workshop (SETAC 1992) and the Sandestin, Florida, workshop (SETAC 1993). The impacts on this list range from global to local. The above list is not definitive and the methodological problems needed to deal with the different types of impacts in a proper way are by no means resolved. Other impacts may be taken into account which are of special relevance for the system being studied.

3.5.2 Characterization

Characterization is the step in which analysis/quantification, and where possible, aggregation of the impacts within the given impact categories takes place. This step should be based on scientific knowledge about environmental processes.
There are various approaches to characterization. One method is to relate the data from the inventory table in a generic way to, for instance, No-Observable-Effect Concentrations (NOECs) or to environmental standards. On the other hand, there are approaches which attempt to model (in a generic fashion) both exposure and effects and apply these models in a site-specific way. Presently, much attention is given to the development and use of equivalency factors for the different impact categories, such as the Global Warming Potential (GWP) and the Ozone Depletion Potential (ODP). No direct measure of effects takes place in these approaches.

A further development of the characterization step is to normalize the aggregated data per impact category in relation to the actual magnitude of the impacts within this category in some given area. The reason for doing this is to increase the comparability of the data from the different impact categories and thus provide a basis for the next step, the valuation.

The outcome of the characterization step may be referred to as the impact profile, consisting of a number of impact measures or descriptions. Often other types of impact information, which can not be quantified, may be needed. Whatever approach is used for this part of LCA, it is essential that the basis for any conclusions drawn from Impact Assessment is fully explained in the study report.

3.5.3 Valuation

Valuation is the step in which the contributions from the different specific impact categories are weighted so that they can be compared among themselves. The aim of this step is to arrive at a further interpretation and aggregation of the data of the impact assessment. If, for instance, two or more alternative systems are compared, and if one aims at an unambiguous outcome, the different impacts will, in general, have to be valued in some fashion. One cannot tell which system has the least adverse environmental impact if one system makes a lesser contribution to global warming, while the other poses less risk to
human health from toxic emissions (either in the work place or outside the plant), unless the relative importance of the impact categories can be assessed.

The importance of the impact categories in relation to each other is a value-bound procedure based on an assessment of the relative environmental harm. This assessment will therefore reflect social values and preferences.

A variety of tools, often referred to as decision theory techniques, have the potential to make the valuation a more rational and explicit process. These techniques utilize both expert judgement and input from interested and/or affected parties. A distinction can be made between quantitative and qualitative procedures. In a quantitative procedure (e.g., multicriteria analysis), explicit factors may be used to aggregate the impacts. In a qualitative procedure, the factors remain implicit; the arguments leading to a decision on environmental preference should then be stated.

Although it is recognized that not all applications of LCA would require the use of decision-theory techniques, the tools appear to hold promise for application in this field. Further research is needed.

### 3.6 Improvement Assessment

Improvement assessment is the component of an LCA in which options for reducing the environmental impacts or burdens of the system(s) under the study are identified and evaluated. Improvement assessment has not yet undergone the consensus examination of the methodology, as has the inventory analysis and to some degree the impact assessment component. However, improvement assessments based upon life-cycle studies are already being conducted.

Improvement assessment deals with the identification, evaluation, and selection of options for environmental improvements in products or processes. The inventory analysis may be used to reveal aspects which
can be improved. Both improved efficiency inputs and outputs (such as smaller electricity demand or greater production yield) and environmental outputs (such as less resource use and fewer emissions) can offer opportunities with respect to environmental improvement per functional unit.

The actual technical redesign of a product or process is not a part of LCA -- it is one of the applications. The results of all stages of the LCA provide the process/product designer with information on the environmental impacts of the system and will often point the user to those parts of the operations where there is the most apparent opportunity for improvements in environmental performance.

3.7 Analyses and Interpretation of Results

The commissioner or user of an LCA expects an analysis and interpretation of results and recommendations for improvement. Data alone are not sufficient; the report should explain the findings in terms appropriate to the goal of the study.

An LCA only provides data about the environmental releases, burdens, or impacts of the system under study. For decision-making, information is also required about other aspects, such as information on economy (e.g., cost, market size), product behavior (e.g., performance, storage), and public opinion (e.g., campaigns, press publications).

The results of an LCA should not be used in support of decisions for change without an appreciation of the reliability and validity of the information. This requires the performance of a quantitative sensitivity analysis to:

- assess the effect of key assumptions on the final results;
- check data whose quality is suspect or unknown;
- show if study results are highly dependent on particular sets of input data; and
• evaluate life-cycle effects of changes being considered.

Conclusions should be made only on study results with consideration of the data variability, and resulting variability of the findings. Work is still needed to develop such a statistically based judgement process.
Assessing and reporting data quality in LCAs is essential if results are to be properly interpreted and communicated. To date, the definition of how such considerations should be incorporated into the conduct of LCAs is at an early stage (SETAC, in press). Specific quality assurance procedures have not been developed, particularly for activities beyond evaluation of the quality of input data.

