United States Environmental Protection Agency
Research and Development

Risk Reduction Engineering Laboratory
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EPA

Project Summary

Life-Cycle Assessment: Inventory Guidelines and Principles

Battelle, and Franklin Associates, Ltd.

The U.S. Environmental Protection Agency (EPA) is describing the process, the underlying data, and the inherent assumptions involved in conducting the inventory component of a life-cycle assessment (LCA) in order to facilitate understanding by potential users. This inventory consists of an objective aggregation of the resource usage and environmental releases associated with a product, production process, package, or activity.

The report includes a brief discussion of the history of LCAs, the basics of the LCA methodology, the procedural framework for conducting a life-cycle inventory, and descriptions of the life-cycle stages.

This study was conducted in cooperation with the EPA Office of Air Quality Planning and Standards (OAQPS), the Office of Solid Waste (OSW), and the Office of Pollution Prevention and Toxics (OPPT).

This project summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, Ohio, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

As public concern has increased, both government and industry have intensified the development and application of methods to identify and reduce the adverse environmental effects of the consumption of manufactured products and marketed services. These adverse effects occur at all stages of the life cycle of a product.

LCA can be used as an objective technical tool to evaluate these environmental consequences of a product, production process, package or activity holistically, across its entire life cycle.

A complete life-cycle assessment can be viewed as consisting of three complementary components (1) the identification and quantification of energy and resource use and waste emissions (inventory analysis); (2) the assessment of the consequences those wastes have on the environment (impact analysis); and (3) the evaluation and implementation of opportunities to effect environmental improvements (improvement analysis). The life-cycle assessment procedure is not necessarily a linear or stepwise process. Rather, information from any of the three components can complement information from the other two. Environmental benefits can be realized from each component of an LCA independent of the completion of the other components.

This report provides neutral, scientifically-oriented, consensus-based guidelines on the conduct of the inventory component of LCA.

Procedure

A properly conducted life-cycle inventory analysis will provide a quantitative catalog of energy and other resource requirements, atmospheric emissions, waterborne effluents, and solid wastes for a specific product, process, or activity, as well as identify and set boundaries among the life-cycle stages (raw materials acqui-

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sition, manufacturing, use/reuse/maintenance, and recycle/waste management). To date, there has been no documentation which attempts to describe this procedure in a manner that would facilitate understanding and use of the process and lead to uniform application. The literature contains little published information describing the technical basis for LCAs. In an attempt to begin filling this information gap, EPA contracted with Battelle and Franklin Associates to document a procedure for conducting a life-cycle inventory analysis. This report of life-cycle inventory guidelines and principles is the result of that effort.

Results

Procedural Framework for Life-Cycle Inventory

The inventory process begins with clearly defining the purpose for conducting the inventory analysis and identifying the boundaries which define the life-cycle system. When the boundaries have been determined, a system flow diagram can be developed to pictorially describe the system, as illustrated in Figure 1.

Once the purpose and boundaries have been defined, a checklist (see Figure 2) is a useful tool to cover most decision-making areas in the performance of an inventory. It includes geographic scope, types of data used, how the data were gathered and developed, how the data were modeled, and how the results are presented. A tool such as this one can help the researcher clarify the issues, boundaries, and conditions to be dealt with in a particular study. Worksheets can be used by the analyst to collect and qualify data from facilities. A checklist also can be used as a communication tool.

A peer review, started early in the study, should be conducted to address the validity of results, the methodology/scope, the data/compilation, and the communication of results. This review should include examination of how the boundaries were defined and the quality level of the data used before any statements regarding the results of the analysis are published. Careful interpretation is required in order to avoid making unsupported statements. Any limitations should also be communicated to the public along with the results.

LCAs are data intensive and, therefore, data quality can affect the outcome of an analysis. Data collected for an inventory should always be associated with a quality measure. Stand-alone data must be developed for each subsystem to fit the subsystems into a single system. Possible sources of data are industrial data, government reports, papers and books in the open literature, product specifications and laboratory test data. The purpose, scope, and boundary of the inventory help determine the level or type of information that is required. Whenever possible, it is best to get well-characterized industry data for production processes. Manufacturing processes often become more efficient or change over time, so it is important to seek current data. Inventory data can be facility-specific or more general and still remain current.

