

# **EVALUATION OF LIFE-CYCLE ASSESSMENT TOOLS**

## **FINAL REPORT**

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# EVALUATION OF LIFE-CYCLE ASSESSMENT TOOLS

## 1. INTRODUCTION

Life-cycle assessment (LCA) is a process to evaluate the resource consumption and environmental burdens associated with a product, process, package, or activity. The LCA process encompasses the identification and quantification of energy and material usage, as well as environmental releases across all stages of the life cycle; the assessment of the impact of these energy and material uses and releases to the environment; and the evaluation and implementation of opportunities to effect environmental improvement.<sup>1</sup>

In recent years, LCA has gained general acceptance as a tool with a range of uses, such as environmental labeling, product environmental improvement, eco-design, and policy evaluation. As the acceptance of LCA has increased, so has the development of software tools and databases for performing LCA. Many of these software tools and databases are available for licensing or purchase. Targeted users of these materials are expert LCA practitioners and/or general users.

The Canadian government is facilitating the availability of accurate, up-to-date data for the inventory component of LCA by compiling the Canadian Raw Materials Database (CRMD). The life-cycle data concerning six primary materials will be made available to producers and other users for the use in LCA and other pollution prevention activities. Of critical importance in the use of the CRMD is the availability of software tools which can accept the data and process it in a manner that is consistent with the users' intended purpose and goals.

This project, conducted by the University of Tennessee Center for Clean Products and Clean Technologies, is an objective evaluation of the available LCA software tools for potential use with the CRMD. The evaluation consisted of two phases: an initial screening of available software tools, and subsequent appraisal of five software tools selected for an in-depth assessment based on the results of the initial evaluation.

## 2. INITIAL EVALUATION

The initial evaluation accomplished the following four tasks, the results of which are discussed below.

1. Established a comprehensive list of software tools (and vendors) currently available for LCA;
2. Reviewed demonstration copies of software tools which were available through vendor contacts;

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<sup>1</sup> Fava, James, et. al. (ed), *A Conceptual Framework for Life-Cycle Impact Assessment*, Society of Environmental Toxicology and Chemistry (1992), Pensacola, FL.

3. Reviewed literature concerning the available software tools from the vendors and third-party sources;
4. Identified five (5) LCA software tools to evaluate in full according to criteria developed in cooperation with Environment Canada.

## **2.1 Comprehensive List of LCA Software Tools**

From the U.S. and Europe, 37 software tools (and vendors) were identified; the comprehensive list is presented in Table 1. To establish this list, a variety of information sources were utilized. Published literature from the Society for the Promotion of LCA Development (SPOLD) and Atlantic Consulting, “The LCA Sourcebook” and “LCA-Software Buyers’ Guide” respectively, were used to identify commonly-known LCA software tools. The World Wide Web was also used to gather up-to-date information on other established software tools, while subscribers to various Internet list servers were solicited for information on newly developed or developing tools.

The 37 LCA software tools listed in Table 1 are in various forms of development and use. Four software tools are not yet fully developed (EcoSys, EDIP, LCAD, and SimaTool) and are denoted “Prototype” in the third column of Table 1. Some software tools are only available in a language other than English or French; CUMPAN, REGIS, and Umcon are examples of these software tools. Still other software tools were developed exclusively for private industry clients and are not commercially available (e.g., LCA1).

## **2.2 Initial Review of Demonstration Software and Literature**

Demonstration discs and users manuals for 14 software tools were obtained from vendors and evaluated in the initial review. These 14 tools are identified in bold type in the first column of Table 1. Included in the review was additional literature either supplied by the vendor or third-party sources.

Each of the 14 software packages was evaluated using a common review format. Within this format, six general categories of information are presented. These categories of information, identified in Figure 1, were selected to present general information which could be used to assess the capabilities of each software tool and to select the tool(s) which meet user-defined goals and functions. The Features category contains the primary evaluation results for each demonstration software tool; the other five categories offer support documentation including contact information and computer requirements. Appendix A represents the results of the initial evaluation of the 14 demonstration software tools.

**Table 1 - Comprehensive List of Life-Cycle Assessment Tools**

Name <sup>a</sup>	Vendor	Version	Cost, \$K	Data Location
1. <b>Boustead</b>	Boustead	2	24	Europe
2. <b>CLEAN</b>	EPRI	2	14	U.S.
3. <b>CUMPAN</b>	Univ. of Hohenheim	Unknown	Unknown	Germany
4. <b>EcoAssessor</b>	PIRA	Unknown	Unknown	UK
5. <b>EcoManager</b>	Franklin Associates, Ltd.	1	10	Europe/U.S.
6. <b>ECONTROL</b>	Oekoscience	Unknown	Unknown	Switzerland
7. <b>EcoPack2000</b>	Max Bolliger	2.2	5.8	Switzerland
8. <b>EcoPro</b>	EMPA	1	Unknown	Switzerland
9. <b>EcoSys</b>	Sandia/DOE	Prototype	Unknown	U.S.
10. <b>EDIP</b>	Inst. for Prod. Devel.	Prototype	Unknown	Denmark
11. <b>EMIS</b>	Carbotech	Unknown	Unknown	Switzerland
12. <b>EPS</b>	IVL	1	Unknown	Sweden
13. <b>GaBi</b>	IPTS	2	10	Germany
14. <b>Heraklit</b>	Fraunhofer Inst.	Unknown	Unknown	Germany
15. <b>IDEA</b>	IIASA	Unknown	Unknown	Europe
16. <b>KCL-ECO</b>	Finnish Paper Inst.	1	3.6	Finland
17. <b>LCA1</b>	P&G/ETH	1	Not Avail.	Europe
18. <b>LCAD</b>	Battelle/DOE	Prototype	< 1	U.S.
19. <b>LCAiT</b>	Chalmers	1.1	3.5	Sweden
20. <b>LCASys</b>	Philips/ORIGIN	Unknown	Unknown	Netherlands
21. <b>LIMS</b>	Chem Systems	1	25	U.S.
22. <b>LMS Eco-Inv. Tool</b>	Christoph Machner	1	Unknown	Austria
23. <b>Oeko-Base II</b>	Peter Meier	Unknown	Unknown	Switzerland
24. <b>PEMS</b>	PIRA	3.1	9.1	U.S.
25. <b>PIA</b>	BMI/TME	1.2	1.4	Europe
26. <b>PIUSSOECOS</b>	PSI AG	Unknown	Unknown	Germany
27. <b>PLA</b>	Visionik ApS	Unknown	Unknown	Denmark
28. <b>REGIS</b>	Simum Gmbh	Unknown	Unknown	Switzerland
29. <b>REPAQ</b>	Franklin Associates, Ltd.	2	10	U.S.
30. <b>SimaPro</b>	PRE' Consulting	3.1	3	Netherlands
31. <b>SimaTool</b>	Leiden Univ.	Prototype	Unknown	Netherlands
32. <b>Simbox</b>	EAWAG	Unknown	Unknown	Switzerland
33. <b>TEAM</b>	Ecobalance	1	10	Europe
34. <b>TEMIS</b>	Oko-Institute	2	Unknown	Europe
35. <b>TetraSolver</b>	TetraPak	Unknown	Unknown	Europe
36. <b>Umberto</b>	IFEU	Unknown	Unknown	Germany
37. <b>Umcon</b>	Particip Gmbh	Unknown	Unknown	Germany

<sup>a</sup> Demonstration discs and users manuals were obtained for tools shown in bold type.

**Figure 1 - Initial Review Categories**

<b>Software</b>	<b>Computing</b>
C Name	C User support
C Acronym	C Operating system
	C Software platform
	C Hardware requirements
<b>Vendor</b>	<b>Commercial Specifications</b>
C Company name	C Price and conditions
C Address	C Demo availability
C Contact	
C Phone and fax	
<b>Features</b>	<b>Customers and Reviews</b>
C Version	C Number of users
C System type	C Targeted type of users
C Data	C Published reports/reviews
C User interface	
C Calculation methods	
C Output	

### 2.3 Selection for In-depth Evaluations

From the initial evaluation of 14 LCA software tools, five tools were selected for an in-depth evaluation utilizing complete versions of the software. The five packages selected were as follows: KCL-ECO, LCAiT, PEMS, SimaPro, and TEAM. This selection was based on a number of criteria, some of which are presented in Table 2 and discussed below.

**Table 2 - Basic Selection Criteria and Corresponding Software Tools**

<b>Criteria</b>	<b>Software Tools</b>
highly detailed and representative life-cycle inventory	KCL-ECO and TEAM
impact assessment capabilities and flexibility	LCAiT and PEMS
extent of use within industry	SimaPro

One factor influencing the selection process was a consideration of the ultimate user of the software tool and the user's goals. For many users, a highly detailed and representative life-cycle inventory may offer enough flexibility to be useful. KCL-ECO and TEAM were selected based on this criterion. Although the version of KCL-ECO evaluated (version 1.0) does not have impact assessment capabilities (version 2.0 will), the software does present inventory information in a detailed, user-friendly manner and supports data export to various data management systems. TEAM offers a similar inventory management tool which is much more advanced.

System flexibility, impact assessment capabilities, and ease of use represent three additional parameters which resulted in the selection of two other software tools: LCAiT and PEMS. Each system possesses impact assessment capabilities, including user-defined parameters and weighting factors.

In addition to its ease of use, SimaPro was selected because it is already used as the data management tool for various commercially available life-cycle databases. IVAM and IDEMAT, both from the Netherlands, and ETHZ, from Germany, all use this software tool for data management. Furthermore, SimaPro is the program of choice for many companies as the analysis tool for LCA and product improvement projects.

### **3. IN-DEPTH EVALUATION**

The in-depth evaluation of the five LCA software tools began with the selection of criteria against which the tools would be compared. To offer a common and systematic approach to the evaluation, generic life-cycle systems were created which were developed in each of the five LCA software tools. A survey of current LCA software tool users was also conducted to offer an experienced, "real world" perspective to the generic evaluation. The criteria, generic systems, and survey are described in the following sections. A summary of results which compares the main features of each tool and the survey results follows these descriptions.

#### **3.1 Criteria for In-Depth Analysis of Tools**

The criteria considered in the initial evaluation represent only a few criteria which were considered in the full evaluation of the selected LCA software tools. The complete list of criteria used to evaluate these software tools was determined by the Center for Clean Products and Environment Canada. Six primary categories of criteria were identified: computer requirements and interface; system definition; data and data management; flexibility; calculations and comparisons, and outputs and exports. These general categories and supporting criteria are presented in Figure 2. An explanation of each criterion follows.

**Figure 2 - Criteria for In-Depth Evaluation**

<b>Computer Requirements and Interface</b>		<b>Flexibility</b>	
C	Hardware requirements	C	Unit flexibility
C	Software requirements	C	Use of formulas
C	Interface (e.g., graphical)	C	Allocation
<b>System Definition</b>		<b>Calculations and Comparisons</b>	
C	System development	C	Sensitivity analysis
C	System editing	C	Impact assessment
C	Archiving	C	Comparison of results
<b>Data and Data Management</b>		<b>Outputs and Exports</b>	
C	Embedded data	C	System
C	Data quality indicators	C	Tables and graphs
C	Other descriptive fields	C	Export options
C	Data protection		
C	Data editing		
C	User-defined data		

### 3.1.1 Computer Requirements and Interface

Computer requirements are the basic hardware and software requirements for each of the LCA software tools. Memory requirements and minimal processing unit capabilities are the primary *Hardware Requirements*. *Software Requirements* are those applications which are required for the software tool to operate properly. This may include the type of platform (Macintosh, Windows or DOS), as well as supporting applications not supplied by the LCA tool (e.g., spreadsheet applications such as Excel).