Although there is not now a consensus on the details of conducting LCA data quality assessments, some considerations can be pointed out based on current use by practitioners. The accuracy of the results of LCAs can only be as good as the accuracy of the input data. Indicators of data quality include quantitative attributes, such as precision, and qualitative attributes, such as completeness. The selection and application of data quality indicators for specific data should be made by the practitioner, based on the nature of the data and on the uses to which they will be put. The application of data quality indicators may be sequential. For example, it is important to have some understanding of how complete a data set is and then establishing the variability within that data set.
4.1 Primary Data Quality

For primary data (i.e., information directly obtained from individual companies), several factors should be taken into account. Assuming that the LCA is attempting to characterize an industry-average practice rather than a manufacturer-specific practice, the data set should be representative of the population.

Primary data will rarely be obtainable from every possible facility or source; thus the data will represent a sample from the population. Generally this sample will not be random, but will either be a set of sources believed by the practitioner to be representative of the population or will be self-selected. Self-selected samples tend to be sources that choose to participate in a survey and may not be "average" in operational characteristics. In either case, the practitioner should strive to understand and report the potential bias present in the sample, independent of the variability in the actual data. Even within a nominally similar grouping of plants producing the same output product, data can vary due to systematic differences in technology, maintenance procedures, location, and random statistical variation. Some of these characteristics may be difficult to determine in any practical sense. The sample sizes typical of LCA data sets are often too small to be amenable to standard statistical treatments based on assumed data distributions.

Second, within the data supplied by industry or other organizations, there are factors that affect the quality of the data. Four main areas are of concern: operational complexity, accuracy of records, format of records, and the sharing of common facilities (Boustead, 1992). Few operations in industry or in product sales and distribution occur in isolation. Because it is usually necessary to rely on the plant operators to provide the information, errors can arise in how the various interrelated operations were monitored and assigned to the activity of interest. All practitioners should carefully examine the data from several similar plants to identify possible discrepancies.
Even when the inclusion of specific operations is complete and accurate as defined by the practitioner and the plant operator, there are potential random and systematic errors in the measurements or estimates. Factors such as weighing errors, materials in transit, stock changes, etc. can affect how well the data represent the operations over the specified time-averaging period. Estimates of accuracy for this type of data will vary from one source to another, but typically they are in the range of 5 to 25 percent (Boustead, 1992; Fecker, 1992).

Though often difficult to assess for some data sets, the data quality characterization of the original input data is quite important if the final results are to have meaning. The data used in LCAs are typically collected for another purpose and transformed to produce the output mass loadings necessary for the LCA. Depending on the original intended use, the practitioner will need to ensure minimal quality degradation during the conversion into useful LCA units.

Finally, input from common supply sources (e.g., steam plants) and output services (e.g., wastewater treatment) must be allocated among the operations. Although the overall supply or aggregated input may be monitored with reasonable accuracy, data quality may be affected in the allocation of these values to the product or process of interest. Sometimes the allocation process may be largely subjective.

4.2 Secondary Data Quality

Secondary data are those obtained from published sources in the form of data bases, industry or government publications, journals, or books. As a practical matter, secondary data are affected by all of the issues raised above, as well as data quality issues associated with the averaging and homogenization of data from different sources. Data obtained from data bases sometimes contain information on the original source and its quality characteristics, but this is unusual. In most cases, practitioners will have to infer the quality of the data from their
knowledge and the context in which the data are presented. Cross-checking data from several different sources can be beneficial in identifying quality characteristics.

Some secondary data must come from "educated guesses." Information on use-equivalence and the number of cycles that a reusable item makes, for example, can be subject to considerable uncertainty. Most of the time, there will have been no scientific surveys upon which to base a single value and so the judgmental uncertainty in the estimate should be reflected in alternative computations spanning the likely range of estimated values. Use of secondary data should be reported.

4.3 Overall Study Quality

There is considerable value and interest in producing quantitative estimates of quality (e.g., the overall results in an LCA specifying the accuracy of the total energy requirement of the system under study). However, there is at present no accepted methodology for computing such estimates because of the nature of the information and the associated error types in LCAs. Nevertheless, systematic application of data quality assessment principles to the lower tiers of information in a study will maximize the overall study quality. Careful use of the peer review process can also contribute to the overall study quality.
LCA APPLICATIONS AND LIMITATIONS

Whether practitioners choose to conduct rigorous LCAs or to apply the life-cycle concept through other methodologies, careful consideration must be given in all cases to using study information and findings for suitable purposes. This chapter outlines some of the more important areas for consideration by sponsors of studies, practitioners, and users. When combined with guidance given in Chapter 6 on Presentation and Communication, and in Chapter 7 on Peer Review, these considerations form the basis to provide consistent guidance in most LCA applications.

5.1 Intended Use of Life-Cycle Assessments

LCAs may support decisions for a wide range of applications. In the goal definition and scoping step of an LCA, there should be a complete description of the intended use of the LCA. Possible uses may include, but are not limited to:

**Internal uses such as:**

- strategic planning or environmental strategy development;
- product and process design, improvement and optimization;
• Identification of environmental improvements opportunities and tracking improvement progress;
• support of the establishment of purchasing procedures or specifications; and
• environmental auditing and waste minimization.