The next stage is the model construction. It consists of incorporating the data and material flows into a computational framework typically using a computer spreadsheet. The systems accounting data that result from the computations of the model give the total results for the energy and resource use and environmental releases from the overall system.

When writing the final report, it is important to thoroughly describe the methodology used in the analysis and explicitly define the system analyzed and the boundaries that were set. All assumptions made in performing the inventory should be clearly explained. If the inventory was conducted for purposes of product comparison, the basis for comparison among systems should be given, and any equivalent usage ratios that were used should be explained.

The results from the inventory can be presented most comprehensively in tabular form. The choice of how the tables should be created varies, based on the purpose and scope of the study. Graphical presentation helps to augment tabular data and can aid in interpretation.

How the results will be interpreted also depends on the purpose for which the analysis was performed. Careful interpretation is required to avoid making unsupported statements.

General Issues In Performing a Life Cycle Inventory

There are several general issues which are common to every stage of a life-cycle inventory. These issues pertain to the type of information these studies quantify and the decisions or assumptions that must be made in evaluating the information. One major tool in life-cycle inventory analysis is the template, which is a pictorial

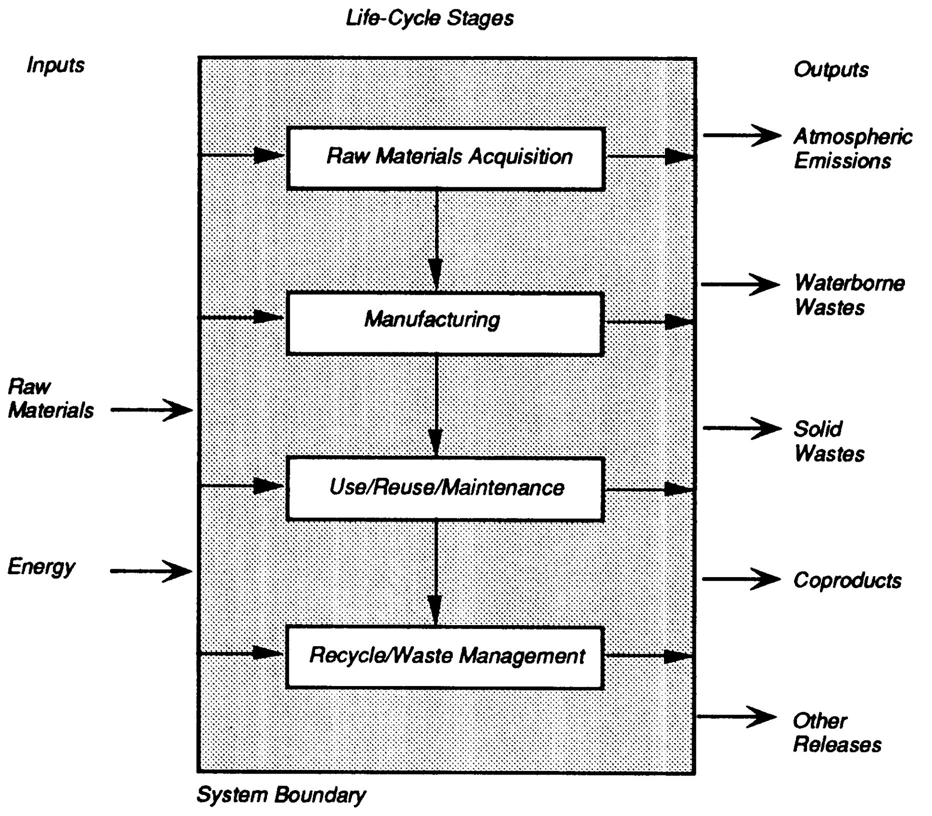

Figure 1. Defining system boundaries.

LIFE-CYCLE INVENTORY CHECKLIST PART I—SCOPE AND PROCEDURES
INVENTORY OF: ____________________

Purpose of Inventory *(check all that apply)*

Private Sector Use

Internal Evaluation and Decision Making

1 Comparison of Materials, Products, or Activities
1 Resource Use and Release Comparison with Other Manufacturer's Data
1 Personnel Training for Product and Process Design
1 Baseline Information for Full LCA

External Evaluation and Decision Making

1 Provide Information on Resource Use and Releases
1 Substantiate Statements of Reductions in Resource Use and Releases

Public Sector Use

Evaluation and Policy-making

1 Support Information for Policy and Regulatory Evaluation
1 Information Gap Identification
1 Help Evaluate Statements of Reductions in Resource Use and Releases

Public Education

1 Develop Support Materials for Public Education
1 Assist in Curriculum Design

Systems Analyzed

List the product/process systems analyzed in this inventory: ____________________

____

Key Assumptions (list and describe)

____

____

____

Define the Boundaries

For each system analyzed, define the boundaries by life-cycle stage, geographic scope, primary processes, and ancillary inputs included in the system boundaries.