*Interface* describes the basic screens with which the user must interact while developing and manipulating the product/service life cycle under investigation. This interface, and the development of system life cycles is further evaluated and described in the following section, System Definition.

### 3.1.2 System Definition

System Definition includes the three evaluation criteria of 1) system development, 2) system editing, and 3) archiving.

*System Development* describes how the user can specify steps within a manufacturing process or stages within the product/service life cycle to define the system under investigation. This includes how flows of materials, emissions, and other burdens are specified within each step/stage, and how transportation and energy requirements are incorporated into the system. The different ways in which each software tool defines functional flows/functional units are also included under this heading.

*System Editing* is a brief explanation of system editing capabilities and limitations as the user develops a new or changes an existing life-cycle system. Adding or deleting steps/stages, changing flows, and manipulating the developed system within the software interface are considered in this section. Data editing is addressed separately in the general category Data and Data Management.

*Archiving* as an evaluation criterion assesses the capabilities of each LCA software tool to reuse previously defined systems (or sections of systems) in new life-cycle evaluations. As a library of life-cycle systems is developed, the user may find it necessary and convenient to reuse all or some of the saved information. For example, a common energy matrix or waste disposal scenario may be used for many different life-cycle systems.

### 3.1.3 Data and Data Management

There are a number of issues surrounding life-cycle data, databases, and data management capabilities which must be addressed when assessing the capabilities of each software tool. Under the criterion of Data and Data Management there were six areas of interest: embedded data; data quality indicators; other descriptive fields; data protection; data editing; and user-defined data.

*Embedded Data* describes the types of data available within databases accompanying each software tool. A brief assessment of data quality is also included under this heading. For a full description of data quality, see the results from the initial evaluation presented in Appendix A.

The various ways in which a user can specify data quality indicators is included under *Data Quality Indicators*. Text fields which allow the user to specify the source of data, dates of data collection, geographic regions, etc., are features addressed within this criterion. The quality of embedded data is not assessed under this heading. Other descriptive text fields, such as system title, process notes, etc., are included under the *Other Descriptive Fields*. User-defined descriptive fields, such as these, are features which strengthen the life-cycle assessment process, as well as simplify the interpretation of the assessment results.

*Data Protection* and *Data Editing* document the various ways in which the information contained in the database (whether embedded or user-defined) is presented to the user, shielded and/or protected from other users, and available for editing. Data protection considers both embedded data protection and user-defined data protection. The protection of embedded data can include complete inaccessibility to the data, view only, or copying/editing capabilities. The

protection of embedded data can include the use of user names and passwords, levels of security clearance, etc. User-defined data protection can include, for example, features which offer data access and editing capabilities to only the user who created the data set, as well as various levels of access similar to those described for embedded data protection.

*User-Defined Data* describes the process by which the user can define data for inclusion in software databases. Data import capabilities are included within this heading.

#### 3.1.4 Flexibility

Three separate criteria were identified under the general heading of system Flexibility: unit flexibility; use of formulas; and allocation. *Unit Flexibility* describes whether the tool supports user-defined units or whether the user must convert all entries to consistent software-defined units. The *Use of Formulas* offers another degree of flexibility. To determine/specify material flows, energy requirements and environmental releases based on user-defined variables can permit the user to develop a more dynamic system. *Allocation* of burdens among co-products and/or open-loop flows is an issue of interest for all LCA practitioners. There are various ways by which burdens are allocated to a product or service (e.g., by weight, by economic value, etc.). The way(s) in which each tool allocates burdens was evaluated and discussed in this sub-category.

#### 3.1.5 Calculations and Comparisons

Uncertainty analysis, impact assessment, and comparison of results represent three data manipulation capabilities which may or may not be a function of each LCA software tool. Calculations and Comparisons, as an evaluation criterion, assesses each tool for these manipulation capabilities.

With each bit of information and data entry within an LCA, there exists a degree of uncertainty. The capability of an LCA software tool to manage this uncertainty may be a characteristic of importance to the user. Therefore, the various methods to perform uncertainty analysis, such as sensitivity analysis, within each software tool was assessed, and presented under *Uncertainty Analysis*.

Impact assessment, as defined in “Life-Cycle Impact Assessment - A Conceptual Framework, Key Issues, and Summary of Existing Methods” (EPA, July 1995), includes the classification, characterization, and valuation of life-cycle inventory results. The flexibility to incorporate user-defined parameters for these and other assessment methods is of primary interest to many LCA practitioners and the users of LCA software tools. Each tool was evaluated for these capabilities, the results of which are summarized under *Impact Assessment*.

*Comparison of Results* summarizes the ability of each tool to compare the results (inventory or impact assessment) of two or more systems. For example, a comparison may be of two identical systems with different recycle rates or raw material inputs; a comparison may also be of two completely different and competing products/technologies to accomplish the same function.

### 3.1.6 Outputs and Exports

Outputs and Exports, the final assessment category, evaluates the various ways in which the life-cycle system and the calculated results can be viewed, printed, exported, and otherwise manipulated.

The flow diagram or sequence of steps/stages evaluated in the LCA represents the system. Printing and export functions of this system are presented under *Systems*.

*Tables and Graphs* summarizes the ways each software tool presents database information and the results of the inventory analysis, impact assessment, and other calculations. Editing capabilities and user-defined formats for tables and graphics are also included under this heading.

The ability to utilize the information created in the LCA software tool in other computer applications for report purposes, presentations, further manipulations, etc. is yet another capability of each software tool evaluated. *Export Capabilities* such as data export, inventory export, and impact assessment export were among the factors included in this criterion summary.

## **3.2 Generic Life-Cycle Systems**

The five LCA software tools selected for an in-depth evaluation were assessed under each of the above criteria. To accomplish this in-depth evaluation, four simple, fictitious life-cycle systems were developed in, and analyzed with each of the software tools. These systems, pictorially presented in Figures 3 through 6, represent the following scenarios:

1. straight-line manufacturing and use;
2. manufacturing, use, and closed-loop recycle;
3. manufacturing, use, and open-loop recycle; and
4. manufacturing with co-production and use.

The actual numbers calculated for each scenario were not compared between LCA software tools. The purpose of these scenarios was to allow the evaluators to become familiar with each tool, and to address each of the criteria in a systematic and consistent fashion.

**Figure 3 - Straight-Line Manufacturing and Use System**



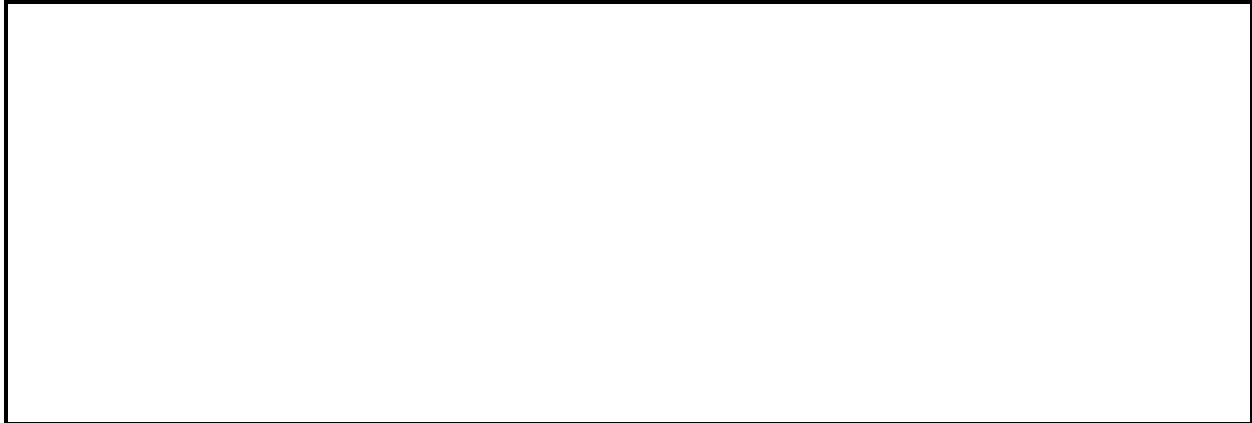
**Figure 4 - Manufacturing, Use, and Closed-Loop Recycling System**



**Figure 5 - Manufacturing, Use, and Open-Loop Recycling System**



**Figure 6 - Manufacturing with Co-Production and Use**



### **3.3 Survey of Software Users**

To give additional depth to the evaluation, a survey of current LCA software tool users was also conducted. Though the evaluation utilizing the criteria and scenarios described above was detailed, this survey of current LCA tool users offers a real-world perspective. The survey (see Appendix B) was used to assess the current applications of each software tool, the individuals using each tool, and the impressions formed by these users of the tool’s features and capabilities. The Center for Clean Products distributed the survey to software users, either directly to contacts supplied by software vendors, or through software vendors when client confidentiality was an issue. Table 3 summarizes survey distribution numbers and percent responses. Unfortunately, the number of completed surveys received from software users was not adequate to offer definitive and comparable results across LCA tools. Therefore, a separate summary of survey results will not be presented. Survey responses that were received are included in Appendix B.

**Table 3 - Survey Responses for Each LCA Software Tool**

Software	Number Distributed	Number Received	Percent Response
KCL-ECO	2	0	0
LCAiT	1	1	100%
PEMS	unknown <sup>(1)</sup>	8	-
SimaPro	unknown <sup>(1)</sup>	1	-
TEAM	5	1	20%

<sup>(1)</sup> Survey was distributed through software vendors (i.e., PIRA and PRe respectively).

### 3.4 Summary of Results

The results of the evaluation which utilized the criteria and generic scenarios are presented in Tables C1-C6 of Appendix C. The five software tools evaluated have many common capabilities. There are, however, a number of unique features/capabilities not found in every LCA software tool. A condensed and comparative evaluation of these unique software features is presented in Table 4. A brief description of these unique features is presented below. Refer to Appendix C for details of these unique features and other software capabilities.

**Table 4 - Comparison of Unique Software Features**

	<b>KCL-ECO</b>	<b>LCAiT</b>	<b>PEMS</b>	<b>SimaPro</b>	<b>TEAM</b>
Graphical Interface	U	U	U		U
Data Protection			U	U	U
Unit Flexibility	U			U	U
Use of Formulas	U				U
Uncertainty Analysis	U		U		U
Impact Assessment		U	U	U	U
Comparison of Results			U	U	U
Graphical Display of Results		U	U	U	

SimaPro was the only LCA software tool evaluated that did not offer a graphical interface for system development. Though the version of TEAM evaluated in this study did not support a graphical interface (version 1.15), the current version of the software leased by Ecobalance, Inc. (version 2.0) does support the graphical development of a life-cycle system.

Data protection is a feature offered by three of the five software tools: PEMS, SimaPro, and TEAM. PEMS data protection maintained the integrity of the embedded database, but offers little flexibility for user-defined data protection. The data protection feature of SimaPro is only supported in the multi-user version of the software. Similar to TEAM, data protection in SimaPro utilizes user passwords and access codes allowing each user to maintain their own database. TEAM offers the most extensive and flexible data protection options of all the software tools. As detailed in Appendix C (Table C3.2), three levels of protection can be specified for each project and defined data set.

Though unit flexibility is a feature supported by KCL-ECO, SimaPro, and TEAM, only SimaPro requires the conversion of user-defined units to standard system-defined metric units. Once defined, unit convention must be maintained in KCL-ECO and TEAM.