External uses such as:

• marketing or support for specific environmental claims;
• labelling, including setting criteria for eco-labeling;
• public education and communication;
• policy-making; and
• support of the establishment of purchasing procedures or specifications.

Some applications are considered internal to the study sponsor. In such cases, study information and results are not publicly released. Information can then be freely exchanged, confidentiality concerns are mitigated, assumptions can be harmonized within a common framework, and partial information is easily put in to context so that misleading conclusions can be avoided. These factors enable the internal user to employ LCA as one of the fundamental environmental management tools within the organization.

When the study sponsor proposes to communicate LCA results outside the organization, however, there are many expectations from external audiences to be met. LCA information can be used for educational or informational purposes, to support environmental labeling or claims, or to support policy decisions.

In external applications of LCAs, detailed and specific disclosure of information is necessary to ensure the credibility of the findings of the study. These applications can be more controversial than internal uses. There is a requirement for transparent reporting of data sources and data handling, as well as methods used. Withholding confidential information can present a barrier to meet fully the expectations of
external audiences. External studies also face a fundamental challenge of balancing the amount of detail in order to describe accurately the LCA information and assumptions, while providing information in a form and language that meets the needs of the target audience.

5.2 Completeness of the LCA

It is generally agreed that only full "cradle-to-grave" evaluations should be described as LCAs. However, much useful information may be derived from studies whose boundaries are narrower than "cradle-to-grave" or for which a full impact assessment has not been conducted, such Life-Cycle Inventories (LCIs). An important concern among LCA practitioners is the use of LCA information or findings for inappropriate applications.

Given the current state-of-the-art of LCAs, it is likely that less-than-complete studies will be conducted. This limitation of scope may refer to:

- stages of the life-cycle that are investigated;
- components of the LCA methodology that are included (e.g., only LCI); and
- environmental release or impact categories that are taken into account in the study.

Studies that do not encompass the full scope of LCAs are encouraged to follow the procedures and methodological rules recognized for LCAs and described in this document and elsewhere (SETAC 1991, 1992, and 1993). The limited nature of such studies should always be made clear in the study report.

The LCI can be used for product system improvements if, according to the data, a negative consequence from the action does not ensue. For example, energy or material consumption could be reduced, whereas a substitution of a raw material would require a full impact assessment.
If LCI information is to be used for external purposes, the information conveyed should reflect the depth and the scope of the study and provide the necessary detail for appropriate interpretation by target audiences. This includes transparent presentation of the information developed in the study. Peer review may be important and sometimes mandatory for external LCIs. Databases put into the public domain may also be subject to peer review.

5.3 LCA Utilization in Environmental Labeling and Claims

The question of whether LCA or LCI methodologies are sufficiently developed to serve as a basis for applications such as eco-labeling, product-certification programs, or environmental claims is a subject of considerable debate. Views concerning the degree to which such applications can or should rely on LCA or LCI information vary considerably.

Several eco-labeling and product-certification programs have developed their own methodologies, some of which have been influenced by LCA methodology. Others are pursuing broader life-cycle based approaches to provide a basis for product evaluation or selecting product performance criteria. Labeling or product-certification programs that use LCA as a basis for decision-making should follow the recommendations contained in this guide, both in performing the studies and in communicating the results.

Many claims (e.g., claims of biodegradability or recyclability) do not need to be substantiated through a LCA. In fact, claims of this type may require testing or may need to meet criteria that cannot be accommodated by the LCA methodology. In these cases, any link to a LCA is not necessary.

LCAs or LCIs, however, are sometimes cited in support of broader environmental statements or claims that impute some measure of
overall impacts from a product. Guidance on the relevance and use of LCAs for such purposes was provided by SETAC (1991) in its testimony to the United States Federal Trade Commission. It acknowledged that LCA studies or any part of these studies generally do not lend themselves to supporting general claims such as "friendly to the environment" or "clean." Furthermore, any claims that (1) imply that they reflect the overall environmental impacts of a product or process, or (2) indicate that they have been based on a LCA, would require, at a minimum, both an inventory and an impact assessment.

Finally, because the integrity and credibility of the LCA methodology largely depends on how results are used and communicated in the public domain, any claims based on LCAs or LCIs should accurately reflect the full scope of study results. Selective reporting of LCA or LCI results should be avoided because it can lead to erroneous conclusions, thereby affecting the overall credibility of LCAs.
6

PRESENTATION AND COMMUNICATIONS

6.1 Introduction

Presentation and communication are a vital element of any LCA. Without effective communication to decision-makers, LCAs will not contribute to improving environmental performance. Reporting should be objective and transparent, and there should be a clear indication of what has and what has not been included in the study.

The needs of different audiences should be recognized and addressed when presenting or disseminating the study. Target audiences can be internal or external to the sponsoring organization. These audiences can include companies, trade associations, government agencies, environmental groups, scientific/technical communities, and other non-government organizations (e.g., consumers). Communication in the public domain is especially critical because the risks of misinterpretation are heightened when LCA-derived information is provided to audiences not familiar with complexity of the methodology.