Postconsumer Solid Waste Management Options: Mark and describe the options analyzed for each system.

1 Landfill ____________ 1 Open-loop Recycling ____________
1 Combustion ____________ 1 Closed-loop Recycling ____________
1 Composting ____________ 1 Other ____________

Basis for Comparison

1 This is not a comparative study. 1 This is a comparative study.

State basis for comparison between systems: *(Example: 1000 units, 1,000 uses)* ____________________

____

If products or processes are not normally used on a one-to-one basis, state how equivalent function was established.

____

Computational Model Construction

1 System calculations are made using computer spreadsheets that relate each system component to the total system.
1 System calculations are made using another technique. Describe: ____________________

____

Describe how inputs to and outputs from postconsumer solid waste management are handled. ____________________

____

____

Quality Assurance (state specific activities and initials of reviewer)

Review performed on:
1 Data Gathering Techniques ____________ 1 Input Data ____________
1 Coproduct Allocation ____________ 1 Model Calculations and Formulas ____________
1 Results and Reporting ____________

Peer Review (state specific activities and initials of reviewer)

Review performed on:
1 Scope and Boundary ____________ 1 Input Data ____________
1 Data Gathering Techniques ____________ 1 Model Calculations and Formulas ____________
1 Coproduct Allocation ____________ 1 Results and Reporting ____________

Results Presentation

1 Methodology is fully described.
1 Individual pollutants are reported.
1 Emissions are reported as aggregated totals only.
Explain why: ____________________

____

1 Report is sufficiently detailed for its defined purpose.
1 Report may need more detail for additional use beyond defined purpose.
1 Sensitivity analyses are included in the report.
List: ____________________
1 Sensitivity analyses have been performed but are not included in the report. List: ____________________

____

Figure 2. *Sample life-cycle inventory checklist worksheet.*

LIFE-CYCLE INVENTORY CHECKLIST PART II—MODULE WORKSHEET

Inventory of: ______________________ Preparer: ______________________

Life-Cycle Stage Description: ______________________

Date: ______________________ Quality Assurance Approval: ______________________

MODULE DESCRIPTION ______________________

	Data Value [a]	Type [b]	Data [c] Age/Scope	Quality Measures [d]
MODULE INPUTS				
Materials				
Process				
Other [e]				
Energy				
Process				
Precombustion				
Water Usage				
Process				
Fuel-related				
MODULE OUTPUTS				
Product				
Coproducts [f]				
Air Emissions				
Process				
Fuel-related				
Water Effluents				
Process				
Fuel-related				
Solid Waste				
Process				
Fuel-related				
Capital Repl.				
Transportation				
Personnel				

(a) Include Units

(b) Indicate whether data are actual measurements, engineering estimates, or theoretical or published values and whether the numbers are from a specific manufacturer or facility, or whether they represent industry-average values. List a specific source if pertinent, e.g., "obtained from Atlanta facility wastewater permit monitoring data."

(c) Indicate whether emissions are all available, regulated only, or selected. Designate data as to geographic specificity, e. g., North America, and indicate the period.

(d) List measures of data quality available for the data item, e.g., accuracy, precision, representativeness, consistency-checked, other, or none.

(e) Include nontraditional inputs, e.g., land use, when appropriate and necessary.

(f) If coproduct allocation method was applied, indicate basis in quality measures column, e.g., weight.

Figure 2. *Continued*

guide that identifies the information that must be obtained for every step involved in an inventory analysis.

Major Concepts

Templates, or material and energy balance diagrams, are tools used to support data gathering and development for life-cycle inventory analyses.

Data for processes producing more than one product are allocated based on the relative weights of product output or another justifiable method.

Data quality objectives are the required performance specifications for information in a life-cycle inventory. Establishment of these specifications is determined by the defined purpose of the life-cycle inventory.