The use of formulas offers a dynamic dimension to the LCA process. Formulas and variables are used in KCL-ECO and TEAM in a similar manner. Each tool is able to support uncertainty analysis (described below) as a result of formula and variable utilization. See Table C5 of Appendix C for details of variables and formulas; see Table C5 for uncertainty analysis details.

The ability to perform uncertainty analysis by the three identified software tools is quite different. In KCL-ECO, uncertainty can be applied to selected variables (i.e., +/- X%), and the number of analysis cycles can be specified by the user. Though this technique is flexible, the graphical presentation of uncertainty results has limited utilization outside the program. PEMS and TEAM offer similar uncertainty analysis capabilities. Different scenarios must be run separately and saved as individual files; TEAM supports automation of these scenario runs. In PEMS the user can then analyze the percent difference (i.e., +/- X%) between two scenarios for various user-defined parameters. Analysis of scenario results in TEAM is performed in TEAMPlus as a comparison of results.

A commonly accepted methodology for impact assessment is still under development within the LCA practitioners community. Despite this lack of agreement, four of the five evaluated software tools support impact assessment capabilities: LCAiT, PEMS, SimaPro, and TEAM. Each tool supports the assessment of impact based on emission loadings to common environmental parameters such as global warming, greenhouse gases, and solid waste. Weighting factors are applied to the emissions calculated for a life-cycle inventory, and the resulting values are placed under the appropriate parameter(s). LCAiT and PEMS supports user-defined parameters; SimaPro allows the user to define their own parameters and weighting factors; and version 2.0 of TEAM requires the user to use system-defined weighting factors and parameters. PEMS and SimaPro offer additional assessment analyses which can be reviewed in Table C5 of Appendix C. The upcoming version of KCL-ECO will also offer this feature.

Comparison of results is supported by three of the five evaluated software tools. PEMS supports the comparison of up to six separate systems using any user-defined template of results (graphical or tabular). SimaPro and TEAM offer the unique ability to compare assemblies, sub-systems, waste disposal scenarios, etc. in any combination. For example, in SimaPro you can compare the emissions from the manufacture process of an assembly with the emissions resulting from a waste disposal scenario. Substances or impact assessment parameters can be compared. Similarly for TEAM, if inventories for a sub-system are created and saved, a comparison of results is possible. A limitation of TEAM, however, is that only one parameter can be compared at a time from only two inventories; the comparison is presented graphically.

The graphical display of results is the last feature common among only a few software tools. LCAiT offers only a graphical depiction of the calculated inventory results. PEMS supports a wide range of user-defined graphical results that can also be viewed in tabular form. Finally, SimaPro presents characterization (classification), normalization, and valuation calculations in graphical form; graphical depiction of inventory results is not supported.

Though each software tool has common capabilities within the remaining criteria categories, the

flexibility and functionality of these capabilities vary significantly from tool to tool. While completing the evaluation, overall impressions of each software tool's capabilities, limitations, and ease of use were formulated by the evaluators. These impressions of the evaluators are presented below. The reader should refer to Appendix C for further details.

### 3.4.1 KCL-ECO

The graphical interface of KCL-ECO makes system development easy. Editing of the system, data, and variables list from anywhere within the program offers the freedom to develop the system as it is conceived by the user. The reuse of archived systems and sub-systems is one of the easiest among the evaluated tools. System variables (inputs and outputs) can be specified by the user. Units are associated with each variable and can also be defined by the user. Once defined, this unit convention must be maintained throughout the LCA project. Allocation among co-products is not a function of the tool. All allocation must be performed before the system is developed and the flows specified. The use of variables and equations allows for user-defined flows and parameters, and offers another degree of flexibility when defining the system. Sensitivity analysis within the program is one of the most versatile among the tools evaluated. Customization of result tables is supported in a limited way; graphical displays are not an option given by the software. Survey responses from KCL-ECO users were not received.

Unique features offered by KCL-ECO include the following:

- C Access to the variables list at any point within the program allows the user to define new variables from anywhere within the program as the system is being developed.
- C The descriptive field accompanying each process block can be invoked on the graphical interface and is included in the table of results.
- C The output of one process block does not have to have the same name as the input to another process block when the flow is connected between blocks.

Limitations of the software tool include the inability to compare results and perform impact assessment, and the lack of support for exporting results. However, version 2 of KCL-ECO, expected out later this year, will possess impact assessment capabilities, as well as allocation methods.

### 3.4.2 LCAiT

System development within LCAiT is not as simple as that experienced with other software tools evaluated. Including emissions, wastes, *and* resources in process block details is difficult to conceptualize; though resources are typically thought of as inputs, they are outputs in LCAiT and cannot be used in further system units/steps. Connections between blocks do not have/require material flows assigned to them. Data editing and user-defined data capabilities, however, are simple and straightforward. The use of descriptive text fields is extensive. Unit flexibility of the tool is typical of most software; data must be entered in system-defined units. Allocation is not supported by the software tool; the user must allocate all burdens before entering data into the

system. The lack of sensitivity analyses and comparison of results limits the tool's application as a management tool. Impact assessment capabilities, however, are good. Only graphic results are supported within the user interface; export capabilities in tabular form are supported. A description of the different colors used in the graphic display of results is not offered.

Unique features of LCAiT include the following:

- C The ease of user-defined data entry using software-supplied templates; and
- C The ability to import an entire life-cycle system into a process block of a new system, allowing highly detailed and complex systems to be simplified.

A limitation of the software tool is that only four material flows can be assigned to each side of a process block, limiting the complexity of the system developed.

### 3.4.3 PEMS

The graphical interface of PEMS makes system development intuitively very easy. The inputs and outputs are compiled and a mass balance for each process block is calculated and reported to the user on each Properties card. Material flows and transportation are represented by arrows between blocks. Ample descriptive fields allow the user to offer narrative information for all process blocks and the system as a whole. Data developed by the user, however, are difficult to input into the database format, and archiving systems for reuse is tedious. Unit flexibility and allocation capabilities of the tool are typical of most software; data must be entered in system-defined units, and the allocation is by weight. The manual offers a very detailed explanation of other allocation methods but the tool does not support these methods. Finally, the manipulation and presentation of data is well supported by the system. Sensitivity analysis, impact assessment, and comparison of results are easy to understand and customize. Tables and graphs can be easily customized, and export to other applications is well supported.

Unique features of PEMS include the following:

- C User is informed (warned) if a flow represents less than one percent of total;
- C Multiple transportation options can be defined for a single flow allowing urban, rural, and motor way combinations to be selected. The inclusion of a 'utility' factor allows the user to represent return trips as well.
- C PIRA offers membership to the PEMS User's Club; as members PEMS users have the opportunity to discuss and participate in the further development of LCA and LCA standards, as well as the development of future PEMS versions.

A limitation of PEMS experienced during the evaluation was the lack of a run-time version of Excel; software failure occurs when using an Excel application above Version 5. This dependence on Excel has been eliminated in the version of PEMS expected out later this year (1996).

#### 3.4.4 SimaPro

SimaPro has features that support its extensive use as a product development and LCA management tool. Though a graphical interface for system development is not offered, SimaPro is very easy to use and flexible. Access to, and unrestricted editing of the five database files is the characteristic which offers most of this flexibility and ease. Aside from data protection, all data and data management options are excellent and easy to operate. Embedded data are extensive and well documented; adequate descriptive fields are offered for each database entry; and user-defined data are easily input through templates offered by the software program. Various impact assessment options for system and block impact (e.g., easily accessible indicator values, characterization/normalization/valuation calculations, and ‘thermometer’ scales) are available at all times while in the program. Results presented in a graphical format are supported, but tables are not.

Unique features of SimaPro include the following:

- C The ability to link database entries;
- C Access to numeric and visual indications of impact for each stage, assembly, process, and material in a life cycle system; and
- C A multiple-users version of SimaPro is available (at a reduced cost for educational purposes) which offers unique features such as data protection and networking.

Limitations of SimaPro include the lack of graphical interface, sensitivity analysis and possibly the DOS interface.

#### 3.4.5 TEAM

TEAM is the most powerful and flexible of the tools evaluated in this in-depth study. Because of this, however, the features and capabilities were the most difficult to fully understand and utilize. Selecting and defining inputs and outputs within the lowest process/unit level is quite simple using the tool bar; flows may be defined by values or variables and equations. Unit flexibility is similar to KCL-ECO; units are associated with each variable (i.e., termed an “Article” in TEAM) and can be defined by the user. Once defined, this unit convention must be maintained throughout the LCA project. The use of formulas to specify allocation methods for each process unit is a unique feature of TEAM. At each process level, Check and Compile options allow the user to ensure system consistency and integrity even before the system is fully defined. Calculating the LCA inventory from anywhere within the system (called “propagation”) is yet another flexible feature of TEAM. Tabular results are typical of other software tools evaluated, with customization and export capabilities supported. Graphical representation of results is not supported.

Unique features of TEAM include the following:

- C The ability to propagate inventory calculations from anywhere within the system;
- C The ability to define allocation rules within the lowest process/unit level for any flow; and
- C The various data protection and data access levels allow easy maintenance of data integrity.

Limitations of TEAM include the lack of support for user-defined weighting factors for impact assessment and the limited (only one parameter between two inventories) comparison of results capabilities. A separate and inaccessible database may be viewed by many as another limitation of TEAM. A new version of TEAM is expected out later this year which will support user-defined weighting factors, as well as a database linked directly to the LCA tool.

## **Appendix A**

### **Results of Interim Evaluation**

**SOFTWARE:** The Boustead Model

**VENDOR:**

**Company:**

**Address:** 2 Black Cottages, Worthing Road, West Grinstead, Horsham, West Sussex,  
Great Britain RH13 7BD<sup>(1)</sup>

**Contact:** Dr. Ian Boustead

**Phone:** 44-403-864-561

**Fax:** 44-403-865-284.

<sup>(1)</sup> The U.S. sales representative is Consoli Consulting, Inc., 619 N. Heilbron Drive, Medea, PA 19063.

**FEATURES:**

**Version:** 2.0

**System Type:** LCI with extended integral database.

**Data:** Includes extensive data modules for energy carriers, fuels production and transportation. Individual process, segment, and complete product data are included for common process operation segments and commodity materials manufacturing sub-systems. Unit processes are coded by number and ample space is available in the database for user-specified data. Data are input via the construction of a data table for each process. For any given numbered process that produces a defined unit of product, the user places in the table names and amounts of any input raw materials, energy requirement (generated outside the process), intermediate inputs, i.e. those not drawn from the earth, and any air, water, and solid waste emissions. The associated code number of the tabulated items is also entered to allow the program to link any particular table with any other table in order to create the process flow sheet. The core database, i.e., the accumulation of the items supplied with the program, are grouped into categories because the user must input the codes when generating a new data table. Although the most frequently used ones can be memorized, the user will need to refer to the listings for less frequently specified items. The database contains information on over 2,000 unit operations. Unit operations data represent a mixture of U.K., general European, and U.S. conditions. The standard list of emissions in the core database contains up to about 2 dozen items for each process. The user may add additional items as needed.

The data for the fuel producing industries are especially well represented by country. Data sets are included for average conditions in 23 countries. Furthermore, the electric generation data for the U.S. and Canada are disaggregated into 9 and 5 regional electrical grids, allowing a finer level of analysis.

Data are generally in SI units, but there is no reason why alternative units cannot be selected by the user provided they are consistent. However, there is a preferred set of data units. Most of

the data are believed to be secondary except for some specific data on local systems collected by the author. No explicit data quality indicators are used.

