Lifecycle Assessment (LCA) White Paper

International SEMATECH
Technology Transfer #02014238A-TR

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Abstract: This white paper summarizes current lifecycle assessment (LCA) tools being used and being developed to identify further needs for additional efforts. An LCA assesses the environment, safety, and health (ESH) burdens of a product or process beginning with the extraction of raw materials, material manufacturing, then product manufacturing, use, and disposal. This report includes a review of related International SEMATECH (ISMT) and industry project results, including CARRI, ESH Cost of Ownership (COO)/Return on Investment (ROI), and the S70 Design for ESH (DFESH) Mass and Energy Balance model, Applied Materials' Environmental Values Systems (EnV-S), and Agere Systems' Target Method; and a literature search of documented case studies and commercially available software packages applied in the case studies.

Keywords: Applications Programs, CARRI, Cost of Ownership, Equipment Development Lifecycle Design for ESH, Lifecycle Assessment

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Acronyms

Chemical Engineering	ChemE
Civil Engineering	CE
Cost of Ownership	COO
Design for Environment	DFE
Design for Environment, Safety, and Health	DFESH
End of Life	EOL
Environmental Engineering	EnvE
Environmental Value	EnV
Environmental Value Systems	EnV-S
Environment, Health, and Safety	EHS
Environment, Safety, and Health	ESH
Industrial Engineering	IE
Institute of Electrical and Electronics Engineers, Inc.	IEEE
Integrated Circuits, Semiconductors	ICs
International Organization for Standardization	ISO
Lifecycle Assessment	LCA
Lifecycle Inventory	LCI
Mechanical Engineering	ME
Pollution Prevention	PP
Return on Investment	ROI
Volatile Organic Compounds	VOCs

1 EXECUTIVE SUMMARY

While there is an increasing interest among member companies to use lifecycle assessment (LCA) as a tool to communicate and evaluate its environmental impact on product or processes, there are also concerns about conducting LCA activities. For example, it is generally very time-consuming and costly. Given the quickly changing nature of technologies and processes in the semiconductor industry, LCA results might not be timely enough to help improvement. It also requires a lot of data collection. This white paper is meant to gather the information about integrated circuit (IC)-related LCA activities completed or under development. The information will be used to help define the tasks of LCA projects starting in 2002.

The Internet was the primary tool used for the literature search. It showed that the IEEE published many LCA-related papers relevant to many different industries. Only a few (less than ten) are integrated circuit-related case studies. For example, Motorola Advanced Technology Center - Europe and Motorola Semiconductor Products Sector, in cooperation with Fraunhofer IZM, conducted a Lifecycle Inventory (LCI) study for semiconductor manufacturing [1]. STMicroelectronics and Telecom Italia S.p.a. published the LCA of an IC product [2]. Agere Systems (formerly Lucent Technologies) has been developing a universal environmental metrics called “Target Method” [3, 4].

After reviewing CARRI [5], the environment, safety, and health (ESH) Cost of Ownership (COO)/Return on Investment (ROI) model [6–8], S70 Design for ESH (DFESH) Mass and Energy Balance model [9–11] and Applied Materials’ EnV-S [12–16], it was found that S70 and EnV-S could be helpful in developing a tool-centric (or generic use-cluster) inventory.

2 INTRODUCTION

LCA typically takes a cradle-to-grave approach. A full LCA consists of three stages: the lifecycle inventory (data collection), the impact assessment, and the interpretation of results (also called “improvements”). A full LCA boundary assesses the ESH burdens of a product or process beginning with the extraction of raw materials, material manufacturing, then product manufacturing, use, and disposal. A modified LCA boundary could assess the ESH impacts of the manufacturing process. It should be noted that in most cases a modified LCA approach is the most practical because nearly all of the ESH impacts lie with the processing and not with the processed wafer itself. A modified LCA could be a gate-to-gate approach. When Tokyo Electron, Ltd. (TEL) conducted an LCA of their tools, the results showed that more than 95% of the impacts are with the use of the tools. Since there is no fixed definition, an LCA can mean different things. There is no standardized methodology for collecting lifecycle inventory data or for conducting lifecycle impact assessments on semiconductor devices.

The goal of the *International Technology Roadmap for Semiconductors* (ITRS) is to establish a full LCA methodology for the semiconductor industry by 2006. One of the major difficulties with conducting a LCA is data collection for the lifecycle inventory. Huge amounts of data have to be collected that are not readily available to the member companies (such as confidential lifecycle data on manufacturing chemicals and materials supplied to semiconductor manufacturers). The impact assessment and interpretation of environmental impact data always contain a subjective element and therefore is difficult to standardize. Standardization of the data collection process would be a good starting point to enable the industry to conduct LCAs. This could be of great help to the member companies if there were an industry-wide accepted inventory and impact assessment methodology.

3 SCOPE OF THIS WHITE PAPER

The scope includes a review of related International SEMATECH (ISMT) and industry project results, including CARRI (Technology Transfer # 95052843C-ENG), ESH COO/ROI (Technology Transfers #97093350A-ENG, #97093349A-ENG, and #95072888B-ENG), and the S70 DFESH Mass and Energy Balance model (Technology Transfers #97013230A-XFR, #97063294A-XFR, and #97063293A-ENG), Applied Materials' environmental values systems (EnV-S), and Agere Systems target method, and a literature search of documented case studies and commercially available software packages applied in the case studies.

4 REVIEW OF RELATED ISMT AND INDUSTRY PROJECTS

Three ISMT-related projects were reviewed: CARRI, the ESH cost model, and the S70 DFESH Mass and Energy Balance model. The S70 model was found to be more related to future LCA projects. It has been designed as a tool for engineers to evaluate the mass and energy consumed, transformed, and discharged as waste from their factories. S70 has 57 operation units (e.g., immersion etch, chemical vapor deposition [CVD], chemical mechanical polishing [CMP], diffusion) in the database. The input data are the process information of each unit operation. The output results are air emission and waste discharge of chemicals. S70 intended to develop software to run the model, but insufficient funds prevented this. Therefore, the Excel spreadsheet is not very user-friendly. Comprehensive algorithm and test spreadsheets were developed for each unit operation (Technology Transfer #97013230A-XFR). S70 is very similar to Applied Materials' Env-S. Applied Materials and the University of California-Berkeley (UC) reviewed S70 and commented that the primary drawback is that process links were not strong. Also, the EnV-S is a more predictive model and has stronger links with process sequences.

Neither CARRI nor the ESH cost model pertain to future LCA projects. CARRI is designed to evaluate the relative risks of chemical usage by assessing both the inherent hazard properties of the chemicals and the potential for exposure to them. To do this, CARRI uses the characteristics of the chemicals and processes in its database. The weighting factors are used to assign the relative importance of each impact group, i.e., worker health, worker safety, general public health, environmental, regulatory, and cost of ownership. The primary criticism of CARRI is that it relies on the database to evaluate risks; therefore, it cannot evaluate new chemicals that are not in the database. It takes long time to gather the information about new chemicals to be put in the database. By the time all related information is collected and integrated in the database, the choice of which chemical or process to use has already been made. The ESH cost model is a financial software model that profiles the cost impact and profitability potential of ESH activities. It is designed to account for activities that drive ESH costs, estimate their financial impact, and allocate the costs to the manufacturing process responsible for their generation. The model calculates the incremental cost difference between alternative process change options, after-tax cash flows, and net present value. The cost model addresses the following phases in the process lifecycle: upfront, acquisition, use/disposal, post-disposal, closure, and incidents. Many of the cost items in the model depend on ESH and process support "staff labor rates" and on estimated production volumes. Since it is difficult to allocate staff labor to existing processes and alternative processes, it is not very practical to use this model to get meaningful incremental differences.