Good reporting and communication practice starts at the outset of the LCA, that relevant project details and all data are obtained and
compiled in a way that allows subsequent access, manipulation, and if necessary, scrutiny. Once the LCA has been completed and all the data processed, the next stage, ideally, is the production of a complete report.

A complete report should contain tables of data used and should ensure transparency and consistency of all the methodologies and data employed. The report should constitute the primary input to the scientific/technical audience and be a base from which summary reports to other target audiences could be prepared. These latter summaries need to be tailored to the recipient requirements, labeled as summaries only, and include appropriate reference to the primary report and data sources in order to ensure that they are not taken out of context.

6.2 Requirements of report

6.2.1 Objectives of the study

The presentation or communication of any LCA must include a clear and concise statement of the overall objective of the study. Objectives could include internal improvement assessments, comparative analysis, a basis for labeling, or other purposes. The degree of analysis and resulting documentation will vary, depending on these differing objectives, and it is recognized that the depth of documentation increases with any external use of the LCA report.

6.2.2 Scope of the Study

The extent to which a complete LCA, as defined in Chapter 3, has been attempted must be communicated as a minimum requirement of all LCAs, independent of overall objective. The extent and scope of the study is directly linked to the objective and potential use of the study results.
6.2.3 System Boundaries

Full analysis of all operations in a system may be extremely difficult and complex. Therefore, the system boundaries should be made clear to any reader. The reason and potential significance for any exclusions should be provided.

6.2.4 Flow Diagram

The flow diagram(s) should clearly describe the system, system boundaries, and all major input, products, and co-products. Several flow diagrams in different levels of detail may be required to adequately describe the system. The link between the flow diagram(s) and the data should be clearly evident to the reader.

6.2.5 Methodology

A full description of the methodology used for a particular LCA needs to be presented. It is recognized that the various current methodologies contain numerous assumptions, all of which may influence the overall results. Minimum requirements in communicating methodologies should include a statement about the extent to which the chosen methodology differs from a complete LCA. LCAs should explicitly identify all assumptions and value judgements and provide a basis for these assumptions. It may also be desirable to include a discussion of previous studies which addressed similar products or processes. Such a discussion is routinely included in scientific studies.

6.2.6 Data

The data used in LCAs come from a wide range of sources, which can be of differing quality, variability, and uncertainty. All such issues should be addressed in the report. Data can be gathered from public and private sources. While private sources are usually of better quality (more current), in many cases they are covered by confidentiality agreements for proprietary or competitive reasons. Any such data used
in a public study but not disclosed should be clearly noted. The sources of all public data (for example, specifically referenced textbooks, government reports, or previous LCAs) should be clearly identified. When used, public data should be included in the report. To prevent losing information by the way data are presented, the same level of detail used in collection should be maintained in reporting.

Key indicators of data quality should also be reported. Some data quality indicators are:

- age;
- frequency and method of collection;
- geographic scope (site-specific vs. industry averaged);
- time-period covered (points collected for one week, one year, etc.);
- completeness (missing or partial data; data gaps);
- representativeness (degree to which data represent the population);
- accuracy;
- precision;
- uncertainty (lack of consistency; use of estimates from different processes -- similar, more-easily measured -- or of non-detectable limits); and
- estimates of variability (mean/median, standard deviation, ranges, confidence intervals).

Because conclusions cannot be reasonably drawn without knowledge of result ranges, the reporting of variability estimates is important. These variability estimates should be included with the data presentation.

Finally, any data treatment, such as aggregation, should be noted. It is especially important to describe any treatment of data used for impact assessment, because it is an emerging methodology and may sometimes use subjective data.
6.2.7 Data Presentation

Data should be presented in full detail in the report, utilizing simplifications only when necessary or when protecting proprietary data. It is often appropriate to present the data in the form of histograms, spread sheets, grids, etc., to facilitate interpretation. There should be a complete reference to all data sources.

6.2.8 Conclusions

Any conclusions drawn from the study should be explicit, limited to the materials or processes actually examined, appropriate to the variability of the data used in the analyses, and wholly based on the results and methodologies presented in the report. Where additional material is introduced to augment the conclusions or for purposes of comparison, appropriate reference should be made to its source in order to preserve transparency. The conclusions should be honest and unbiased, and cover the whole study.

Implications derived from the conclusions involve interpretations and are thus subjective. Ideally, they should be based solely on the conclusions of the study and incorporate an explicit explanation of the subjective process which form the bases upon which they are founded.

The inclusion, and extent, of any implications will be determined by the target audience of the LCA.

6.2.9 Summary report

The report should contain an appropriate summary. The summary should be able to stand alone without compromising the results of the LCA. The target audience of the report typically will be decision-makers, who may not have time or background for reading the full report. The summary report should therefore also fulfill the same criteria about transparency, consistency, etc. as the complete report.
The summary report should as a minimum include the objective, the scope, and an overall flow diagram of the system studied, and should clearly indicate what is expected to be achieved by the study. The main results from the inventory and impact assessment components should be presented in a manner to ensure the proper use of the information, and statements about data quality, value judgements, and confidentiality should be included. Finally, the summary report should state any recommendations made and conclusions drawn by the practitioner of the LCA.