**User Interface:** The current version of the Boustead model and its supporting documentation is in English. The user actually interacts with the model through the initiation of a sub-program either from a system menu or directly from the DOS prompt. File manipulation and printing are all controlled in this manner. One group of sub-programs writes data to files in ASCII format for later post-processing. One convenient feature of the program is the printing of a *proforma* questionnaire for the data collection process. Creation of models containing only linear sequences of unit operations is quite straightforward. Use of pre-defined segments, as for example the cradle-to-get data from the American Plastics Council, or models involving recycling loops are more complicated.

**LCI Calculation Method(s):** The “program” actually consist of a collection of routines which perform discrete functions. The user selects from a listing of these programs the desired function and executes the program. Input is sought and output collected to allow progression through the construction of the data, checking of units consistency, assembly into an LCI, printing of intermediate worksheets, and the formatting and printing of reports. Categories of sub-programs include:

- C Setting Defaults (file size and printing configurations)
- C Amending the Database (amends data in input tables and elsewhere; inserts or deletes data in specified tables, blocks or data sets)
- C Preparing Primary Data (converts unit quantities and prints data acquisition questionnaires)
- C Calculating Data (computes the specified aggregated inputs or outputs for the core components, i.e. those contained in the core database and the top components, i.e., the user input materials and processes)
- C Reading Data to the Screen (presents information on the monitor for a code number)
- C Printing Worksheets (prints intermediate calculation data)
- C Printing Reports (prints composite and data subsets in report format)
- C Writing Data in ASCII format (outputs data to a floppy drive file)
- C Transferring Data (moves data from/to a floppy drive and a hard drive)
- C Initial Installation (creates files and converts version 1 to version 2 structure)

The topmost analysis unit is the product. The checking of the data sets for errors is facilitated through the code structure and a search program which allows any operation code contained in an input table to be flagged for examination as a possible mis-entered data point.

**LCIA Calculation Method(s):** Not applicable

**Output:** The flexible report generation capability allows the reader to create any number of tabular representations of the data. The format of these tables are fixed by the program.

Export to a word processor via the ASCII file writing capability, however, does allow additional tailoring. The basic report contains columns of data for each environmental medium for each input/output. Headers and a footer as well as page numbers are printed in the report generator. No graphical capability exists within the program.

## **COMPUTING:**

**User Support:** Available in the U.S. through Consoli Consulting (sales primarily) and Dr. Derek Augood (private consulting through an agreement with Dr. Boustead); customization and additional user support available through the author.

**Operating System:** DOS 5.0 or higher

**Hardware Requirements:** 386-SX processor, 2 MB RAM, and 35 MB disk space minimum; 486-DX or higher performance processor preferred; requires up to 100 MB of disk space depending on complexity of model.

## **COMMERCIAL SPECIFICATIONS:**

**Price and Conditions:** \$24,000 initial lease; renewal negotiable

**Demo Availability:** No

## **CUSTOMERS AND REVIEWS:**

**Number of Users:** Unknown at present

**Targeted Type of Users:** Expert users in general, although model is generally straightforward to operate; typically the model has been supported by a trained user within the leasing organization.

**Published Reports:** Numerous application reports in Europe and the USA

**SOFTWARE:** Comprehensive Least Emissions Analysis (CLEAN)

**VENDOR:**

**Company:** Science Applications International Corporation (SAIC)<sup>(1)</sup>  
**Address:** 4920 El Camino, Los Altos, CA 94022  
**Contact:** Dwight Agar  
**Phone:** 415-960-5918  
**Fax:** 415-960-5965

<sup>(1)</sup> The development of CLEAN was sponsored by Electric Power Research Institute (EPRI) in conjunction with several utilities.

**FEATURES:**

**Version:** 2.0

**System Type:** LCI of energy emissions from fuel production, electric generation, and end-use (note: downstream emissions, such as equipment maintenance and disposal, are not yet included in the database or calculations). A costing module is also part of the program.

**Data:** Includes 150 end-use technologies in over 20 different activity groups; for example, *150,000 ft<sup>2</sup> facility with T-12 lamps and magnetic ballasts* represents a technology in an *office lighting* activity. Residential, commercial, and industrial technology-activity groups are covered. Six default supply-side emissions data sets covering various geographic regions of the U.S. are included which represent marginal emissions data for year 2000. Also included is a supply-side emissions data set for New England Electric Systems for 1993. Units of emissions can be specified: either gr., kg., lb., or tons. (lb. is default.) Users are able and encouraged to model end-use technologies and activities, as well as customize the database to meet individual needs (e.g., provide utility-specific electric generation emission curves). Data can be viewed and edited in the program's user interface, or imported/exported from structured ASCII files. The references for system supplied data can be checked by accessing the Reference option found under the Edit menu in the Main Window.

**User Interface:** software and manual are in English. The software is also equipped with a complete on-line help screen. The user is prompted through a series of menus to define activities, technologies, and supply-side emissions data. No graphical interface is offered.

**LCI Calculation Method(s):** Based on user selected supply-side emissions data, end-use activity, and end-use technology, the program calculates the emissions of electrical technologies based on pre-defined hourly electric demand and marginal emission factors (one times the other). Calculations take into account varying emission factors of the generation plant, varying electrical demands of end-use technologies, efficiency of end-use technologies, and transmission/distribution losses. For non-electric technologies, CLEAN calculates the yearly emissions as a function of yearly energy use, the efficiency and the emissions factors associated

with the selected technology and fuel. Calculations determine the weight of emissions for 19 substances (equivalent CO<sub>2</sub>, NO<sub>x</sub>, SO<sub>2</sub>, TSP, PM10, CFC-11, HCFC-22, HCF-123, IFC-134A, ROG, CO, water use, solid waste, waste water, CFC-12, hazardous waste, CH<sub>4</sub> and N<sub>2</sub>O).

**LCIA Calculation Method(s):** Not applicable

**LC Cost Calculation Method(s):** The software will calculate the marginal cost to the utility for generating the required electricity and the net present value of the technology based on user-defined parameters (OEM, capital, installation, inflation rate, expected life, etc.)

**Output:** Both text (files) and graphic output support are provided. Input data and calculated results can be copied to a file in ASCII form. Graphical depiction of results includes bar graphs, off- and on-site emissions, load curves and supply curves. Report options include eight different formats, all of which have export capabilities and user specified options.

#### **COMPUTING:**

**User Support:** On-line help available through program. SAIC offers on-site training and support over the phone.

**Operating System:** DOS, MS Windows 3.1, Microsoft Access

**Hardware Requirements:** 386-SX, 16 MHz, 4 MB RAM and 5 MB free hard disk space

#### **COMMERCIAL SPECIFICATIONS:**

**Price and Conditions:** \$14,000 for industry and private firms; some arrangements for academic and research facilities can be made. Availability of software is by contract only.

**Demo Availability:** Yes, manual and disk.

#### **CUSTOMERS AND REVIEWS:**

**Number of Users:** Over 250 software copies have been ordered by industry.

**Targeted Type of Users:** Non-expert user

**Published Reports:** Unknown

**SOFTWARE:** EcoManager

**VENDOR:**

**Company:** Franklin Associates, Ltd.  
**Address:** 4121 83rd Street, Suite 108, Prairie Village, KS 66208  
**Contact:** Bruce Kusko  
**Phone:** 913-649-2225  
**Fax:** 913-649-6494

**FEATURES:**

**Version:** 1 (January 1994)

**System Type:** LCI using generic data.

**Data:** System provides generic data, the use of which will apply to average or typical process/product situations. Four databases are available: materials, energy, waste, and transport. Within the demo manual there was no indication of the extent or contents of these databases or data quality indicators. Weight in pounds (lbs.) is the unit in which all non-energy data must be entered and evaluated. Use of other units must be manually converted to lb. Energy units must be MBTU and be relative to the reference quantity of the process. Three of the databases can be updated (materials, waste, and energy); transportation cannot. Data input procedures were not clarified in the materials (demo) provided.

**User Interface:** EcoManager is in English, both manual and software. All processes must be predefined by the user prior to creating a new inventory. The user is prompted through simple menu screens to enter the material, transport, and energy flows from each process step. The data management spreadsheet for each process is also accessible to edit and add data as desired. No graphical representation of the created system is supported.

**LCI Calculation Method(s):** The model uses backward-chaining processing, or processes in which the environmental burdens are linked to the amount of output required. Thus, a functional unit must be specified; the life cycle inventory will be normalized/calculated against the weight of this functional unit. The model works backwards through the system, thus the first process evaluated is the last within the system (prior to waste disposal). For each process, a reference quantity which was the basis for the inventory data must be defined by the user. Links between processes are not dynamic.

A maximum of four material outputs can be entered for each process. Five closed loop input materials can be entered into a single process. Only one co-product can be specified per process, thus multiple co-products must be grouped. The allocation method used is by weight; other allocation methods require manual calculations to weight. Up to twenty stages using transportation can be defined. Distance traveled and a utility factor are the two data parameters the user can define. Waste management options include default transport data.

Data are maintained and manipulated by an Excel spreadsheet. Energy outputs for the system are limited to one electrical and one heat. No clear definition of recycle loops was offered.

**LCIA Calculation Method(s):** Not applicable

**Output:** The model supports only tabular output of calculations. Each defined process is identified as a column heading, below which are three columns which contain "notes," "references," and "calculated values." Notes allow the user to track materials and energy through the system; reference columns contain data about the inputs and outputs of material/energy relative to the reference quantity for that process; and the calculations column presents the inputs and outputs based on the functional unit defined for the system. Data and calculations are managed in a Excel spreadsheet, therefore export of results is supported.

#### **COMPUTER:**

**User Support:** Not explicitly stated.

**Operating System:** DOS 3.1 or higher, Windows 3, and Excel 4

**Hardware:** 386 or 486 with at least 4 MB RAM

#### **COMMERCIAL SPECIFICATIONS:**

**Price and Conditions:** \$10,000

**Demo Availability:** Yes; demo manual is extremely limited in its explanations of demonstration of system capabilities.

#### **CUSTOMERS AND REVIEWS:**

**Number of Customers:** 6 industrial users

**Targeted Type of User:** Intended user is the non-expert. With the lack of a graphical interface (all entries are prompted via dialogue) and complexity of data input, this intended user is not practical.

**Published Reports:** Unknown

**SOFTWARE:** ECOPACK2000

**VENDOR:**

**Company:** Private consultant  
**Address:** Esslenstrasse 26, CH-8280, Kreuzlingen, Switzerland  
**Contact:** Max Bolliger  
**Phone:** Unknown  
**Fax:** Unknown

**FEATURES:**

**Version:** 2.2

**System Type:** LCA oriented towards packaging systems with equivalency and scarcity based impact characterization methods.

**Data:** Includes two sets of data modules for energy carriers, materials production and transportation. One set of data are derived from the Swiss BUWAL (Swiss Office for the Protection of the Environment, Forests, and Scenery) study of 1992. (Note: This study is being updated and expanded and new data are expected in 1996.) Some data are included for process operations associated with packaging materials (film production, blow molding, injection molding, and lacquer application) and commodity materials manufacturing for typical packaging items, e.g., aluminum, glass, various commodity thermoplastics (HD-PE, LD-PE, PA, PET, PP, PS, HIPS, PVC), various papers and paper boards, and tin-plate. A second data set represents an average of European data primarily from the Boustead database. The Euro-average data are less complete. Data are in SI units. All of the data are believed to be secondary except for some European average data on electrical energy systems and polymer resin production collected by Ian Boustead and the APME. Very limited capability for user input data fields are provided in the model. No explicit data quality indicators are used.

**User Interface:** The current version of EcoPack2000 is in English. The user manual has also been translated to English, however, the detailed documentation of the methods and database work up are in German.