Applied Materials, in cooperation with UC Berkley, has been developing a design tool for semiconductor process tools called The Environmental Value Systems (EnV-S) Analysis. EnV-S allows users to characterize cost, process performance, and ESH impacts of manufacturing

process sequences. The case studies of a) process selection for CMP effluent treatment and water recycling, b) the Centura and Producer platforms, and c) plasma enhanced (PE)CVD chamber cleaning of C_2F_6 versus NF_3 have been published. Applied Materials has indicated that EnV-S helps tool users estimate ESH aspects like air emission, wastewater discharge, etc., without actual measurement. It can be very helpful to the Tool ESH Metrics project and the development of more tool-centric lifecycle inventory. It is recommended that a more in-depth understanding of Env-S be undertaken in 2002.

Agere Systems has been developing a method to evaluate the environmental aspects of commercial and industrial activities in relation to the earth's "carrying capacity." This "target" method evaluates the sustainability of products and services based on their relationship to the carrying capacity of the environment. It also links the economic contribution of a business (e.g., percentage of gross domestic product (GDP) with its effect on carrying capacity. Agere is working with New Jersey Institute of Technology (NJIT) on defining carrying capacities. Agere has also taken this target method externally and have received positive responses from organizations dedicated to the development of LCA methodologies. It is recommended that this method be introduced to member companies and be considered as a candidate method for assessing environmental impact.

If LCA is to be used to provide timely information (e.g., as a tool to predict environmental impact of existing and future processes), it might require development of a more tool-centric (or process-centric or generic use-cluster) type of inventory. Three parties have conducted these types of efforts:

1. Motorola Advanced Technology Center – Europe and Motorola Semiconductor Products Sector, in cooperation with Fraunhofer IZM, conducted an LCI study for semiconductor manufacturing. [(1)]
2. University of Texas is funded by the National Science Foundation (NSF)/Environmental Protection Agency (EPA) to conduct a project, Development of Lifecycle Inventory Modules for Semiconductor Processing, from 2000 to 2003. This project was supported by ISMT and Motorola in 1999.
3. Applied Materials in cooperation with UC Berkley has been developing a design tool for semiconductor process tools called the Environmental Value Systems (EnV-S) Analysis. EnV-S allows tools users to characterize cost, process performance, and ESH impacts of manufacturing process sequences.

5 SUMMARY OF LITERATURE SEARCH

During the search, it was apparent that a considerable amount of work has been done in LCA, however not in relation to the semiconductor industry. To help establish a methodology for LCA and to get some ideas, examining LCA in the electronics sector proved to be valuable. Companies are definitely looking at ways to improve the environmental burdens of their products, and performing LCA is a useful tool to support this goal. However, it is difficult for companies to perform an LCA because of time and financial constraints. A full LCA can take several years and cost a substantial amount of money.

Several valuable information sources were found. Past work on the development of a methodology for LCA can be found through conference proceedings at IEEE. It is also important to realize that homepages of several companies did not show any information about LCA. However, when the companies were contacted personally, they indeed were very involved with

LCA. It is important to use several different sources and means for finding out the necessary information.

Several articles found on the Internet allowed a table of case studies to be constructed. The table lists the product, company performing or involved in the case study, the items included in the LCA study, the lifecycle phases and focus areas, the method and/or software implemented, the year in which the LCA was performed, and any comments. See Table 1 in Appendix A.

The case studies of importance to this report are those on ICs. Five such case studies were found. Two discuss the development of EnV and Env-S, which are discussed in Section 4; the remaining three will be discussed following.

5.1 Case Study One

The first case study involved a lifecycle inventory analysis of an IC by Motorola and Fraunhofer IZM [1]. The focus was to generate a complete mass and energy data set and to identify the environmentally significant areas in IC manufacturing. The consumption of energy, raw water, chemicals, and gases and the origin of water, wastewater, and emissions were considered. The use clusters were divided into the infrastructure and the fab process modules. The infrastructure use clusters include make-up air, recirculating air, ultrapure water, process cooling water, compressed dry air, central plant, exhaust, and wastewater treatment. The fab process modules are patterning/photoresist, thermal, thin film (epitaxy), dry etch, ion implantation, wafer cleaning (wet benches), and back-end (CMP). The functional unit was wafer area times average number of mask layers. Basic questionnaires were used to collect the basic technical data such as wafer geometry, wafer starts, and yields. Detailed questionnaires were used to collect data for certain data categories for all processes and material and energy flow data for a certain process module. If no data were available, an educated guess by experts was used. The data were divided into roughly 70 material and energy categories and presented for one year.

The environmentally significant areas were identified throughout the infrastructure and fab. The cooling water supply, recirculating air, and make-up air are the most energy-consuming processes in the infrastructure. The thin films and dry etch modules are the most energy-consuming fab processes. The most raw water used and wastewater generated are by the ultrapure water supply in the infrastructure and by the wafer cleaning/wet benches module in the fab. The main consumer of organic chemicals is patterning/photoresist, while wafer cleaning/wet benches are the main consumers of inorganic chemicals. The thermal, thin films, and ion implant processes use the most highly toxic and corrosive gases. Acidic and volatile organic compound (VOC) emissions are from thin film and patterning/photoresist, respectively. The most waste generation comes from the wafer cleaning/wet benches processes due to the origin of sludge.

The environmental impact assessment was done using ProTox and GaBi 3.2. ProTox is a process toxicity screening software developed by Fraunhofer IZM. It is based on hazardous Substances Declaration (R-values), Allowable Workplace Concentration (MAK), and the Water Pollution Classification (WGK), derived from German and international legislation. For each substance, a single value, the Toxic Potential Indicator (TPI per mg), is generated. Sulfuric acid was identified to be the most critical chemical followed by hydrofluoric acid. The wafer cleaning/wet benches were identified to be the most environmentally significant aspect because of their toxicity potential. The impact categories for this case study were Global Warming Potential (GWP), Acidification Potential (AP), Photochemical Oxidant Creation Potential (POCP), Human Toxicity Potential (HT), Ecotoxicity Potential into air (ETair), and Ecotoxicity Potential into water (ETwater). The impact assessment was carried out using GaBi 3.2. Energy (electricity and

natural gas) and nitrogen have the highest impact in all categories except for POCP where fab emissions have the highest impact. The high impact of the emissions from the fab comes from the VOC emissions into the air.

5.2 Case Study Two

The next case study relevant to ICs was an LCA performed by STMicroelectronics, Telecom Italia Lab, and Politecnico di Torino [2]. An E-PROM IC was chosen as the device for this analysis. The data inventory was obtained from detailed technological analysis, information obtained directly from material suppliers, and a commercial database. The study was done according to ISO 14040 and ISO 14041. The input material was a Czochralsky growth (CZ) pre-epitaxial silicon wafer with a 6-inch diameter. The output was the complete EPROM device. The complete process required 21 masking steps, two levels of metallization, and roughly 180 single technological steps. The functional unit was different for the front-end and the back-end. For the front-end, a single silicon wafer processed to obtain the EPROM chips was used; for the back-end, a single EPROM device. The use clusters were divided up into front-end (oxidation, masking, etching, doping, dielectric deposition, metallization, passivation, electrical test); transport; and back-end (cut, welding base, bounding, packaging, electrolytic tinning, surface clipping, insert on tube). A subset of more than 400 materials was used. Several databases had to be used since there is not one database available that is specific to the electronic industrial sector. The databases used were TEAM, Boustead Model, EIME, and several ad hoc LCA “modules.” The CML approach to impact assessment used the global warming, stratospheric O_3 depletion, acidification, and nutrient enrichment categories. Water is the most raw material consumed. The highest environmental impact related to materials is in the back-end phase, while electrical energy consumption is largest in the use phase.