6.2.10 Peer review

Reports of external studies should include the main findings of the peer review panel, and contain as a minimum:

- endorsement or refutation of each of the major conclusions of the study;
- in cases where conclusions are refuted, the peer review team should summarize the grounds for their position;
- a brief description of the peer review process, including dispute resolution, as employed in the study; and
- the names and affiliations of the peer review team.

6.2.11 Qualifications of practitioner

A résumé of the practitioners’ experience, with focus on LCA experience, should be included as part of the report.

6.3 Audience Needs and Form of Communication

The full report and summary report described above may be used for a variety of communication purposes. The report may also provide the basis for other forms of communication (e.g., eco-labeling systems). Table 4 indicates how results might be communicated to different audiences with different needs.
Table 4. Audiences, Needs, and Form of Communication

<table>
<thead>
<tr>
<th>Audience</th>
<th>Need</th>
<th>Form of Communication</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientists and Regulators</td>
<td>Data for R&amp;D/other studies; Credibility; Potential regulations</td>
<td>Full report(^{(a)})</td>
</tr>
<tr>
<td>Environmental/NGOs; Politicians; Insurance and Investor Groups</td>
<td>Understanding and credibility</td>
<td>Summary of full report(^{(a)}) or full report on request</td>
</tr>
<tr>
<td>(External) Client of Practitioner</td>
<td>Record; Internal and external uses</td>
<td>Full report(^{(a)})</td>
</tr>
<tr>
<td>(Study within) Own Company</td>
<td>Record; Internal and external uses</td>
<td>As necessary; Full report(^{(a)}) for external use</td>
</tr>
<tr>
<td>Public: Media</td>
<td>Press releases; News; Advertisements</td>
<td>Synopsis written by Client/approved by Practitioner; Full report(^{(a)}) on request</td>
</tr>
<tr>
<td>Public: Consumer</td>
<td>Product choice</td>
<td>Environmental Labels; Full report(^{(a)}) on request</td>
</tr>
</tbody>
</table>

\(^{(a)}\): Excluding proprietary information.

6.4 Terminology

Conflicting and ambiguous terminology has been one cause of contention and dispute between different LCA practitioners and LCA reports. Thus, because terminology is an inherent part of the communication process, it is essential that accepted and unequivocal terminology be used wherever possible, or precise definition and
clarification given where it is not. Throughout SETAC involvement in the LCA area, participants at SETAC-sponsored LCA workshops have consolidated and evolved terminology to achieve these aims. It is recommended that this terminology be applied or adopted uniformly, to which end a glossary of terms is given in Appendix 1.
7

PEER REVIEW

7.1. Introduction

The development and use of a peer review process will be a key feature in the advancement of LCAs. Among the benefits of peer review are:

(1) the peer review process enhances the scientific and technical quality of LCAs; and

(2) the process helps to focus study goals, data collection, and provides a critical screening of study conclusions, thereby enhancing study credibility.

A traditional peer review of a scientific work is carried out at the end of the research and is defined by the publication policies of professional journals or associations. Among others, the purposes of this type of peer review are to verify the validity of the data, the data collection, the procedures used to carry out the study, and the adequacy of the conclusions drawn. Conventional scientific peer review is compatible with studies that advance LCA methodology and some LCA applications, but the peer review process used for those LCAs
with public policy and advertising applications should be more extensive than that traditionally used for the publication of research in professional journals.

The reasons for this are:

- because some LCA applications have regulatory and public-policy implications, a broad consultative approach is desirable in the review process to reach conclusions; and

- where proprietary information is used in LCA studies to reach conclusions that will be made public, protection of the proprietary information requires novel methods of peer review; and

The complexity of the data collection/definition and of the LCA process requires a more multidisciplinary peer review process than is required in most scientific studies.

For LCA studies directed toward public audiences, an interactive peer review process at various stages of the LCA can ensure that the study is credible. This chapter will define a process for this interactive peer review.

This interactive peer review ideally should be carried out in three phases:

- at the beginning of the LCA to review the goals, scope, boundaries, and the data collection planned;

- after initial data collection or modelling, to review the progress and offer advice or comments; and

- at the final report stage, to review the adequacy of the study and the credibility of the conclusions.
While the three-phase peer review process is desirable, in some instances only a review of the final study report and supporting data may be possible. Further, in any peer review there may be some details of the process that are study-dependent. For example, the selection of peer reviewers, the level of documentation, and the number of meetings of the peer review panel required in studies that are to be released to the public may be different than for studies intended only for internal uses.

7.2 Selection of the peer review panel

Selection criteria for individuals participating in the review are summarized below.

7.2.1 General criteria for selection

The general criteria for selection of reviewers include experience with the technical framework, design, and conduct of life-cycle studies; some experience or expertise with the subject matter of the study; a willingness to interact positively as part of a peer review panel; and a lack of any conflicts of interest that would potentially jeopardize the independence of the peer review.