**LCI Calculation Method(s):** The topmost analysis unit is the product description. Once the user identifies the system(s) of interest and selects the database to be used, the actual definition of the profile is performed by inputting the mass of the various units used for the material inputs, e.g., 10 grams of aluminum with 100 percent recycled content and 50 grams of glass with 74.8 percent recycled content. In addition to specifying the materials (which in principle incorporates the rolled up energy and emissions to produce the designated amounts of the material, and presumably inclusive of the inherent energy), the user specifies additional processing and transport operations. Some of the choices are not obvious from the on-screen information or the limited available help file. The user manual is very sketchy on how to add the miscellaneous operations, although some of the possible choices can be discerned with some

thought. For example, the burdens from a car equipped with a catalytic converter are included by inputting the number of km traveled. Similarly, the other transportation segments are added via specification of the tonne-km used, necessitating some off-line effort to estimate these quantities.

Loops (e.g., recycling) are solved via a mathematical process not described in any detail in the documentation. The user can insert various recycling rates for selected materials as appropriate. Energy credits are applied for post-consumer recovery of energy from incineration facilities. The inherent energy of the material is multiplied by the fraction of waste incinerated and the fraction of incineration facilities in Switzerland (neither of which is user accessible for modification) to derive the credit. The reduction in virgin material requirements for a recycled product is credited based on the fraction recycled. Co-product allocation is made on a basis not described anywhere in the documentation but presumed to be identical to that used in the BUWAL study, which is based on the relative mass of products produced. The lack of user capability to define the nature of the system and the linking of operations makes the LCI portion of this model very limited in respect to supporting applications to systems other than packaging.

**LCIA Calculation Method(s):** The impact assessment method partially follows SETAC guidelines for that portion that is based on equivalency conversions. There is no attempt to define the full range of classification factors that may be applicable to a given product or service system. Both the “critical volumes” approach, which relies on the computation of a dimensionless ratio of the inventory output divided by a regulatory standard, and the Eco-Points Method, which assigns environmental load points based on the relationship of a particular inventory parameter to a target, have been discussed in the LCA literature and considered in the SETAC LCIA framework development. However, the limited capability to compute critical volumes for the range of impacts now considered relevant to LCA and the specific constraint of the Eco-Points Method to Swiss or German conditions, particularly as implemented in this program, make it very limited for application elsewhere. (Note: A more flexible software package for implementing this method, from the standpoint of allowing greater user input of the system description, is available as the EcoPro model. However, the more fundamental problem of defining the appropriate algorithm for the calculation of the number of eco-points per functional unit of emission remains.)

**Output:** Both text and graphics output support are provided. The basic program menu screen is used to compile the results according to the comparison of alternatives desired. Up to five systems can be defined and the results presented at one time. The text output consists of a set of tables whose content consists of total system energy usage and aggregated critical volumes to air, water, landfill as well as the computed total eco-points. Actual inventory load values are not available. Numerical values for the output are provided as point estimates; no uncertainty information is given and any sensitivity analysis is done manually. Simple bar-chart graphics are available from the print menu. Printer support is minimal. Import or export of data or results files is not supported.

**COMPUTING:**

**User Support:** Not available in U.S.; customization and user support available through the author.

**Operating System:** DOS 3.2 or higher

**Hardware Requirements:** 286 processor, 640 K RAM, and 1 MB disk space, minimum.

**COMMERCIAL SPECIFICATIONS:**

**Price and Conditions:** Approximately \$5800

**Demo Availability:** Yes

**CUSTOMERS AND REVIEWS:**

**Number of Users:** More than 9

**Targeted Type of Users:** Non-expert users; the model generally very straightforward to operate.

**Published Reports:** SETAC LCA News, Vol 5, No. 2, March 1995.

**SOFTWARE:** GaBi

**VENDOR:**

**Company:** Institut für Kunststoffprüfung und Kunststoffkunde  
and, PE (address and phone/fax listed below)

**Address:** Product Engineering GmbH, Kelterstrasse 93, D-73265 Dettingen/Teck,  
Germany

**Contact:** unknown

**Phone:** +49 7021 942 660

**Fax:** +49 7021 942 661

**FEATURES:**

**Version:** 2.0

**System Type:** LCI and Impact Assessment model

**Data:** The database includes 800 different energy and material flows. Each flow belongs to a flow group which allows the user to develop a hierarchical system. For example: PP granules belong to the flow group *raw materials*; an aluminum fender belongs to the flow group *parts*; and CO<sub>2</sub> belongs to the flow group *emissions to air*. Ten generic process types which contain 400 specific industrial processes are also included in the database. The 10 process types include 1) industrial processes, 2) transportation, 3) mining, 4) power plants, 5) transformation processes, 6) servicing, 7) cleaning, 8) repairing, 9) wear, and 10) processes of reduced consumption. Flows are contained within these process types. Multi-functional dialogue boxes allow user to input and edit data and comments as desired (not clearly demonstrated). Besides common process data from around the world, the database consists of special data from IKP research and cooperation with industrial companies from different sectors in Germany. No indication of data quality was specified.

**User Interface:** Demonstration disc (non-interactive) is in English. A full version of the software is only available in German; an English version is expected out in mid-/late-1996. The user develops the product system for analysis through a graphical Plan window. Data editing and entry from this window is supported. Software offers on-line help, as well as image and text editing.

**LCI Calculation Method(s):** The modular design of the model distinguishes between six working areas: inventory (i.e., flows), scenarios, methods, balances, valuations, and general tools. Only the inventory area of the software, used to create the system under evaluation, was demonstrated (non-interactively). A system is developed using the graphic Plan window of the program. Sub-processes in a system can be developed on separate plans, saved, and later combined in the system plan. The software layers these connected plans and allows easy for easy transfer between layers.

Plans are developed by simply dragging and dropping industry types from the tool box displayed on the Plan window. Flows between industry types are created by dragging a line between them. Database parameters can be viewed for any industrial type from the Plan window. The use of text and image editors, though not demonstrated, allow the user to change plans and specify process data. The method of calculation was not demonstrated or explained within the demonstration material.

**LCIA Calculation Method(s):** The valuation area of the software allows the user to define the criteria of valuation. Monetary, technical, and ecological assessments are possible. Weighting keys for the valuation criteria allow the user to realize individual preferences. The non-interactive demonstration, however, did not allow this feature to be demonstrated or tested. Literature describing the software states, 'the standard LCIA method is subdivided into five steps: selection of the critical ecological fields; classification; determination of the impact assignments; standardization; and evaluation.' Ecological fields can be classified using indexes stored in the database (e.g., resource consumption, ozone depletion, release of toxic effective substances, acidification, etc.).

**Output:** Several balance sheets are available within the software, including energy, mass, and valued balances. Export of balance sheets to MS Excel applications is possible. From the non-interactive demonstration, it was apparent that calculation summary sheets can be customized. Graphical display of results was not explicitly discussed in the demo.

## **COMPUTING:**

**User Support:** Unknown

**Operating System:** DOS, MS Windows

**Hardware Requirements:** Unknown

## **COMMERCIAL SPECIFICATIONS:**

**Price and Conditions:** Approximately \$10,000 (14,000 DM)

**Demo Availability:** Only non-interactive demonstration disc with no manual

## **CUSTOMERS AND REVIEWS:**

**Number of Users:** Unknown

**Targeted Type of Users:** Experienced LCA practitioner; graphical interface and various analysis areas may lend themselves to a more novice user.

**Published Reports:** Unknown

**SOFTWARE:** KCL-ECO

**VENDOR:**

**Company:** Oy Keskuslaboratorio - Centrallaboratorium Ab (The Finnish Pulp and Paper Research Institute)

**Address:** Tekniikantie 2, P.O. Box 70, FIN-02150 Espoo, Otaniemi, Finland

**Contact:** Tiina Pajula

**Phone:** 358-9-43-711

**Fax:** 358-9-464-305

**FEATURES:**

**Version:** 1.0 for Windows

**System Type:** LCI

**Data:** KCL-ECO does not include data modules other than fictional ones used in demonstration flowsheets. KCL-ECODATA is a separate product containing modules based on Finnish and general European data related to the pulp and paper industry and its related services. There are free text fields available for documentation of information sources. However, one of the unusual features of this program is that the relationships among the inputs and outputs of a unit operation are determined by a set of linear equations together with the functional unit definition. Therefore, unlike the situation where input and output data quality become the sole basis for establishing the uncertainties, the uncertainty in an equation may be specified as a range. This range later can be incorporated into a formal sensitivity analysis. Based on a review of the data contained in the sample library, individual data set documentation appears to be minimal. Other than the range estimates other data quality attributes are not used.

To facilitate construction of complex systems, the process and conveyance modules from other libraries and other flow sheets may be cut and pasted into a scenario that is being developed. Upon clicking the “add from library” button, the user enters a dialog box to choose which modules are to be selected. After identifying the module(s), pushing the “use” button pastes them onto the flowsheet where the appropriate flow connections may be made.

**User Interface:** The KCL-ECO program takes advantage of the Windows graphical user interface. The placement on and positioning of modules within the work surface can be done via the usual “drag and drop” functions. Flow connections and other operations are controlled by selecting the item from the toolbar or from the pull down menus. Double clicking on a module box or flow connection opens a dialog box for definition/selection of input variables, output variables, and specification of linking equations. The screen presentation actually consists of two panes, one showing the flow diagram and one showing the results. As the calculations are performed, the results screen is updated so that it is possible to have intermediate results available before the entire system is defined.

**LCI Calculation Method(s):** The KCL-ECO program uses either a sequential or a sparse linear matrix equation solver (method not specified) to solve the set of derived equations describing the system. It is unclear how the LCI calculation treats over-determined systems (where the number of equations exceeds the number of variables) or how iteration to solve recycling loops is accomplished. As far as can be ascertained there is no need for a user specified tolerance to terminate calculations in iteratively solved equation sets, although more than one computational strategy is available. The default appears to be the sequential method. All of the details of the calculations at each stage are preserved in both the calculations and the reports. One could, for example, solve for just a subset of processes. The level of disaggregation is dependent entirely on how the user defined the equations. If the relationships were specified in highly aggregated terms, then the calculation would be on this basis. The only requirement is to have the requisite number of equations. The user determines their form and can have more than one way to specify a given system (which does not result in different answers).

The method for co-product allocation is not discussed in the user manual. In KCL-ECO version 1.0, the user is expected to perform co-product allocation when defining the equations of appropriate modules. The program does not track inherent energy separately from other energy flows. In fact, energy is only shown in the LCI summary in energy units when it is derived from electricity; other energy carriers are shown as the material quantities.

An unusual and highly desirable feature of KCL-ECO is the inclusion of an uncertainty propagation method in the basic computational engine. The user may select either a quick method in which the variables contributing the most to the flows are automatically selected or an exact method where the user can specify the variables, their statistical distribution (normal or uniform), and the uncertainty range. The Monte Carlo method is employed with a user specified number of cycles (2000 is the default).

**LCIA Calculation Method(s):** Not applicable

**Output:** The output from KCL-ECO is very detailed and arranged in a very logical manner. The report lists, by module, all of the inputs, outputs and governing equations along with the specified amounts. Any notes entered in the text file are printed at the top of each section. These details are followed by a summary results section for the system as a whole followed by a listing of all of the variable names, units, quantities and group designation, e.g. emissions to air. Finally, if a sensitivity analysis is performed a distribution along with descriptive statistics is provided. The flow diagram can also be printed. The report can be saved as a text file for later workup via a text processor. There is no apparent capability for graphical presentation of results.