5.3 Case Study Three

The last case study is a comparison of LCA for silicon and gallium arsenide transistors by Chalmers University of Technology, Gothenburg [19]. Note that this case study was done for educational purposes and that a lot of the data was estimated. The total environmental load was evaluated with the Swedish Environmental Priority Systems (EPS) in Product Design. The environmental impact multiplied by the environmental index gave the relative environmental load. One environmental load unit (ELU) is the society’s will to prevent or restore a negative environmental impact. The lifecycle of the transistor included extracting the raw material and making the semi-product, producing the transistor, applying or using the transistor, and finally handling the waste. The main environmental loads are from the application (customer use) of the transistors. The other majority of the environmental load comes from the production of the transistor. The functional unit was a wafer that contained 1,000 discrete transistors. Different use clusters were used for the transistors. The use clusters for the silicon transistor were production of silicon wafers, production of silicon transistor (oxidation, etching, doping, photolithography), encapsulation of the transistor, application, waste, and deposition to a landfill. The use clusters for the gallium arsenide transistor were arsenic and gallium extraction, production of gallium arsenide wafer, production of gallium arsenide transistor (epitaxial, etching, photolithography), encapsulation of transistor, application, and waste disposal.

It was determined that for manufacturing the wafers energy consumption was the main impact for silicon wafers, while the use of arsenic is the main impact for gallium arsenide wafers. The environmental impact is much more significant for the gallium arsenide wafer. The main contribution to the environmental impact in the manufacturing of the transistor is the energy

consumption. The encapsulation and transportation impacts were deemed insignificant compared to the other processes. Energy consumption during the application phase is the most dominant impact of all processes. The impact of the gallium arsenide transistor impact is less than the silicon transistor. When comparing all processes, the gallium arsenide transistors have a larger environmental load because of the complex manufacturing process and hazardous chemicals used.

5.4 Software Databases and Packages

One aspect of the literature search was to determine what software databases and packages are available for use in the semiconductor industry. If the package was not pertinent to the semiconductor industry, not available commercially, or not in English, that information was recorded and no other information was sought. If some of the information was relevant to the semiconductor industry, then a more extensive review was conducted. Databases were evaluated according to the step(s) in the lifecycle analysis that they included and other information such as language, demonstrations, and availability, all of which were documented. The results from this software review are found in Table 2 in Appendix A. A blank field signifies that the information was not available on the website and there was no response to e-mail sent to the organization. It is noted that this is not an exhaustive list of available databases. However, after reviewing these packages, it is obvious that there is not a package that is specifically designed for the semiconductor industry. The three main software packages used by the semiconductor industry are GaBi, SimaPro, and TEAM.

GaBi has simple and quick modeling and analysis of complex and data-intensive problems. It can also generate ISO-conformable LCAs. GaBi also includes a consistent and detailed cost evaluation of assessed system (lifecycle costing [LCC]). SimaPro is the world's most widely used LCA software. It can easily model and analyze complex lifecycles clearly and transparently, following ISO 14040 series recommendations. SimaPro can also be used to screen products for environmental improvements from the first stages of development to the realization phase or to do a LCA for existing products to discover hotspots and compare options for improvements. TEAM can evaluate the lifecycle environmental and cost profiles of products and technologies. It can build any system easily regardless of complexity. It is a comprehensive database with over 600 modules and complies with ISO 14040 recommendations.

6 THE PROCESS OF THE LITERATURE SEARCH

The task of conducting a literature search about LCA, particularly within the semiconductor industry, can be a challenge. The initial approach was to locate organizations, schools, and companies with an interest in LCA and learn the approaches commonly used to perform an LCA. An alternative would be to locate software or tools that aid in LCA and determine how the information was collected.

To start, an Internet search was done using Microsoft Network (MSN) Search and the keywords lifecycle analysis, lifecycle assessment, and LCA. Several websites were found that directed the search. The first website was the Semiconductor Subway (http://www-mtl.mit.edu/semisubway) provided by MIT Microsystems Technology Laboratories. It provides links to several companies and organizations in the semiconductor industry. The first link was for the ESH Subway, which allowed the user to link to several organizations such as National Science Foundation (NSF)/Semiconductor Research Corporation (SRC) Engineering Research Center (NSF/SRC ERC) for Environmentally Benign Semiconductor Manufacturing, Semiconductor

Environmental, Safety & Health Association (SESHA), International SEMATECH (ISMT), Semiconductor Equipment & Materials International (SEMI), Semiconductor Industry Association (SIA), Environmental Protection Agency (EPA), and the Institute for Environmental Science. All links were visited except for the Institute for Environmental Science, because it did not work and a website could not be found when an individual Internet search was conducted. The results from these searches are found in Table 3. Once at the website for the organization listed, a search was conducted of that particular website, if available. The keywords used in the search were lifecycle analysis, lifecycle assessment, and LCA. The phrases were all enclosed within parentheses, so that only results with that exact phrase were returned. The number of results returned was recorded along with what pertinent information those results contained. If no search of the website was available, the results in the table were listed as "n/a." In such cases, the website was browsed more intently to determine if it contained any information on lifecycle analysis. Because LCA is not a universally accepted acronym for lifecycle analysis, the results returned for LCA were not always for lifecycle analysis.

The next link on the Semiconductor Subway that was examined was the Organizations Subway. The websites that were not repeats from the ESH Subway were investigated. Since most of the websites on the Organization Subway were not fruitful, the results from those searches were not included in any of the tables in this report. The only website that proved to be full of information was the IEEE website. Of particular interest were the conference proceedings from the International Symposia on Electronics and the Environment (ISEE). The only information available to non-members was the table of contents of the conference proceedings. From the titles, it was clear that several articles pertained to lifecycle analysis. The abstracts and papers are available on-line to members of IEEE who also have an on-line account. These conference proceedings contained some information on lifecycle analysis in the semiconductor industry and lots of information on lifecycle analysis in the electronics industry. However, they contain only limited information about the methodology for the lifecycle analysis and instead focused on the results of the lifecycle analysis. From the organizations, schools, and companies involved in the symposia, an extensive list was prepared to start another search on the entities with LCA interest.

The list of organizations, schools, and companies was formed not only from the IEEE ISEE conference proceedings, but also from the initial broad searches on the Internet. An alphabetized list of the companies and their web addresses are in Table 4. A search for the organizations, schools, and companies with LCA interest began by first trying to find their websites using MSN Search or guessing the web address. Once the correct website was found, a keyword search was performed using lifecycle analysis, lifecycle assessment, and LCA. The phrases again were enclosed within parentheses. The number of results returned was recorded along with what pertinent information those results contained. If no search of the website was available, the results in the table were listed as "n/a." In such cases, the website was browsed more intently to determine if it contained any information on lifecycle analysis. Some organizations, schools, and companies either do not have a website or it could not be easily found. In such cases, they were still listed in the table to document attempts to locate relevant sites. The results of the search for organizations, schools, and companies can be found in Table 3, Table 5, and Table 6, respectively.

Next, a search of International SEMATECH and its member companies was completed. The search was carried out in the same way as for the organizations, school, and companies. The number of results returned was recorded along with what pertinent information those results contained. If no search of the website was available, the results in the table were listed as "n/a." In such cases, the website was browsed more intently to determine if it contained any

information on lifecycle analysis. The results from the search of International SEMATECH and its member companies can be found in Table 7.

A search of material in the International SEMATECH library was also done. The librarian was asked to search on lifecycle analysis and lifecycle assessment in the electronics industry, especially relating to the semiconductor industry. This search returned roughly 20 articles. Because most of these articles were from the IEEE ISEE conference proceedings, it was decided to looked at the IEEE website to determine if there was any more information that might be useful. Indeed, there were several articles of interest.