7.2.2 Panels for internal and external studies

The backgrounds of individuals required for a peer review panel will be determined by the audience for which the LCA is intended. For example, studies intended for advertising claims or product labeling will require different peer review panels than studies that are not intended for public release. If a study is to be released externally, regulators, environmental or consumer activists, and the scientific community are some of the potential study audiences. Therefore, representatives from these constituencies should be considered for selection as members of the peer review panel.
For an internal LCA for which peer review is desired (e.g., done for product optimization or establishment of baseline conditions), the main audience to be assured of study quality is the sponsor of the study. The sponsor needs to determine the types of technical expertise and review that are needed to insure confidence in internal decisions resulting from the study. Potential reviewers could include LCA practitioners, internal process experts, customer or supplier process experts, or any of the groups identified for external peer reviews.

7.2.3 Selection of the peer review panel

For internal studies, selection of the reviewers may be made by the sponsor and/or the practitioner, although the sponsor will usually direct the selection. For external studies, the sponsor should begin the selection by naming the chair of the review panel. The chair then selects the other members. The sponsor and LCA practitioner can have input into the selection of panel members. The final choice, however, is the responsibility of the chair of the peer review panel. Neither the sponsor nor the practitioner shall participate as members of the peer review panel of an LCA intended for public release.

7.3 Peer review process

The peer review process is ideally carried out in three stages. The goals of the review at each of these stages are outlined below.

7.3.1 Review of goal definition, scoping, and boundary definition

An initial peer review discussion is beneficial during the early scoping and planning stages of the LCA. Early resolution of issues between the peer review panel and the LCA practitioner reduces the need for re-analysis of data. Early review also reduces the chance that a panel would disagree with specific study conclusions.
In examining study scope, boundaries, and assumptions, the peer review panel should consider:

- the purpose(s) for conducting the LCA study (product/process/activity improvement, public policy, education, etc.);
- the study boundaries;
- the choice of functional unit and range of alternatives;
- the assumptions used in determining study boundaries and functional units;
- anticipated data availability;
- data quality goals;
- the choice of impact categories, if appropriate;
- proposed data aggregation procedures;
- anticipated data variability and mechanisms for addressing variability; and
- the consistency of objectives, boundaries, assumptions, and data availability.

There may be additional issues which the panel considers and there may be issues for which the peer review panel wishes to consult with experts outside the panel. Consultation is appropriate within the constraints of preserving data confidentiality, but the membership of the panel should remain constant throughout the study.
7.3.2 Peer review of data

This step involves the review of emission, waste, and resource data and it may also involve review of data for impact assessment. The chronology of data collection and the expertise needed for peer review are different for inventory and impact data. Nonetheless, the criteria against which raw data should be reviewed are the same for inventory analysis and impact assessment, and may include, but are not limited to:

- the documentation of data sources;
- the representativeness and precision of the data;
- data gaps and steps taken to address those gaps;
- the documentation and scientific basis for study calculations and assumptions and an assessment of data variability; and
- data quality goals.

Again, the panel may wish to consult external experts in addressing these issues.

7.3.3 Review of the final report

This step would begin after the data have been summarized and presented in the final draft report. Suggested guidelines for review are:

- was the methodology adequately documented? Was the documentation of sufficient detail for someone to repeat the study?
- how were the data aggregated, summarized, and presented?
- were sensitivity analyses adequate?
• were the conclusions appropriate based on the data and analysis?

The results of this step should be written comments on the draft final report. The comments should be discussed with the practitioner and the sponsor. If the LCA draft report is modified in response to the panel’s report, the revised final report should be resubmitted to the peer review panel. The panel may then modify its report to reflect the changes. LCA reports should not be altered between the final panel review and public release.

7.4 Documentation

The peer review panel should compile comments at each stage of the peer review process and forward them to both the practitioner and the sponsor. The practitioner is responsible for responding to all comments of the panel.

If a multiple-step peer review process is being employed, all reviewer comments should be addressed before the study proceeds to the next step. The comments of the review panel and the practitioner’s responses should be preserved in the records of the study, although they do not need to be reproduced in their entirety in the final project report. The project report, however, should contain the conclusions and recommendations of the peer review panel.

This report, as a minimum, should contain:

• endorsement or refutation of each of the major conclusions of the study. In cases where conclusions are refuted, the peer review team should summarize the grounds for their position;
• a brief description of the peer review process, as employed in the study; and

• the names and affiliations of the peer review team.

If disputes arise, it is recommended that they be summarized in the peer review documentation. Further, it is recommended that every practitioner and peer review group discuss mechanisms for dispute resolution before the review process is initiated.

7.5 General issues associated with peer review

The LCA peer review process is still relatively new, and has not been fully tested and optimized. Two potential issues that may hinder the process have been identified in peer reviews conducted to date: cost and availability of reviewers. It is anticipated that as the peer review process becomes more common and LCA methodologies are more firmly established, the inefficiencies that increase cost will be reduced and the number of qualified peer reviewers will increase. Additionally, it is anticipated that as standard methods for LCA are developed, the need for peer reviews may be reduced.
Consensus building on the methodological framework and the practice of LCAs is expected to continue as practitioners gain experience in the application of this evaluative tool. As exemplified in this guide, the various aspects of LCA methodology are in diverse stages of development. In the course of preparing this publication, LCA practitioners have identified areas where further discussions and consensus on the methodological process and the application of LCAs are being pursued and these are listed below. This list is not exhaustive. Rather, it is indicative of the nature and direction of the collective individual research interests within the LCA community assembled at this workshop.