## COMPUTING:

**User Support:** Because this model has been developed by an industry technical institute, it is unclear whether independent user support is available apart from the institute staff. The user manual is clearly written and the on-line help capability better than average. Most users should have minimal need for continuing off-line support.

**Operating System:** Windows 3.1 or later; DOS 5.0 or higher, Filemaker Pro needed to run database

**Hardware Requirements:** 486-SX Processor or better; 3 MB hard disk space; SVGA display.

#### **COMMERCIAL SPECIFICATIONS:**

**Price and Conditions:** KCL-ECO program \$3,600; KCL-ECODATA \$2,400; \$24 per custom module (1995 prices)

**Demo Availability:** Yes

#### **CUSTOMERS AND REVIEWS:**

**Number of Users:** As of August 1996: 50 within the Finnish forest industry; 20 external clients.

**Targeted Type of Users:** Research and environmental management staff within companies; independent research institutes; LCA practitioners.

**Published Reports:** None known

**SOFTWARE:** LCA Inventory Tool (LCAiT)

**VENDOR:**

**Company:** Chalmers Industriteknik  
**Address:** Chalmers Teknikpark, S-412 88 Göteborg, Sweden  
**Contact:** Lisa Person  
**Phone:** 46-31-772-4237  
**Fax:** 46-31-82-7421

**FEATURES:**

**Version:** 2.0

**System Type:** LCI with integral database and limited capability to apply valuation index factors to the raw inventory data.

**Data:** The program provides a limited database for energy carriers and production and for transportation modes. Complete cradle-to-gate life-cycles for a limited number of chemicals, plastics, pulp and paper products are also included. Additional data are available and the author's organization can create additional data sets. Data developed for one life-cycle scenario can be saved and imported into another analysis. Imported data can consist of a single process or transport card or an entire life-cycle. This latter situation may be useful if an improvement assessment consists of only limited substitution of new materials or processes compared to the baseline. The data documentation in the two supplied databases is contained in a notes box associated with each process and transport mode. The data provided are well documented as to the source and consist of a mix of primary information obtained during the LCA studies of the authors and secondary data from the general European data sets shared by most practitioners, e.g., the energy portion of the Boustead/PWMI plastics data and the BUWAL data. No North American data are presently resident in either data set.

There are no attempts to provide any quality assessment of the data. Data are in SI units and the program is sensitive to the mixing of units among processes.

**User Interface:** The program uses some of the graphical interface capabilities in Windows to facilitate setting up the flow diagram and defining the governing relationships. However, there are some limitations and not all of the features are implemented as intuitively as some of the other Windows-based LCA programs.

**LCI Calculation Method(s):** The program solves a set of linear equations based on the flow connections defined for each of the process and transport cards selected and on the definition of a special card that defines the reference flow (usually the functional unit.) For cards with multiple flows the user must specify the percentage of the total flow allocated to each flow. If this is not done correctly so that the totals balance, the program will not calculate the life-cycle. Also, not more than 16 material inflows can be specified for each process card. Although this

will not be a limitation in most cases, it is a potential problem for complicated processes. The program also has some limitations in dealing with the splitting of flows once they have been aggregated. For example, a series of materials comprising a package that are co-mingled at the consumer stage cannot easily be separated back into their individual entities for waste management and recycling. The program does maintain the separate calculation of the inherent and process energy components if the user has set up the description in this manner.

**LCIA Calculation Method(s):** Essentially not applicable although there is a capability to assign multipliers to selected emissions in order to create a relative weighting scale. So for example a factor of 10 could be assigned to methane to indicate its global warming potential per unit emission mass is 10 times that of carbon dioxide. Another way this could be used is to express relative importance of various emissions/categories relative to one another. Thus, if toxic chemicals were determined to be very important, all of the emissions could be factored by 100 to elevate their significant relative to more conventional material emissions.

**Output:** A variety of copying and printing options is available. The Windows copy capability allows cutting and pasting of the flow diagram into a text processor as a meta-file. The inventory summary graph may also be copied to a text processor. Export to other programs is also available via the "Export" command. Exportable information includes the entire active life cycle to a text file, a cross tabulated matrix showing the emissions and energies in the rows and the process and transport cards across the columns, or the inventory profile listing the energies and emissions into a tab-delimited file readable by LOTUS and Excel.

## **COMPUTING:**

**User Support:** User support is available from the authors who also can assist with data acquisition. The user's manual is also reasonably clear and easy to follow with simple examples to illustrate key features.

**Operating System:** DOS, Windows 3.1 or better, database runs on an internal platform not exportable

**Hardware Requirements:** 486 processor with 2 MB RAM and 2.5 MB hard drive space minimum.

## **COMMERCIAL SPECIFICATIONS:**

**Price and Conditions:** \$3,500 approximate 1995 price

**Demo Availability:** Yes

## **CUSTOMERS AND REVIEWS:**

**Number of Users:** Exact number unknown but is one of the more popular programs in Europe.

**Targeted Type of Users:** Program is straightforward enough to be used by non-expert users but a moderate level of understanding of materials and energy flow modeling would be helpful to understand some of the underlying assumptions and avoid the limitations.

**Published Reports:** SETAC LCA news, Vol. 3, No. 5 and Vol. 5, No. 4; also mentioned in several theses and other academic studies in Sweden. Used as part of a large eco-design project in Scandinavia.

**SOFTWARE:** Life Cycle Interactive Modeling System (LIMS)

**VENDOR:**

**Company:** Chem Systems, Inc.  
**Address:** 303 South Broadway, Tarrytown, NY 10591-5487  
**Contact:** Don F. Bari  
**Phone:** 914-631-2828  
**Fax:** 914-631-8851

**FEATURES:**

**Version:** Not specified

**System Type:** LCI for simple and multi component systems, assessment and economics.

**Data:** Presently contains over 1,000 modules (i.e., emission data files) representing raw material extraction, manufacturing, utility generation, transport, recycling, and waste disposal. Geographic coverage is primarily North America, with some European and Japanese data. Both SI and English units are available. The user has the option to input independent data or use the default modules. No explicit data quality indicators are used.

**User Interface:** Software and manual are in English

**LCI Calculation Method(s):** An assessment begins by the user defining a product or process of primary interests. LIMS then "automatically" creates the up-stream ("cradle") process and material pathways, and the down-stream ("grave") pathways (as interpreted from the non - interactive demonstration disc).

Modules are used to represent a step or series of steps in the product network. As each module is selected to create a system, the user is required to input factors which define how the inputs and energy/environmental burdens associated with the module should be allocated among the outputs of the module. Though flexibility was stated as a feature of LIMS within this allocation process, the various methods and how they apply were not clearly identified. After the modules have been completed, the "linking and solution" algorithm of the model links all modules through their inputs and outputs. This algorithm solves the overall network to provide the net resource and environmental burdens associated with the product network.

**LCIA Calculation Method(s):** LIMS translates the inventory data into assessment categories according to their environmental burden classification (e.g., global warming, ozone depletion, etc.). Where relative factors are available, each species in a category is converted to a common category basis. Assessment categories include, but are not limited to, acid rain precursors, global warming, bioaccumulation, VOC, etc. The default factors in the model can be replaced with user-defined values.

**Economic Calculation Method(s):** The demonstration software and literature did not clearly present the method by which LIMS translates environmental burdens to economic indicators.

**Outputs:** Graphic and database presentation of results is possible. The model can be used to determine the contribution of any module to the net burden. For the assessment of competing products, or of alternative process or recycling options, LIMS provides a “bullet” comparison, or weighted burden categories (“ ” ! ), to represent the impact assessment results. Up to four unique LCI cases can be compared (viewed) at one time. The user can also print tables or graphs in a Lotus format. Data and results export was not explicitly stated.

#### **COMPUTING:**

**User Support:** On a consultant basis for an annual fee.

**Operating System:** DOS, Windows 3.1+, and Lotus 5.0+

**Hardware Requirements:** IBM compatible 486/66, 8 MB RAM, and 12 MB of free hard disk capacity.

#### **COMMERCIAL SPECIFICATIONS:**

**Price and Conditions:** \$25,000 which includes 200 default database modules. Additional modules are \$2,000 each.

**Demo Availability:** Yes, non-interactive, no users’ manual provided.

#### **CUSTOMERS AND REVIEWS:**

**Number of Users:** Unknown

**Targeted Type of User:** Experienced LCA practitioner or novice with consulting assistance from Chem Systems, Inc.

**Published Reports:** Unknown

**SOFTWARE:** Pira Environmental Management System (PEMS)

**VENDOR:**

**Company:** Pira International  
**Address:** Randalls Road, Leatherhead, Surrey, KT 22 RU, United Kingdom  
**Contact:**Carolynn Ponsford  
**Phone:** 44 0 1372 802000  
**Fax:** 44 0 1372 802238

**FEATURES:**

**Version:** 3.1

**System Type:** LCI covering materials, transportation, energy, and waste management as well as LC impact assessment capabilities (problem or medium oriented).

**Data:** Full range of standard LCI analysis studies calculating Western European averages, and European site-specific data. Database is fully annotated with explanations of data sources and assumptions made to arrive at presented information. Included in the package are inventories for 109 materials, 49 energy sources, 16 transportation options, and 37 waste management options. Data included in PEMS Model cannot be changed/edited. User specified data entry is an option.

**User Interface:** Database and full/demo manual are in English. System management (development of flow schemes) is accomplished pictorially and in tabular form.

**LCI Calculation Method(s):** All data are calculated back to a functional unit (e.g., X pounds of detergent or so many gross of nails). The working template is a pictorial working sheet onto which processes are added by process blocks. With each process block comes burden information (not including closed loop materials/energy inputs or outputs) which is added to an underlying Excel spreadsheet which performs the calculations. Any number of energy and material inputs/outputs can be added to the template. Connections created between any series of blocks represent either energy or material flows; with each material flow the user is prompted to specify (if desired) transportation burdens. Distribution blocks can also be added to the system spreadsheet which allow the combination or splitting of multiple material streams. The allocation of emissions between co-products can be accomplished/determined through a variety of factors; avoided emissions system, allocation by weight, allocation by energy content, allocation by chemistry and allocation by economics are each explained within the manual. Distribution blocks offer the user the capability to choose between these options. A variety of options is also described and available for recycled and re-used material/energy streams. A mass balance for each process block is automatically performed.

**LCIA Calculation Method(s):** Two impact assessment calculation methods are available within the PEMS software: problem-oriented and media-oriented, critical-volume assessment methods. Problem-oriented impact assessment is accomplished through three steps. First, the inventory data are aggregated according to the relative contributions made to ten environmental concerns. Relative impacts to each environmental concern use factors obtained from a single documented source. Normalization represents the second step and relates the process emissions to world annual effect scores. Valuation represents the final assessment step and is used to calculate a single number for a product system. PEMS leaves the determination of weighting factors to the user in this valuation step.

Media-oriented, critical-volumes assessment calculations are also possible with this software. In this method, inventory data are aggregated into air, water or soil/land emissions. Once aggregated, regulatory standards are used to calculate the volumes of air and water that would be necessary to dilute the emissions to such an extent regulatory standards are met. Limit values are German/Swiss.

**Output:** Both tabular text and graphics outputs are possible. Summary reports present inventory data by combining similar columns (i.e., Entered Data, Linked Materials, Linked Energy, Transport, and Waste Management or other user defined categories). Standard templates (up to 25) can be used or edited for graphical output.

## **COMPUTING:**

**User Support:** Telephone hotline and PEMS Users Club.

**Operating System:** MS-DOS version 3.1 or higher, Windows 3.1 or higher, and Excel version 4 or 5.

**Hardware Requirements:** IBM 386 or higher, minimum of 4 MB of RAM if running Excel 4, or 6 MB of RAM if running Excel 5.