7 CONCLUSIONS

1. A need to improve inventory: Information about many of the chemicals used in semiconductor industry is not available in existing LCA databases. There is a need to develop more semiconductor-specific databases to perform impact assessment. The tasks will involve reviewing LCA databases to evaluate existing information and information needs. Chemical suppliers and member companies need to collaborate to define the content for a common environmental impact database.
2. Development of more tool-centric (or process-centric or generic use-cluster) types of inventory (gate-to-gate inventory): If LCA is to be used to provide timely information for evaluating new processes, a data collection methodology must be developed for creating a lifecycle inventory for manufacturing processes. While this type of approach may be too complicated and time-consuming, it is generally agreed that this is a promising approach.
3. Evaluation and/or building consensus of impact assessment tools: A method for quantifying environmental impact should be evaluated. SimaPro, GaBi, TEAM, Boustead Model, and Agere target methods have been used by member companies.

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[28] E. Cobas, C. Hendrickson, L. Lave, F. McMichael, “Economic Input/Output Analysis to Aid Lifecycle Assessment of Electronics Products,” *Proceedings IEEE International Symposium on Electronics and the Environment*, Orlando, FL, May 1–3, 1995, pp. 273–278.

APPENDIX A – COLLECTED DATA

Table 1 LCA Case Studies

Case Study		Item(s) Included in Lifecycle Study				Lifecycle Phases Included					Lifecycle Focus Area			Miscellaneous	
Product	Company	ICs	Other Components	System Assemblies	Final Product	Raw Material Acquisition	Material Mfg.	Product Mfg.	Use	Disposal	Inventory	Impact	Improvement	Methodology	Date, Comments
Semiconductor[1]	Motorola, Fraunhofer IZM	yes			semiconductor			X			X	X		ProTox and GaBi 3.2	2001
Semiconductor[2]	Telecom Italia Lab S.p.a., STMicroelectronics	yes			EPROM			X	X		X			Team, Boustead Model, EIME, and several ad hoc LCA "modules"	2001
Silicon and gallium arsenide transistors[19]	Chalmers University of Technology, Gothenburg	yes			transistor	X	X	X	X	X	X	X	X	EPS (Environmental Priority Strategies in product design)	1998
Semiconductors[12]	Applied Materials, NSF/SRC, Berkeley	yes			semiconductor			X			X	X	X	Environmental Value Systems (EnV-S) Analysis	2000
Semiconductors[14]	Applied Materials	yes			semiconductor									Environmental Analysis Software (EnV)	2000
Telecommunication product (pager)[20]	Motorola	no	battery	PWB, molding of housing	pager	X		X	X	X	X	X	X	GaBi 2.0	1999
Thin-film CdS/CdTe PV Modules[21]	6 companies or research entities in Japan	no			solar cell		X	X	X		X	X		energy payback time, CO_2 emissions	2001
(Engineering) Products[22]	Environmental Resources Management	no	blade	motor	blender	X	X	X	X	X	X	X	X	streamlined LCA, compared virgin blender and re-conditioned blender	1999
Amphorous Silicon Photovoltaic Modules[23]	University of Michigan and United Solar Systems Corporation	no	aluminum frame, EVA encapsulant, steel backing plate		photovoltaic module	X	X	X	X		X	X	X	energy payback time, electricity production efficiency	1997
Si-based solar cells[24]	Roskilde University, Institute of Mathematics and Physics, Energy & Environment Group	no			solar cell	X	X	X	X	X	X	X		social costs	1998
Computer workstation[25]	Digital Equipment Corporation, EPA	no			computer										1993, wanted to conduct a traditional lifecycle analysis, but lack of data and complexity made it impossible
Face plates used in telecommunication industry[26]	BNR Europe (parent company is Northern Telecom)	no			plastic versus aluminum face plates	X	X	X		X	X	X		Pira Environmental Management System (PEMS)	1994
Third Generation Systems[27]	Ericsson	no			Third Generation Network			X	X	X	X	X	X		2001

Case Study		Item(s) Included in Lifecycle Study				Lifecycle Phases Included					Lifecycle Focus Area			Miscellaneous	
Product	**Company**	**ICs**	**Other Components**	**System Assemblies**	**Final Product**	**Raw Material Acquisition**	**Material Mfg.**	**Product Mfg.**	**Use**	**Disposal**	**Inventory**	**Impact**	**Improvement**	**Methodology**	**Date, Comments**
Electronic Products[28]	Carnegie Mellon University	no			Household Refrigerators and Freezers, Computers and Office Equipment, Household Audio and Video Equipment			X				X		EIO-LCA	1995

Table 2 LCA Databases and Software Packages

Name	Web Address	Demo Available?		Available in English?		Commercially Available?		Applications	Database(s) Used	
		Yes	No	Yes	No	Yes	No		Inventory	Impact
Athena Model	http://www.athenasmi.ca							Buildings		
Boustead Model 4.4	http://www.boustead-consulting.co.uk	X		X		X		Adhesives and paints, containers, consumer goods, inorganics, metals production, mining operations, organics, paper products, plastics, retailing, and transport operations	Boustead Consulting, Ltd.	Boustead Model
BUWAL 250	http://www.ecosite.co.uk	X		X		X		Packaging materials, energy, transport, waste treatments	BUWAL, Boustead	n/a
CALA	Fraunhofer									
Comprehensive Least Emissions Analysis (CLEAN)	http://www.epri.com							Energy emissions from fuel production, electric generation, and end-use		
CMLCA	http://www.leidenuniv.nl/interfac/cml/ssp/cmlca.html	X		X			No fee, mainly for education purposes			
CUMPAN	http://www.debis.com		X	X		X		Batteries, ceramics, circuit boards, metals, plastics, chemicals		
DEAM	http://www.ecobalance.com	X		X		X		Pulp and paper, steel, glass, petrochemicals and plastics, inorganic chemicals, aluminum, other metals, energy conversion, transportation, waste management	DEAM	n/a
Dutch Concrete								Concrete		
Eco-indicator 95	http://www.pre.nl	X		X		X		Several		Eco-indicator 95
Eco-indicator 99	http://www.pre.nl	X		X		X		Several		Eco-indicator 99
Eco-it	http://www.pre.nl	X		X		X		Several		Eco-indicator 99
Ecolab	http://www.port.se/ecolab							No information on website		
EcoManager	http://www.aspexint.com							Manages ESH system, not data		
ECOPACK2000								Packaging		

Name	Web Address	Demo Available?		Available in English?		Commercially Available?		Applications	Database(s) Used	
		Yes	No	Yes	No	Yes	No		Inventory	Impact
EcoPro 1.5	http://www.empa.ch	X		X		X		Several	BUWAL	CML, Eco-indicator 95, Ecoscarcity
Ecoscan 3.0	http://www.ind.tno.nl	X		X		X		Several	Idemat 2000	Eco-indicator 95, Eco-indicator 99, NOH '95 Eco-indicators, Ecoscan '97
EDIP LCV tool	http://www.mst.dk							Electromechanical products		
EIO-LCA	http://www.eiolca.net	X		X		free		Gives environmental impact from producing a certain dollar amount of a commodity	n/a	n/a
Envision	http://www.techsearchinc.com									
Environmental Protection Strategy (EPS)	http://www.assess.se	X		X		X		Several		
EROS								Generates an environmental credit rating of suppliers to support purchasing decisions		
ESAB	Fraunhofer							Inventory of a production site		
ETH	http://www.pre.nl							Energy, electricity generation, transport, processing, waste treatment		
Euklid	http://www.fraunhofer.de							Process and packaging		
Franklin US LCI	Franklin Associates									
GaBi 3	http://www.gabi-software.com	X		X		X		metals, organic and non-organic pre-products, synthetics, mineral materials, provision of energy, end of life, disposal, processing	IKP and PE-Europe; APME (by Boustead)	CML, Ecoindicator 95 and 99
Heraklit	Fraunhofer							Packaging		
IdeMat	http://www.io.tudelft.nl/research/dfs/idemat							Engineering materials (metals, alloys, plastics, wood), energy, transport		
IVAM LCA Data 3.0	http://www.ivambv.uva.nl		X	X		X		Agriculture, building materials, chemicals, fuels, glass and ceramics, ferrous and non-ferrous metals, plastics, paper and board, others, transport, energy, processing, waste (mostly Dutch data)	PRé, IVAM Environmental Research, ETH/BUWAL	