The identification of future research needs is a continuing process. One object of the international SETAC LCA workshops is to identify such needs, and to consider also those emanating from other sources. Initial needs were identified (SETAC 1991, 1992) as follows:

- Data quality and database development;
- Methodology development (notably generic model development), allocation, energy accounting, and communication;
• Minimization of differences between methodologies;

• Gaining of public acceptance of the LCA concept and applications via communication and education; and

• A code of conduct for undertaking LCAs.

Subsequent workshops (SETAC 1992, in press), together with external developments, have clarified the above and identified additional, and in some cases more specific, needs. These were all debated in some depth at the Sesimbra workshop, from which the general and specific needs outlined below were identified.

8.1 General Research Needs

• The development and implementation of effective presentation and communication practices.

• Sensitivity analysis: an assessment of the application of sensitivity analysis to LCA, the benefits which may be obtained, and the development of suitable methodology, preferable substantiated by practical examples.

• The development of computer models and software that are realistic and universally acceptable.

• The derivation of a suitable framework to provide for, and encompass, non-holistic studies within the overall LCA context. This must include defining and consolidating unambiguous terminology.

• Establishment of the role and interaction of LCA in Total quality management, product stewardship, design for the environment etc.
8.2 Inventory Analysis Needs

- The development and use of harmonized spreadsheets and data-grids for inventory compilation.

- Further development and refinement of the methodology for:
  - energy accounting;
  - co-product allocation;
  - electrical power generation, distribution, and allocation;

- Formulation of more substantive methodologies for waste treatment and disposal, especially:
  - the distinction between waste, co-products, and by-products (issue of "marginal" products); and
  - model technologies and procedures for waste disposal (incineration, landfill, composting etc.) which can adequately allocate according to source.

8.3 Data Needs

- Prioritization of data quality criteria, including the establishment of agreed data quality indicators (DQIs).

- Database development. There is a need for generic databases that:
  - contain data of assured quality; and
  - are mutually compatible.
These need to be established according to agreed formats and principles.

- Methodologies and procedures for database maintenance and updating.

- Procedures for handling data from different sources and having variable quality within an LCA, it being recognized that data are invariably obtained from a variety of sources.

- Further "cradle-to-factory gate" studies on basic raw materials and commodities.

- Data requirements for impact assessment need to be specifically addressed.

### 8.4 Impact Assessment Needs

- Establishing guidelines for deciding when impact assessment is appropriate and when it is not.

- The development of general models that account not just for hazard or load but for fate and exposure and, in particular, that can relate site specific concentrations to mass loadings of pollutants.

- Assessment and establishment of data needs for impact assessment. (see above)

- The exploitation of risk assessment data and techniques and development of a constructive interaction with LCA.

- Specific data requirements (see above).
• Validation of procedures for accounting for environmental effects in LCAs, including the use of existing toxicological data.

• Valuation:
  • Conventions and procedures for unequivocally comparing or weighting different impacts; and
  • Development of quantitative or science-based approaches (decision theory, statistical integration, analytic hierarchy processes etc.).

• Procedures for catering for occupational health risks, etc.

• Assessing and quantifying resource depletion, including rational assessment of non-renewable resource stocks.

8.5 Improvement Assessment Needs

Improvement assessment needs to be properly defined and an appropriate methodological framework developed. In doing so, it should be recognized that improvement assessment is applicable to each of the LCA components and is a continuous, rather than an "end-of-pipe," process. As a start to establishing a framework, participants at Sesimbra suggested that the improvement assessment component be broken down into three stages:

1. Possibilities for improvement.
2. Selection of options.
3. Assessment of feasibility.
8.6 Future

Some of the above needs have already been addressed to a limited extent. Others have been recognized and are now being actively tackled through the SETAC LCA Advisory Groups. The pressures are such as to ensure that rapid progress will ensue. This "Code of Practice" is a major step forward. However, because LCA is a relatively new technology that is still developing, subsequent updates, as stated earlier, will be necessary to incorporate the advances made.
Glossary of terms

Actual life: See useful life

Ancillary material: A material that is used by the manufacturing system producing that product, but is not used directly in the formation of the product.

Byproduct: Material, other than the principal product, that is generated and retained for further commercial purposes because it has some alternative value or function.

Closed-loop recycling: Reclaiming, re-using, or reprocessing waste product into a similar product.

Coprocess: See byproduct.

Distribution: All nontransportation activities carried out to facilitate the transfer of manufactured products from their final manufacturer to their ultimate end user. This includes the movement of goods within a warehouse or retailing establishment.

DQI: Data Quality Indicators

End user: Entities (individual consumers, commercial businesses, institutions) that actually use (unpackage and consume, operate, store for their later use, or prepare for their use) a finished product.