## **COMMERCIAL SPECIFICATIONS:**

**Price and Conditions:** \$9150 (£6000) for industry; \$4600 (£3000) for research and educational establishments; \$3800 (£2500) individual licence.

**Demo Availability:** Yes

## **CUSTOMERS AND REVIEWS:**

**Number of Users:** Unknown

**Targeted Type of User:** Graphic interface allows novice users to perform LCI analysis, yet

the system supports a complex system which could be developed by an experienced LCA practitioner.

**Published Reports:** Unknown

**SOFTWARE:** Product Improvement Analysis (PIA)

**VENDOR:**

**Company:** Instituut voor Toegepaste Milieu Economie (TME)  
**Distributor:** PRé Consultants  
**Address:** Grote Marktstraat 24, 2511 BJ 's-Gravenhage, The Netherlands  
**Contact:** Myriam van Niekirk (TME)  
**Phone:** 31-70-346-4422 (TME); 31-33-461-1046 (PRé)  
**Fax:** 31-70-362-3469 (TME); 31-33-465-2853 (PRé)

**FEATURES:**

**Version:** 1.2

**System Type:** LCI with the added ability to input “soft” inventory items such as thermal waste (heat), other residues (e.g., radiation), nuisances, resource scarcity, life time, and space occupancy. These latter fields could be used to track a limited “impact” issue list.

**Data:** There is an embedded data set with information of two types - Dutch data collected by the authors of the software or other Dutch consulting/research organizations and the BUWAL Swiss/European data set. Most of the data appear to be secondary, except for those obtained by the authors during their LCI studies. The data sources are generally well documented. Data and process documentation fields are provided for each data item and process.

**User Interface:** The user creates the system specification by identifying processes and operations and linking them. The linking is done by connecting the product of one process with the raw materials or ingredients of the next. Additional types of processes, each with unique characteristics, are provided for transportation operations, energy processes, and waste management. The system flow diagram can be displayed in pictorial form on the screen via the “tree” function and several options are available to control the complexity of what is shown. The normal mode displays all linked operations and provides full detail in the results matrix. The choices are “half-consolidated,” “consolidated,” and “stripped.” A half-consolidated process is one where all of the upstream entries have been collapsed into the process and the outputs represent the “rolled-up” sums of the process and its preceding steps in both the tree view and the results matrix. Half-consolidated processes can be toggled to normal status if the additional detail is desired. A consolidated process is similar except that the consolidation is permanent. Finally, the stripped process loses all of its links with the other processes. This mode is used primarily to export a process whose linked details are sensitive or to ensure that a subsequent user does not gain access to these details.

**LCI Calculation Method(s):** Once satisfied that the material balance for a process has been specified to an acceptable level (the program tracks this in the process summary sheet), the process may be saved as part of the database. The material balance calculations include a category of output termed “by-products.” Unlike “co-products,” by-products are not used in

another process nor do they carry shares of the allocated burdens. The user then defines the linkages among the system elements, either selecting from the process/transport/energy library (via a screen menu) or creating new application-specific items. When a link is established, the program performs a set of spreadsheet functions to allow the continuing expansion of the system until all links have been defined. The preferred means of creating the system definition is top down, i.e. A6B6C6D6E; limited capability is available for bottom up or random construction and problems with the calculations can occur if these modes are used without great care.

**LCIA Calculation Method(s):** Not applicable

**Output:** The output menu allows the presentation of results (including the tree view) selected by the user to the screen, to a printer, or to an ASCII file. The emissions matrix can also be exported via the creation of a DIF file to a spreadsheet. The content of the output is created by selecting the processes to be displayed and the individual data fields in a process. The table format is fixed. Various combinations of the processes and data fields can be specified and saved during a session as a “set” through a marking procedure that defines a grouping of processes and their associated data fields. These sets are not permanent. Once the user leaves the output menu, the defined sets are erased. The PIA program contains no graphical output capability. Additional presentation of graphical information and or the product tree will need to be done by post-processing the ASCII or DIF file.

## **COMPUTING:**

**User Support:** Available from PRÉ; no North American vendors or technical representatives are known.

**Operating System:** DOS, version 3.3 or higher; network compatible with Novell version 2.0 or higher, Windows

**Hardware Requirements:** 286 processor, 640 K RAM, and 1 MB hard drive space minimum; 486 processor preferred.

## **COMMERCIAL SPECIFICATIONS:**

**Price and Conditions:** \$1,400 (1994)

**Demo Availability:** Yes

## **CUSTOMERS AND REVIEWS:**

**Number of Users:** Unknown

**Targeted Type of Users:** The PIA program is simple enough that non-expert users can run it, although some of the data creation, display, and maintenance functions would be better served by an expert in an organization.

**Published Reports:** SETAC LCA News, Vol. 3, No. 5 and Vol. 5, No. 2.; also listed in the “LCA Sourcebook.”

**SOFTWARE:** Resource and Environmental Profile Analysis Query (REPAQ)

**VENDOR:**

**Company:** Franklin Associates, Ltd. (FAL)  
**Address:** 4121 W. 83rd St., Suite 108, Prairie Village, KS 66208  
**Contact:** Bruce Kusko  
**Phone:** 913-649-2225  
**Fax:** 913-649-6494

**FEATURES:**

**Version:** 1.0

**System Type:** LCI

**Data:** Selected data on packaging materials and configurations from the FAL LCI database have been inserted in the model. The data represent average U.S. conditions and include all the necessary modules from cradle-to-grave aggregated into the packaging system. The user cannot access the database directly and has no ability to extract materials or processes individually. The process data are a combination of primary and secondary data sources. The energy production, transportation, and raw materials extraction processes are exclusively secondary data while the intermediate materials and final packaging assembly processes combine some literature data with average process descriptions derived from FAL's application of LCI methodology to various packaging systems over a period of years. The embedded database size is not precisely known but at a minimum encompasses hundreds of individual processes for most common packaging materials.

**User Interface:** The user screens consist of a combination of menu bars and pop-up menus from which various functions may be accessed. The information fields required for definition of a complete packaging system are:

- C Package Name - allows both a specific name and selected characteristics to be attached to the name, e.g., bleach, 1 gal, 10%, indicating both the size and recycled content,
- C Description - allows a more complete specification of the system, including individual components and materials,
- C Basis - can be any meaningful quantity of the packaging system but usually is the functional unit,
- C Component Name - the description identifying the separate components of the package, e.g., PP cap,
- C Materials/Fabrication Method - the specification, provided in a pop-up menu of the category of material and the associated process, e.g., PL: HDPE blow-molded, where PL stands for plastic, MT for metal, and so on.
- C Weights - the exact amount of the component in pounds per basis unit; REPAQ does

- not perform this analysis automatically as do some other software packages. The user must calculate the specified amounts and pounds must be used, and
- C Recycle % - this field is used to insert specific information for either the post-consumer recovery rate or the recycled content (but generally not both); some error may be introduced by the assumption used to implement this feature for paper based systems and to a lesser extent plastic-based systems.

Additional user-specified materials and operations cannot be entered in REPAQ as leased; FAL can provide additional or custom data augmentation.

**LCI Calculation Method(s):** The basic computational process used by REPAQ starts with the development of modules for each of the relevant operations that make up the package system. A materials balance is constructed for some arbitrary but convenient unit of product output, say 1000 lbs, and all inputs and other outputs are scaled accordingly. Energy requirements for each module are determined in terms of either fuels entering directly into the operation or indirectly via energy in the form of steam or electricity. A set of flow sheets describing the interconnection of all of the cradle-to-grave processes is prepared for each material. Then, given the user-specified basis, the calculated amounts of each material, and working backwards from the final package, the proportionate energy and emissions are computed for the system. Credits are given for recycling in proportion to the displacement of virgin materials and for post-consumer energy recovery in proportion to the heating values of the materials and typical combustion efficiencies/heat recoveries in municipal incinerators.

As is typical with FAL LCI's they apply a consistent set of assumptions to their calculations even though some of these may differ from typical international practice. Some of the potentially more consequential ones include:

**Energy of Material Resource:** The fuel equivalent of input raw materials traditionally used as fuels in the U.S. is recorded as energy consumption to the system. Furthermore, FAL does not compute fuel equivalent values for raw materials not used as fuels. In the case of packaging this predominantly affects wood used for corrugated, paperboard, and paper.

**Co-Product Allocation:** FAL considers two categories of output co-products: 1) situations where the items to be allocated consist of the product of interest and one or more co-products independent economic viability, 2) situations where the primary product is the reason that the process exists and where the co-products are given away or have marginal value. Little or no co-product allocation is done in the latter case. Examples of this situation are mine tailings or power plant ash used for road building and animal manures used for farm field application as soil supplements.

**Insignificant System Components:** Contributions from capital equipment, space conditioning, support personnel requirements, e.g. R&D, sales, and administrative activities, and miscellaneous materials and additives (in total <1 percent of net inputs) are excluded.

**LCIA Calculation Method(s):** Not applicable

**Output:** Both tabular and graphical output are available. About a dozen different report content items can be chosen depending on the application. These may be compared for up to 5 different layouts (systems) at once:

- C Atmospheric Emissions by Component/Layout - shows both the individual component and total system values for that component or layout which generates the maximum of that pollutant; FAL's methodology does not allow the reader access to any individual steps in the life-cycle; emission parameters are limited to a few of the more common ones available from the literature or from regulatory monitoring programs,
- C Atmospheric Emissions by Pollutant - lists each atmospheric pollutant by each component or layout,
- C Energy Profile - reports in millions of BTU the fuels consumed for each component or layout without credit for energy recovery in post-consumer waste-to-energy systems,
- C Energy Usage by Category - shows the net energy (with recovery credit) for each component/layout but broken out by material resource (feed stock energy contained in the material, e.g. natural gas energy in polyethylene, and process and transportation energy contributions,
- C Energy Usage by Category/Graph - presents a bar chart of the data from the previous report,
- C Solid Waste Generation - summarizes the amounts of solid waste by weight and volume broken out by categories of process waste, fuel-related waste, and post-consumer waste for each component and layout,
- C Solid Waste Generation - Weight or Volume/Graph - presents the weight or volume data for solid waste in bar graph format,
- C Summary of Energy Usage and Solid Waste - presents two data sets in one table,
- C Waterborne Emissions by Component/Layout - similar to atmospheric emissions table, and
- C Waterborne Emissions by Pollutant - similar to corresponding atmospheric emissions table.

Reports may be output to any of three devices - the screen, a printer, or an ASCII file. From the ASCII file additional post-processing may be done.

## **COMPUTING:**

**User Support:** Available through FAL; limited training and consulting provided with lease.

**Operating System:** Paradox database, runtime version. DOS

**Hardware Requirements:** 386/486 processor with 4 MB RAM recommended; 3 to 5 MB hard drive space required depending on need for separate installation of runtime version of Paradox.

**COMMERCIAL SPECIFICATIONS:**

**Price and Conditions:** \$10,000 for first year lease; negotiable for subsequent years.

**Demo Availability:** Demo discs and manual

**CUSTOMERS AND REVIEWS:**

**Number of Users:** Unknown

**Targeted Type of Users:** Non-expert users in the packaging engineering or design departments of industrial companies.

**Published Reports:** SETAC News, Vol. 2, No. 4; Vol 3, No. 5; Vol. 3, No. 6, and Vol. 5, No. 2.; also used as part of the SETAC LCA short course in 1994.