Name	Web Address	Demo Available?		Available in English?		Commercially Available?		Applications	Database(s) Used	
		Yes	No	Yes	No	Yes	No		Inventory	Impact
JEM LCA	NEC							Electronics sector		
KCL-ECO 3.0	http://www.kcl.fi/eco							Forest products		
LCA1	Proctor and Gamble						X			
LCAD	Battelle/DOE									
LCAdvantage	Battelle, Pacific Northwest National Laboratory									
LCA Inventory tool (LCAit)	http://www.lcait.com	X		X		X		Plastics, Chemicals, Metals, Forest, pulp and paper, Waste management and recycling activities, energy and transportation	SPINE, Boustead/PWMI plastics, BUWAL, IDEA	EPS 2000, SU Sweden 99, EDIP, Eco-Indicator, Environmental Theme method (ET), Tellus, Ecoscarcity (ECO), ExterE Sweden 98
LCAPIX	http://www.kmlmtd.com	X		X		X		Several	Boustead, TELLUS, TME	EPS
LCNetBase	http://www.sylvatica.com/tools.htm#LCNetBase		X	X		X		several	US federal databases (EPA and Bureau of Economic Analysis' (BEA), Energy Information Administration (EIA))	
Lifecycle Interactive Modeling System (LiMS)	http://www.chemsystems.com							Thermoplastic resins, engineering polymers		
NIRE LCA tool	http://www.nire.go.jp/eco_tec_e/hyouka_e.htm				X					
Oekobase 2.5 for windows					X					
Öekobilanz von Packstoffen					X					

Name	Web Address	Demo Available?		Available in English?		Commercially Available?		Applications	Database(s) Used	
		Yes	No	Yes	No	Yes	No		Inventory	Impact
Pira Environmental Management System (PEMS)	http://www.piranet.com							Printing, packaging, publishing, and paper		
PTLaser	http://www.sylvatica.com/ptlaser.htm		X	X		X		Several, really for cost		
Resource and Environmental Profile Analysis Query (REPAQ)	Franklin Associates							packaging		
Simapro 4	http://www.pre.nl	X		X		X		Several	ETH-ESU 96, BUWAL 250, Industry data, IDEMAT 2001, Franklin US LCI, Data archive, Dutch concrete, IVAM, FEFCO	Eco-Indicator 99, Eco-Indicator 95, CML 92, CML 2 (2001), EDIP/UMIP, EPS 2000, Ecopoints 97
Simbox	http://www.eawag.ch				X					
SPINE@CPM data tool	http://www.globalspine.com	X		X		Free				
TCAce	http://www.sylvatica.com/tcace.htm	X		X		X		Several, mostly for cost		
TEAM	http://www.ecobalance.com	X		X		X		Pulp and paper, steel, glass, petrochemicals and plastics, inorganic chemicals, aluminum, other metals, energy conversion, transportation, waste management	DEAM	CML
Total Emission Model for Integrated Systems (TEMIS)		X		X		X		Energy carriers, production, transportation, materials manufacturing		SETAC
Zeus/Heraklit	Fraunhofer ILV									

Table 3 Organizations

Organization Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
The American Center for Lifecycle Assessment	4	16	17	http://www.lcacenter.org Center was formed in 2001, so website does not have too much information, but in the future it has the potential to be a great resource
American Institute of Chemical Engineers (AIChE)	1	0	1	http://www.aiche.org
Battelle (Memorial Institute)	n/a	n/a	n/a	http://www.battelle.org case studies on electronics, but no specific information
The Centre for Sustainable Design	n/a	n/a	n/a	http://www.cfsd.org.uk mainly EOL, no mention of LCA
Council of Consortia (Organization of CEOs of R&D consortia in the US)	n/a	n/a	n/a	http://www.oai.org/CofC links to member sites, but no searches allowed
Eco-efficiency and Clean Production	22	21	13	http://155.187.2.2/epg/environet/eecp/index.html examples and case studies
EcoSite (worldwide resource for LCA)	n/a	n/a	n/a	http://www.ecosite.co.uk list of software, lots of case studies, but none on ICs or electronic products
EDN Embedded Microprocessor Benchmark Consortium (EEMBC)	n/a	n/a	n/a	http://www.eembc.org no environmental information
Environmental Protection Agency (EPA)	38	2	30	http://www.epa.gov
Extreme Ultra Violet Limited Liability Company (EUV-LLC)	n/a	n/a	n/a	http://www.llnl.gov/str/Sween.html more of an article than a full website
Industrial Technology Research Institute				http://www.itri.org.tw/eng/index.html search did not work, looked around website, but did not find anything relevant

Organization Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
Institute for Environmental Research and Education	8	79	110	http://www.iere.org InLCA conference material, tools for sustainability, Automotive Electronic Devices
Institute of Electrical and Electronics Engineers, Inc. (IEEE)	10	20	31	http://www.ieee.org lifecycle cost, workshops, ISO 14000, abstracts on LCA for telecommunication product, windshield wiper, steel products, packaging and interconnection, re-use of electronic products workshops, recycling plant for post-use electric home appliances, "Life-Cycle Design Check Sheet" for ceramic tiles and sanitary wares, conference proceedings from the International Symposiums on Electronics and the Environment (ISEE)
Interconnection Technology Research Institute – US (ITRI)	n/a	n/a	n/a	http://www.itri.org no environmental information
IVF: Swedish research institute				cannot find a web page
MCNC formerly Microelectronics Center of North Carolina	1	0	0	http://www.mcnc.org searched on environmental programs page; looked at projects and it seems more modeling oriented
Microelectronics Advanced Research Corp. (MARCO)	n/a	n/a	n/a	http://marco.fcrp.org A Focus Center Research Program
National Center for Manufacturing Sciences (NCMS)	2	0	0	http://www.ncms.org
National Electronics Manufacturing Initiative (NEMI)	n/a	n/a	n/a	http://www.nemi.org
Novem: Netherlands agency for energy and environment	0	0	0	http://www.novem.org looked at home page for links to LCA and did not find any information
Research Triangle Institute (RTI)	4	27	12	http://www.rti.org lots of matches to search, but could not find anything specific to electronics industry.