Data quality indicators are qualitative or quantitative characteristics of data. These include accuracy, bias, representativeness, and other attributes that measure data goodness and applicability.

Raw Materials and Energy Acquisition

The life cycle of any product or material begins with the acquisition of raw materials and energy sources. For example, crude oil and natural gas must be extracted from drilled wells, and coal and uranium must be mined before these materials can be processed into usable fuels. All of these activities fall into raw materials acquisition.

Major Concepts

The resource requirements and environmental emissions are calculated for all of the processes involved in acquiring raw materials and energy. This analysis involves tracing the materials and energy back to their sources.

Consequences of the raw materials acquisition stage include non-traditional outputs, such as land use changes, and non-chemical releases, such as odor or noise. To the extent they are quantifiable, such outputs may be incorporated.

When fuel sources become input materials for a manufacturing process, an energy factor accounts for the unused energy inherent in the fuel.

Materials Manufacture

Manufacturing is divided into three steps: materials manufacture, product fabrication, and filling/packaging/distribution. Materials manufacture involves all manufacturing processes required to process raw materials into the intermediate materials from which the finished product will be fabricated. For example, this would include all operations required to produce tallow and sodium hydroxide from which bar soap is made. Transportation between manufacturing steps and transportation to the point of product fabrication is considered part of material manufacture.

Major Concepts

Material manufacture converts raw materials into the intermediate products from which the finished product will be fabricated.

Material scrap from a subsystem can be reused internally, sold as scrap, or disposed of as solid waste. The inventory account for each option is handled differently.

No credits or debits are applied to the subsystem for internally recycled material because no material crosses a subsystem boundary.

Industrial scrap as a coproduct carries with it the energy and wastes to produce it. This ensures consistency with operations that use scrap inhouse.

Product Fabrication

This stage involves processing the manufactured material to create a product ready to be filled or packaged, for example the production of fatty acids from tallow, vacuum distillation, manufacture of neat soap, and, finally, the cutting and drying of the bar soap.

Major Concepts

Final product fabrication converts intermediate materials into products ready for their intended use by consumers.

Facilities for which data are reported on a plant-wide basis will require allocation of the inputs and outputs to the product of interest.

Filling/Packaging/Distribution

This stage includes all manufacturing processes and transportation required between product fabrication and delivery of the product to the customer. Thus, for bar soap, this step includes all operations required to package the soap in wrappers, place the packaged soap into corrugated boxes, and transport the boxes to the retailer and then to the consumer.

Major Concepts

Filling and packaging products ensures that products remain intact until they are ready for use, whereas distribution transfers the products from the manufacturer to the consumer.

In addition to primary packaging, some products require secondary and tertiary packaging, all of which should be accounted for in a life-cycle inventory.

Any special circumstances in transportation, such as refrigeration used to keep a product fresh, should be considered in the inventory.

Use/Reuse/Maintenance

This stage is the one with which consumers are most familiar; the actual use, reuse and maintenance of the product. This stage consists of a discrete set of activities that begins after distribution of finished products or materials to the consumer and ends when these products or materials are either recycled or discarded into a waste management system.

Major Concepts

This stage includes all of the activities undertaken by the user of the product or service as well as any maintenance that may be performed by the user or obtained elsewhere.

Household operation, such as refrigeration, are rarely associated with a single product. Either the allocation of the capital and operating energy and environmental releases to a particular item are too small to affect the results or they can be proportionately included.

Recycle/Waste Management

Normally, after a product and its packaging have been used by a consumer and the product has fulfilled its intended purpose, they are either recycled, composted, or discarded as (post-consumer) waste. Waste management includes incineration and landfilling as well as wastewater treatment.

Major Concepts

Recycle/waste management is the last stage in a product's life-cycle.

In open-loop recycling, products are recycled into new products that are eventually disposed.

In closed-loop recycling, products are recycled again and again into the same product.

Formulas are used to determine the credits that should be assigned to recycled products analyzed in a life-cycle inventory.

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__Mary Ann Curran__ is the EPA Project Officer (see below).
The complete report, entitled "Life-Cycle Assessment: Inventory Guidelines and Principles," (Order No. PB93-139681; Cost: $27.00, subject to change) will be available only from:

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone: 703-487-4650

The EPA Project Officer can be contacted at:

Risk Reduction Engineering Laboratory
U.S. Environmental Protection Agency
Cincinnati, Ohio 45268

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