**SOFTWARE:** SimaPro

**VENDOR:**

**Company:** PRé Consultants  
**Address:** Bergstraat 6, 3811 NH Amersfoort, The Netherlands  
**Contact:** Mark Goedekoop  
**Phone:** 31-33-461-1046  
**Fax:** 31-33-465-2853

**FEATURES:**

**Version:** 3.1S

**System Type:** Full LCA with multiple methods for impact assessment

**Data:** The SimaPro database is one of the more comprehensive ones. Compared with those supplied in other LCA software packages, the database on processes for production of commodity materials is more comprehensive and includes a greater variety of processes associated with non-packaging related materials. All of the embedded data are fully referenced as to their source and there are limited qualitative descriptions of data sets that are considered to be old or weak. No other formal data quality assessment procedures are used. All of the data (with a very few minor exceptions) are for European or more specifically Dutch conditions. The data are primarily secondary in nature, especially those for general European conditions, but there is a significant amount of data from specific LCA studies conducted by the authors.

**User Interface:** The developers of SimaPro have done a remarkable job of emulating a graphical user interface in a DOS-based product. The features of the interface include pull-down menus, mouse support, and point and click activation of many of the features. Although the screen displays are not as smooth or polished as those in a true graphical user interface environment, most users will not find the difference to be overwhelming. All of the on-screen information as well as the user manual are in English.

**LCI Calculation (Method(s)):** The user sets up a system by describing the sequence of operations involved in making, using, and disposing/recycling via a set of dialog sheets selected via the menu. The extensive substance and process library means it is likely that typical users will be able to construct many life-cycles without extensive input of new data. The data are kept disaggregated by parameters during the inventory calculations and not aggregated until the impact assessment.

**LCIA Calculation Method(s):** The impact assessment component of SimaPro consists of a set of buttons designated as “characterization,” “normalization,” and “valuation” to correspond to the current SETAC nomenclature for LCIA. The program accumulates the inventory data into 11 classes of impact issues ranging from global ones, such as ozone depletion, to local

ones, such as heavy metals. The characterization method is not discussed in detail in the limited on-line help capability, but based on discussions with Dutch LCA practitioners, probably consists of equivalency factors for each of the inventory compounds/materials. Some of the equivalency conversions used are not universally agreed upon; however, there is no international standard to provide a basis for judgement either. The normalization method is based on the Dutch Eco-indicators approach in which a defined target for environmental quality has been defined and agreed to by various groups in The Netherlands. Relevancy of the regional or local indicators to conditions outside of the Netherlands is debatable. The indicators are used to compare the particular system under study to the target. The further removed from the target the overall environmental performance and the greater the contribution from the studied system, the higher the normalization value for a given environmental issue. A valuation capability to compare across impact categories thereby deriving a single value from the LCA is also included, however, the method of determination of the weights is not discussed in the on-line help. Because the user manual available is somewhat old, any comments about this portion of the LCIA should be deferred.

**Output:** SimaPro provides both textual and graphical output. The user can toggle between the two modes to decide how best to view the data. In the text mode output is presented for each of the steps from inventory to valuation. In the graphical mode two views are possible. One shows the results of the calculations as a bar chart according to the data or impact categories. The other view, which shows the flow diagram, contains a feature which is unique to SimaPro. In this mode the program inserts a small bar on the right of each process or transport box to illustrate the contribution of that part to the overall system or some subset. Depending on which output item is selected, this is either the inventory loading, the raw impact equivalencies, or the aggregated impact information.

## COMPUTING:

**User Support:** User support is available through PRé Consultancy. The user manual available at present is an older one and may not be representative of current offerings. It covers most topics in a non-detailed fashion but the content and the writing could be better. Unfortunately the on-line help is limited so that users will likely turn to the manual more than otherwise might be the case.

**Operating System:** DOS 5.0 or higher

**Hardware Requirements:** 386 or better microprocessor; RAM and hard disc requirements unknown at this time.

## COMMERCIAL SPECIFICATIONS:

**Price and Conditions:** \$3,000 (approximate price for single user analyst version)

**Demo Availability:** Yes

**CUSTOMERS AND REVIEWS:**

**Number of Users:** Exact number is unknown but believed to be at least a hundred at present.

**Targeted Type of Users:** Two versions are available: an “analyst” version directed at expert users and LCA practitioners and a less detailed and sophisticated “designer” version developed for use by product designers and engineers

**Published Reports:** SETAC LCA News, Vol. 1, No. 5; Vol. 2, Nos. 3 and 4; Vol. 3, No. 5; Vol 5, No. 2: also listed in the “LCA Sourcebook.”

**SOFTWARE:** TEAM™

**VENDOR:**

**Company:** Ecobalance, Inc. (Member of the Ecobilan Group of Companies)

**Address:** 15204 Omega Drive, Suite 220, Rockville, MD 20850

**Contact:** Remi Coulon

**Phone:** (301) 548-1750

**Fax:** (301) 548-1760

**FEATURES:**

**Version:** 1.15 (Windows 3.1, 3.11, and 95) and 2.0 (Windows 95 and NT)

**System Type:** LCI and costing module

**Data:** Model contains ten categories within which are contained 216 individual data files for product and material production, energy generation and transportation. The ten categories are as follows: 1) pulp and paper; 2) petrochemicals and plastics; 3) inorganic chemicals; 4) steel; 5) aluminum; 6) other metals; 7) glass; 8) energy conversion; 9) transportation; and 10) waste management. Within the full program the source of data is indicated; data quality indicators (i.e., geographical representation technology used and date of data) are available. Further data quality indicators are not discussed. User defined input data fields, as well as database editing, are fully supported by the system. Units are defined by the user and can be in any system (e.g., metric).

**User Interface:** Manual and software are in English. Process systems are developed through a series of menus which prompt the user to specify unit operations and links. No graphical development of a system is supported in TEAM™ 1.15 (supported in TEAM™ 2.0 only)

**LCI Calculation Method(s):** Two levels are used in TEAM™, the database level and the calculation level. Within the database level, information representing unit operations (processes, transport etc.) are stored in independent Modules. In the calculations level the system is developed into which flow the Modules data. Within the system, nodes represent process steps. Nodes can be linked and grouped to represent subsystems, and subsystems can be linked to create the total system. Closed loop and recycling inputs/outputs can be defined within a node by the user. Formulas from the package or created by the user can calculate various inputs and outputs within the system. This use of formulas and variables allows the development of a dynamic system which facilitates sensitivity analyst. There is no limit to the number of nodes and linkages possible within TEAM™.

**Outputs:** The output of the inventory is displayed in tabular form thru an "Ecoview." Articles, defined by the user, represent parameters of interest for output from the system. Templates, also defined by the user, represent the format by which the articles are presented in the Ecoview. Thus, the Ecoview is completely defined by the user. No graphical output is

explicitly stated. Inventory results from a system can be exported and saved as the input for subsequent systems.

## **COMPUTING:**

**User Support:** On line help; consultant available.

**Operating System:** IBM-PC compatible, Windows 3.11, Windows for Workgroups 3.11, or Windows 95 (TEAM™ 1.15); Windows 95 or Windows NT (TEAM™ 2.0)

**Hardware:** 486/33 MHz processor, 8 MB RAM and 10 MB free on hard disk

## **COMMERCIAL SPECIFICATIONS:**

**Price and Conditions:** \$10,000

**Demo Availability:** Unknown

## **CUSTOMERS AND REVIEWS:**

**Number of Users:** 30 licensees worldwide

**Targeted Type of User:** Expert LCA practitioner; Ecobalance typically serves as consultant to establish LCA.

### **Published Reports:**

"Some Requirements of an Interactive Software Tool for Life Cycle Analysis," Journal of Cleaner Production, Volume 1 Number 3-4, September-December 1993.

SETAC LCA News, Volume 4 Number 4, July 1994.

Environmental Software Report, July/August 1995.

**SOFTWARE:** Total Emission Model for Integrated Systems (TEMIS)

**VENDOR:**

**Company:** Oko-Institut  
**Address:** Binzengrun 34a, 79114 Freiburg, Germany  
**Contact:** Uwe Fritsche  
**Phone:** 49-761-473130  
**Fax:** 49-761-475437

**FEATURES:**

**Version:** 2.0

**System Type:** LCI with some equivalency based impact characterization conversions, e.g., greenhouse gases; also provides for monetary pricing of external costs of air pollutants and greenhouse gases based on either damage costs (user specific) or control costs (default); can handle non-quantitative impact assessment of eco-impacts, solid wastes, and land use via a valuation procedure based on the “relative significance” of each resource.

**Data:** includes extensive data modules for energy carriers, production and transportation. Some data are included for process operations and commodity materials manufacturing. Data are in SI units, selectively adjustable by the user. Most of the data are believed to be secondary except for some German specific data on local energy systems collected by the authors. Documentation data fields are provided in the model and the source of data is documented. No explicit data quality indicators are used.

**User Interface:** The current version of TEMIS is in English. The user manual has also been translated to English, however, the detailed documentation of the methods and database work up are in German.

**LCI Calculation Method(s):** The topmost analysis unit is the scenario. A scenario is created by linking of one or more segments and/or processes. The linking is based on the functional unit representation and the specified inputs and outputs. A segment is defined as an aggregation of unit processes. Loops are solved via a mathematical recursion process comparing the incremental change in a subsequent solution to a user-selectable delta.

**LCIA Calculation Method(s):** The impact assessment method partially follows SETAC guidelines for that portion that is based on equivalency conversions. There is no attempt to define the full range of classification factors that may be applicable to a given product or service system, although the user could group or perform some of these operations with the output information. The external cost calculation routine represents one type of valuation procedure that has been identified in the LCA literature and implicitly in the SETAC guidelines but is not explicitly incorporated in either.

**Output:** Both text and graphics output support are provided. The scenarios menu is used to compile the results according to the comparison of alternatives desired. Up to 20 scenarios can be loaded at one time. The text output consists of a set of tables whose content is determined via the user selected choices from a menu. The choices include total system and local/global splits of energy usage and emissions. Emission groups can be further selected from several choices: total air emissions, detailed air emissions, land use and solids, greenhouse gases, user-defined emissions, and user-defined residuals. Emissions are presented by individual parameter, e.g. SO<sub>2</sub>. Resources are shown as primary energy, primary materials, and secondary materials. Qualitative impact factors are output in a table with minus and plus signs to indicate the relative intensity. Numerical values are provided as point estimates; no uncertainty information is given and sensitivity analysis is done manually. Simple bar-chart graphics are available from the scenarios menu.

A documentation feature allows creation of an ASCII text file to describe scenarios and to output data to a text processor. Tables are stored in tab-delimited format for import into spreadsheets or graphics packages. Import-export from/to dBase files is also supported through field name and characteristic matching.

## **COMPUTING:**

**User Support:** Not available in U.S.; customization and user support available through the Oko-Institute.

**Operating System:** DOS 3.0 or higher

**Hardware Requirements:** 286 processor, 2 MB RAM, and 2 MB disk space, and DOS minimum; 486-DX or higher performance processor preferred; supports up to 16 MB of extended RAM.

## **COMMERCIAL SPECIFICATIONS:**

**Price and Conditions:** Unknown at this time

**Demo Availability:** Yes

## **CUSTOMERS AND REVIEWS:**

**Number of Users:** Unknown at present

**Targeted Type of Users:** Expert users in general although model is generally straightforward to operate.

**Published Reports:** Numerous application reports including in the USA --

Hohmyer, O. and Ottinger, R, "External environmental costs of electric power - analysis and internalization," Berlin, 1991.

Ottinger, R. et al., "Environmental costs of electricity," report for the NYSERDA, Oceana Publ., 1990.