Organization Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
RIVM: National Institute of Public Health and Environmental Protection	1	2	3	http://www.rivm.nl proceedings of the seminar 'Transport, Environment and Technology"; a lot of the information on the website was not in English
Semiconductor Equipment & Materials International (SEMI)	0	4	3	http://www.semi.org formation of ESH department to perform LCA
Semiconductor Industry Association (SIA)	n/a	n/a	n/a	http://www.semichips.org went to Environmental, Health, and Safety site and then Environmental site; no mention of LCA
Semiconductor Research Corporation (SRC)	0	0	0	http://www.src.org
Semiconductor Safety Association (SSA)	0	0	0	http://www.semiconductorsafety.org
Society for Promotion Of Life-cycle assessment Development (SPOLD)	n/a	n/a	n/a	http://www.spold.org lots of LCA information (more for members), but nothing relevant to ICs
Society of Environmental Toxicology and Chemistry (SETAC)	n/a	n/a	n/a	http://www.setac.org link to LCA on home page; found publications to order and LCA newsletter, but no way to search for information in newsletters.
Strategic Microelectronics Consortium – Canada (SMC)	0	0	0	http://www.smc.ca
Tellus Institute	4	8	3	http://www.tellus.org solid waste management program, LEAP program (long range energy alternatives planning system)
World Semiconductor Council ESH Task Force (EEAC, EIAJ, KSIA, SIA)				cannot find a web page
Non-sponsored website				http://www.life-cycle.org lots of links, good links to specific software web sites

Organization Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
Personal website	n/a	n/a	n/a	http://www.ecoshop.org/Resources/ecoshop_Resources.htm student's website with electronics info, but resources link not finished. Several papers and presentations, but most are in Korean.

Table 4 Alphabetized Table of Organizations, Schools, and Companies

Organization, School, or Company	Web Address
1st Silicon (Malaysia) Sdn. Bhd	http://www.1stsilicon.com
Acushnet Rubber Company	http://www.acushnet.com
Advanced Energy Industries, Inc.	http://www.rfpp.com
Advanced Micro Devices, Inc. (AMD)	http://www.amd.com
Agere Systems	http://www.lucent.com/micro
Alcatel	http://www.alcatel.com
The American Center for Lifecycle Assessment	http://www.lcacenter.org
American Institute of Chemical Engineers (AIChE)	http://www.aiche.org
Analog Devices, Inc.	http://www.analog.com
Applied Materials, Inc. (AMAT)	http://www.amat.com
Armstrong World Industries	http://www.armstrong.com
ATHENA™ Sustainable Materials Institute	http://www.athenasmi.ca/index.html
AT&T	http://www.att.com/ehs
BASF	http://www.basf.com
Battelle (Memorial Institute)	http://www.battelle.org
Bell Labs—Lucent Technologies	http://www.bell-labs.com
BNR Europe	cannot find a web page
Boeing	http://www.boeing.com
Bristol-Meyer Squibb	http://www.bms.com
British Telecommunications plc (BT)	http://www.bt.com
Canadian Microelectronics Corporation	http://www.cmc.ca
Carnegie Mellon University	http://www.cmu.edu
Carnegie Mellon University Economic Input-Output Lifecycle Assessment	http://www.eiolca.net
Carnegie Mellon University, The Green Design Initiative	http://www.ce.cmu.edu/GreenDesign
The Centre for Sustainable Design	http://www.cfsd.org.uk
Chalmers University of Technology	http://www.chalmers.se
Chalmers University of Technology (Competence Center in Environment Assessment and Material Systems (CPM))	http://www.cpm.chalmers.se
Chartered Semiconductor Manufacturing Pte. Ltd	http://www.csminc.com
Cirrus Logic	http://www.cirrus.com
CML (Centre of Environmental Science), Leiden University, The Netherlands	http://www.leidenuniv.nl/interfac/cml
Conexant Systems, Inc.	http://www.conexant.com/cnxt/index.html
Cornell University	http://www.cornell.edu

Organization, School, or Company	Web Address
Council of Consortia—Organization of chief executives of R&D consortia in the US	http://www.oai.org/CofC
Cranfield University	http://www.cranfield.ac.uk
Cranfield University, School of Industrial and Manufacturing Science	http://www.cranfield.ac.uk/sims
CSELT	see Telecom Italia Lab
Da-Yeh University—Industrial Design	http://www.dyu.edu.tw
Delft University of Technology	http://www.tudelft.nl
Dow	http://www.dow.com
DVIJF Consultancy BV	out-of-business—Eco-It
Ecobalance	see PricewaterhouseCoopers
Eco-efficiency and Clean Production	http://155.187.2.2/epg/environet/eecp/index.html
EcoSite—worldwide resource for LCA	http://www.ecosite.co.uk
EDN Embedded Microprocessor Benchmark Consortium (EEMBC)	http://www.eembc.org
Electric Power Research Institute (EPRI)	http://www.epri.com
EMAX Solution Partners	http://www.emax.com
Entegris, Inc.	http://www.entegris.com
Environmental and Occupational Risk Management, Inc. (EORM)	http://www.eorm.com
Environmental Protection Agency (EPA)	http://www.epa.gov
Epson Electronics America (EEA)	http://www.eea.epson.com
Ericsson	http://www.ericsson.com
ESEC Group	http://www.esec.com
Extreme Ultra Violet Limited Liability Company (EUV-LLC)	http://www.llnl.gov/str/Sween.html
Ford	http://www.ford.com
Franklin Associates	cannot access web page
Fraunhofer Institute—Environmental Engineering	http://www.pb.izm.fhg.de/ee
Fujitsu	http://www.fujitsu.com
General Semiconductor Inc.	http://www.gensemi.com
GM-Hughes Electronics	http://www.hughes.com
Georgia Institute of Technology (GT)	http://www.gatech.edu
GT's Systems Realization Lab	http://www.srl.gatech.edu
Hewlett-Packard Company (hp)	http://www.hp.com
Hiroshima University	http://www.hiroshima-u.ac.jp
Hitachi	http://www.hitachi.com
Hitachi Semiconductor	http://semiconductor.hitachi.com
Holtzmann, Wise, and Sheppard	cannot find a web page

Organization, School, or Company	Web Address
Hynix Semiconductor Inc.	http://www.hynix.com/eng/index.html
IBM	http://www.ibm.com
Industrial Technology Research Institute	http://www.itri.org.tw/eng/index.html
Infineon Technologies AG	http://www.infineon.com
Institute for Environmental Research and Education	http://www.iere.org
Institute of Electrical and Electronics Engineers, Inc. (IEEE)	http://www.ieee.org
Intel Corporation	http://www.intel.com
Interconnection Technology Research Institute – US (ITRI)	http://www.itri.org
International SEMATECH (ISMT)	http://www.sematech.org/public/index.htm
Intersil	http://www.intersil.com
IVF: Swedish research institute	cannot find a web page
Jacobs Engineering Group, Inc.	http://www.jacobs.com
J.M Huber Corporation	http://www.huber.com
KLA-Tencor Corporation	http://www.kla-tencor.com
Kokusai Semiconductor Equipment Corporation	http://www.ksec.com
Lam Research	http://www.lamrc.com
Linear Technology Corporation	http://www.linear-tech.com
Lucas Automotive Electrons	cannot find a web page
Lucent Technologies	http://www.lucent.com
Manchester Metropolitan University DFE Group	http://sun1.mpce.stu.mmu.ac.uk/pages/projects/dfe/dfe.html
Massachusetts Institute of Technology (MIT) Program on Technology, Business, and the Environment	http://web.mit.edu/ctpid/www/tbe.html
Maxim Integrated Products	http://www.maxim-ic.com
MCG & Associates	cannot find a web page
MCNC formerly Microelectronics Center of North Carolina	http://www.mcnc.org
Michigan State University	http://www.msu.edu http://www.egr.msu.edu/classes/be230/LCA.htm
Microelectronics Advanced Research Corp. (MARCO)	http://marco.fcrp.org
Microelectronics & Computer Technology Corporation (MCC)	http://www.mcc.com
Micron Technology, Inc.	http://www.micron.com
Mitsubishi	http://www.mitsubishi.com
Mitsubishi Electric	http://www.mitsubishielectric.com
MKS Instruments	http://mksinst.com
Motorola, Inc.	http://www.mot.com/home
Nanya Technology Corporation	http://www.nanya.com