Finished product: A product in the form in which it will be used, including any primary packaging.

Formulating: Processing or making a product by mixing or combining materials in an operation that does not involve the synthesis of a new chemical substance.
Fugitive emissions: Emissions that escape control devices.

HAPS: Hazardous Air Pollution Standards.

Insert: A component that is both an input and output to a process, and is not transformed or otherwise acted upon.

Landfill: (a) Sanitary landfills are land disposal sites for nonhazardous solid wastes at which the waste is spread in layers, compacted to the smallest practical volume, and cover material applied at the end of each operating day. (b) Secure chemical landfills are disposal sites for hazardous waste. They are selected and designed to minimize the chance of release of hazardous substances into the environment.¹

Maintenance: Includes activities such as on-site (e.g., home) repair (which may require a trip to the hardware store for parts), off-site repair by a repair service, or preventive maintenance (e.g., changing the oil in a car, washing laundry). On-site maintenance may require trips away from the site to obtain supplies and then back to complete the maintenance activity. Off-site maintenance includes transport to and from the site of the maintenance facility. Maintenance may occur at the site of the end user or at another site.

Manufacturing: A process or series of processes using one or more materials to make a product.

Manufacturing, process, and formulation: The portion of a life-cycle that converts feedstocks or raw materials into final products.

Mass balance: Mathematical expression in which a summation of all material inputs to a system is equated to a summation of all outputs, accounting for transformation into energy.

NAAQS: National Ambient Air Quality Standards.
Nonenergy raw materials: Minerals, agricultural and forest products, water, and so forth.

Open-loop recycling: Reclaiming, re-using, or reprocessing waste product into a different product.

Post-consumer recycled materials: Any material generated by consumer, business, or institutional sources that has served its intended end use and has been separated from municipal solid waste for the purpose of recycling.²

Pre-combustion energy: An energy figure adjusted to account for the energy required to extract the raw material.

Pre-consumer recycled materials: Pre-consumer recycled materials are materials and byproducts that have not reached a consumer for an intended end use and have been recovered or diverted from solid waste, but are not those re-used within an original manufacturing process.²

Primary energy raw materials: Natural gas, petroleum, coal, nuclear, hydro, and so forth.

Process: An operation performed on one or more raw materials or intermediates leading toward the formation of a product.

Processing: See manufacturing, processing, and formulation.

Product: Something produced that has an existing value or potential use.

Raw material: A primary or secondary (e.g., recovered and/or recycled) feedstock that is used in a subsequent manufacturing process.
Recyclability: Defined by reference to an actual recycling rate as measured in the area set by the study scope (e.g., state, region, nation).\(^2\)

SARA: Superfund Amendment and Reauthorization Act.

Recycled content: The portion of a product or package that is composed of recycled materials, measured by weight.\(^2\)

Recycled material: Material that would otherwise be destined for disposal as solid waste, but is refabricated into marketed end products. This includes, but is not limited to, post-consumer material, industrial scrap material, and overstock or obsolete inventories from distributors, wholesales, and other companies. It does not include those materials and by-products generated from and commonly re-used within an original manufacturing process.\(^2\)

Recycling: The life-cycle activity that diverts materials from the waste management system and delivers them to the manufacturing and processing sector.

Renewable resource: A resource that is being replenished at a rate equal to or greater than its rate of depletion.

Re-use: Includes both on-site (e.g., home) and off-site re-use. On-site re-use may include intentional re-use of a product or package for its original purpose (e.g., Tupperware\(^\circ\)) or incidental re-use for a different purpose (e.g., storage of paint brushes in an old mayonnaise jar). Off-site re-use may include the return of materials to a retailer or manufacturer to be re-used for their original purpose (e.g., a refillable beverage bottle); donating of used items to charities for re-use by another party; off-site re-use also includes rental equipment.

Secondary data: Published or unpublished data reflecting the results of previous data collection and analysis.
Secondary raw material: A recovered and/or recycled raw material.

Semiproduced material: The product of a preliminary processing stage that requires further processing.

Transparency: The degree to which aggregated data can be traced back to the original values. Clear documentation of primary sources and/or aggregation methods is also essential.

Transportation: Movement of materials or energy between operations at different locations.

Use: Activities such as consumption of product, operation of equipment, storage of a product for later use (e.g., refrigeration), or preparation of a product for use (e.g., cooking).

Use/re-use/maintenance: The life-cycle activities that begin after the distribution of products or materials and end when those products or materials are discarded and enter a waste management system.

Useful life: The period of time from when the product arrives in the hands of the end user at the point of use to when that product has been used by the end user and is discarded. It can be expressed in any of a number of units that reflect the actual use patterns of the product.

Waste: (a) An output with no marketable value that is disposed to the environment. (b) Any material released to the environment through either air, water, and/or land, and has no beneficial use.

Waste management system: The mechanism for treating or handling a waste prior to its release to the environment.

2. **Source:** These definitions are based upon the working definitions from a joint Task Force of the Coalition of North East Governors Source Reduction Council and North East Recycling Council.

**All others:** SETAC 1991.
References


Other relevant publications


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