Organization, School, or Company	Web Address
National Center for Clean Industrial and Treatment Technologies	http://cpas.mtu.edu/cencitt
National Center for Manufacturing Sciences (NCMS)	http://www.ncms.org
National Electronics Manufacturing Initiative (NEMI)	http://www.nemi.org
National Pollution Prevention Center (now the Center for Sustainable Systems)	http://css.snre.umich.edu
NSF/SRC ERC for Environmentally Benign Semiconductor Manufacturing	http://erc.arizona.edu
NEC	http://www.nec.com
NedCar	http://www.nedcar.nl
New Jersey Institute of Technology (NJIT)	http://www.njit.edu
Nikon Precision Europe GmbH	http://npeurope.com
Nokia	http://www.nokia.com
Novellus Systems, Inc.	http://www.novellus.com
Novem: Netherlands agency for energy and environment	http://www.novem.org
Oce	http://www.oce.com
Ohio State University (OSU)	http://www.ohio-state.edu
OSU—Department of Industrial, Welding and System Engineering	http://www-iwse.eng.ohio-state.edu/~lcdps/index.html
Oxford	http://www.ox.ac.uk
Philips Semiconductors	http://www.semiconductors.philips.com
PRé Consultants	http://www.pre.nl
PricewaterhouseCooper (Ecobilan Group)	http://www.pwcglobal.com
Princeton University	http://www.princeton.edu
Princeton University—Center for Energy and Environmental Studies	http://www.princeton.edu/~cees
Quantum Corp.	http://www.quantum.com
Research Triangle Institute (RTI)	http://www.rti.org
RF Micro Devices, Inc.	http://www.rfmd.com
RIVM: National Institute of Public Health and Environmental Protection	http://www.rivm.nl
Robert Bosch GmbH	http://www.bosch-pt.com/en
Royal Melbourne Institute of Technology	http://www.cfd.rmit.edu.au
Royal Philips Electronics	http://www.philips.com/indexie4-5.php
Roy F. Weston, Inc.	http://www.rfweston.com
Samsung	http://www.samsung.com
Schuurink	cannot find a web page
Semiconductor Environmental, Safety & Health Association (SESHA)	http://www.semiconductorsafety.org
Semiconductor Equipment & Materials International	http://www.semi.org

Organization, School, or Company	Web Address
(SEMI)	
Semiconductor Industry Association (SIA)	http://www.semichips.org
Semiconductor Research Corporation (SRC)	http://www.src.org
SEMITOOL	http://www.semitool.com
Sheffield Hallam University	http://www.shef.ac.uk
Silicon Laboratories	http://www.silabs.com
SiRF Technology Inc.	http://www.sirf.com
SLDRAM International consortium of synchronous-link DRAM producers	http://www.sldram.com
Society of Environmental Toxicology and Chemistry (SETAC)	http://www.setac.org
Sony	http://www.sony.com
Society for Promotion Of Life-cycle assessment Development (SPOLD)	http://www.spold.org
SP Swedish National Testing and Research Institute	http://www.sp.se/eng
Stanford University	http://www.stanford.edu
STMicroelectronics	http://us.st.com/stonline/index.shtml
Strategic Microelectronics Consortium – Canada (SMC)	http://www.smc.ca
Sun Microsystems, Inc.	http://www.sun.com
Sylvatica	http://www.sylvatica.com
Synergy	http://www.synergyservices.com
Taiwan Semiconductor Manufacturing Company (TSMC)	http://www.tsmc.com/index.html
Technical University of Denmark—Institute for Product Development	http://www.ipu.dtu.dk/ipu_k_uk.htm
Technische Universitat Berlin	http://www.tu-berlin.de/eng/index.html
Telecom Italia Lab S.p.a	http://www.telecomitalialab.com
Telecordia, Research Division—formerly Bellcore	http://www.telcordia.com/research/index.html
Tellus Institute	http://www.tellus.org
Teradyne Inc.	http://www.teradyne.com
Texas Instruments Incorporated (TI)	http://www.ti.com
Texas Tech University	http://www.texastech.edu
Toronto University	http://www.utoronto.ca/uoft.html
Toshiba	http://www.toshiba.com
Tower Semiconductor Ltd.	http://www.towersemi.com
United Microelectronics Corp. (UMC)	http://www.umc.com
University of Amsterdam: IVAM Environmental Research	http://www.ivambv.uva.nl
University of California Berkeley	http://www.berkeley.edu

Organization, School, or Company	Web Address
University of California Berkeley—Consortium on Green Design and Manufacturing	http://greenmfg.me.berkeley.edu/green/Home/Index.html
University of Glamorgan Design Section	http://www.glam.ac.uk
University of Michigan	http://www.umich.edu
University of Stuttgart	http://www.ikpgabi-uni-stuttgart.de
University of Surrey	http://www.surrey.ac.uk/PRC
University of Tennessee	http://www.utenn.edu
University of Windsor	http://www.uwindsor.ca
University of Wisconsin at Madison	http://www.wisc.edu
UNS Environmental Decision Making	http://www.uns.umnw.ethz.ch/uns
Utrecht University—Department of Science, Technology and Society	http://www.chem.uu.nl/nws/www/publica/95057.htm
Varian Semiconductor Equipment Associates, Inc.	http://www.vsea.com
Vignes Consulting	cannot find a web page
Vishay Intertechnology, Inc.	http://www.vishay.com
World Semiconductor Council ESH Task Force (EEAC, EIAJ, KSIA, SIA)	cannot find a web page
Xerox	http://www.xerox.com
Non-sponsored link	http://www.life-cycle.org
Personal page	http://www.ecoshop.org/Resources/ecoshop_Resources.htm

Table 5 Schools

School Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
ATHENA Sustainable Materials Institute	n/a	n/a	n/a	http://www.athenasmi.ca/index.html ATHENA™ database (demo available), case studies, but more building oriented.
Carnegie Mellon University	59	55	85	http://www.cmu.edu Economic Input-Output Lifecycle Assessment (EIO-LCA) at http://www.eiolca.net
Carnegie Mellon University—Green Design Initiative	n/a	n/a	n/a	http://www.ce.cmu.edu/GreenDesign lots of information on LCA, especially Economic Input-Output analysis, but no specific applications to semiconductors. However, a few applications to electronic products. Found a paper entitled "Full Cost Accounting Case Study: Semiconductor Fabrication Facility".
Chalmers University of Technology	36	210	319	http://www.chalmers.se abstract on LCA of power lines, EcoLab, SPINE, case studies on electronics, but only one abstract on ICs, Ekologik, EPS system
Chalmers University of Technology (Competence Center in Environment Assessment and Material Systems (CPM))	n/a	n/a	n/a	http://www.cpm.chalmers.se SPINE database, most LCA work on packaging, building, and sewage systems
CML (Centre of Environmental Science), Leiden University, The Netherlands	10	93	113	http://www.leidenuniv.nl/interfac/cml product lifecycle assessment, LCAnet, guidelines for LCA methodology
Cornell University	16	17	22	http://www.cornell.edu LCA on publishing, buildings, eco-industrial parks, packaging, recycling
Cranfield University	106	59	1	http://www.cranfield.ac.uk mostly on cost

School Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
Cranfield University, School of Industrial and Manufacturing Science	n/a	n/a	n/a	http://www.cranfield.ac.uk/sims
Da-Yeh University—Industrial Design (ID)	n/a	n/a	n/a	http://www.dyu.edu.tw looked at EnvE school, but no specifics on particular research. Also looked at school of ID, but not in English
Delft University of Technology	0	0	4	http://www.tudelft.nl research areas had an Ecoquest and Idemat Environmental Product Development Link
Fraunhofer Institute—Environmental Engineering	n/a	n/a	n/a	http://www.pb.izm.fhg.de/ee
Georgia Institute of Technology (GT)	70	130	171	http://www.gatech.edu carpet LCA, activity-based LCA.
GT—CE	2	0	4	http://www.ce.gatech.edu
GT—Industrial and Systems Engineering	0	4	1	http://www.isye.gatech.edu
GT—ME	0	9	3	http://www.me.gatech.edu
GT—System Realization Lab	n/a	n/a	n/a	http://www.srl.gatech.edu more on design, manufacturing, de-manufacturing, assembly, disassembly
Hiroshima University	n/a	n/a	n/a	http://www.hiroshima-u.ac.jp looked around site, but no info
Manchester Metropolitan University DFE Group	n/a	n/a	n/a	http://sun1.mpce.stu.mmu.ac.uk/pages/projects/dfe/dfe.html Ecotools manual
Michigan State University	32	59	0	http://www.msu.edu lots of information, case studies on kenaf (environmentally friendly paper), industrial paper sacks, chlorinated persistent toxic substances, products derived from plants, auto fuel. Links to case studies at http://www.egr.msu.edu/classes/be230/LCA.htm

School Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
Massachusetts Institute of Technology (MIT) Program on Technology, Business, and the Environment	7	2	3	http://web.mit.edu/ctpid/www/tbe.html automobile case study
National Center for Clean Industrial and Treatment Technologies	n/a	n/a	n/a	http://cpas.mtu.edu/cencitt not much info, mainly pollution prevention
National Pollution Prevention Center (now the Center for Sustainable Systems)	n/a	n/a	n/a	http://css.snre.umich.edu lots of LCA done on transportation, building, packaging materials, renewable energy, agriculture
NSF/SRC ERC for Environmentally Benign Semiconductor Manufacturing				http://erc.arizona.edu headquartered at the University of Arizona in cooperation with MIT, Stanford University, Cornell University, Arizona State University, and the University of California at Berkeley. Tried to do a site search, but it did not work.
New Jersey Institute of Technology (NJIT)	36	14	97	http://www.njit.edu architecture (costing), software tool in works, mainly DFE with some electronics applications, there was no way to tell what the page was about during the search, so had to look at all pages for essentially no information, which was a waste of time
Ohio State University (OSU)	9	6	28	http://www.ohio-state.edu
OSU—Department of Industrial, Welding and System Engineering	n/a	n/a	n/a	http://www-iwse.eng.ohio-state.edu/~lcdps/index.html some info on LCA and electronics
Oxford				http://www.ox.ac.uk search produced too many results, so “explored” department of Environmental Change Institute, but could not find anything on LCA
Princeton University	6	6	587	http://www.princeton.edu

School Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
Princeton University—Center for Energy and Environmental Studies	n/a	n/a	n/a	http://www.princeton.edu/~cees no information
Royal Melbourne Institute of Technology	n/a	n/a	n/a	http://www.cfd.rmit.edu.au clicked on lifecycle assessment link, mainly on paper and packaging
Sheffield Hallam University	12	11	3	http://www.shef.ac.uk building LCA
Stanford University	23	21	102	http://www.stanford.edu recycled thermoplastics, recycled injection molded plastics, manufacturing, modeling, EOL
Technical University of Denmark-Institute for Product Development	n/a	n/a	n/a	http://www.ipu.dtu.dk/ipu_k_uk.htm searched website, but no mention of LCA. Mainly product, process, and production design
Technische Universitat Berlin	40	40	35	http://www.tu-berlin.de/eng/index.html EOL, water softening LCA, rail vehicles LCA
Texas Tech University				http://www.texastech.edu search did not narrow down results, ChemE and EnvE: found nothing on LCA, CE: was lacking information, IE: EOL projects
Toronto University	43	43	104	http://www.utoronto.ca/uoft.html cost, building ATHENA, site remediation, LCA on building material, equipment, and operation, streamlined LCA
University of Amsterdam: IVAM Environmental Research	3	11	16	http://www.ivambv.uva.nl IVAM LCA data, renewable energy-sun, Eco-Quantum (LCA for buildings), basic information, but no case study information
University of California Berkeley	35	52	103	http://www.berkeley.edu DFE, EnV, Econ in/out, Presentation on “Environmental and Health Effects of Semiconductor Manufacturing: Methodologies to Address Concern” at http://www-inst.eecs.berkeley.edu/~ee143/s2001/Lectures/Lec_30.pdf

School Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
University of California Berkeley—Consortium on Green Design and Manufacturing	n/a	n/a	n/a	http://greenmfg.me.berkeley.edu/green/Home no links for publications in the semiconductor industry
University of Glamorgan Design Section	9	9	0	http://www.glam.ac.uk results were not environmentally related
University of Michigan	88	108	107	http://www.umich.edu LCA on residential homes, clothes, clothes cleaning, batteries, vehicles, packaging, drug manufacturing, antifreeze
University of Stuttgart				http://www.ikpgabi.uni-stuttgart.de/
University of Surrey	80	56	3	http://www.surrey.ac.uk/PRC initially did search of all University of Surrey WWW servers, but too many results were returned, so did a search on Chemical and Processing Engineering server. Started Engineering for the Environment program in 2000
University of Tennessee	22	38	95	http://www.utenn.edu LCA on computer display, buildings, household cleaners, vehicles, etc., contract with Saturn to develop Life-Cycle Design Toolkit (a software package that will help carmakers reduce the negative impacts of automobiles), looked at the Energy, Environment, and Resources Center and Center for Clean Products and Clean Technologies (CCPCT), but all information was repeated from initial search
University of Windsor, Environmentally Conscious Design and Manufacturing Lab (ECDM Lab)	n/a	n/a	n/a	http://www.uwindsor.ca link not working to ECDM Lab
University of Wisconsin at Madison	31	37	167	http://www.wisc.edu LCA on automobiles, DFE, PP, went to Engineering Professional Development and CEE websites—nothing
UNS Environmental Decision Making	3	32	29	http://www.uns.umnw.ethz.ch/uns LCA on building, thermal waste, solvents, food products, stoves and ovens, land use

School Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
Utrecht University—Department of Science, Technology and Society				http://www.chem.uu.nl/nws/www/publica/95057.htm summary of 'Environmental life-cycle assessment of multicrystalline silicon solar cell modules'

Table 6 Companies

Company Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
1st Silicon (Malaysia) Sdn. Bhd	n/a	n/a	n/a	http://www.1stsilicon.com
Acushnet Rubber Company	1	3	0	http://www.acushnet.com mentions ISO 14001
Advanced Energy Industries, Inc.	0	0	0	http://www.rfpp.com
Alcatel				http://www.alcatel.com lots of results were returned by the search, but it was not for the entire phrase enclosed in parentheses, so none of the results were environmentally related. The site map lead to the environment page, which showed a commitment to LCA, along with a developed, dedicated software tool (Environmental Information Management and Explorer (EIME))
Analog Devices, Inc.	0	0	0	http://www.analog.com
Applied Materials, Inc. (AMAT)	0	0	0	http://www.amat.com
Armstrong World Industries	n/a	n/a	n/a	http://www.armstrong.com no information for LCA
AT&T	1	8	3	http://www.att.com/ehs voiced a commitment to LCA, but gave no framework/methodology
BASF	11	2	0	http://www.basf.com adopted Eco-efficiency analysis
Bell Labs—Lucent Technologies	2	0	4	http://www.bell-labs.com
BNR Europe				cannot find a web page
Boeing	4	0	6	http://www.boeing.com cost benefit study
Bristol-Meyer Squibb	3	2	0	http://www.bms.com LCA in China and Hillside, NJ on all major product lines starting in 1992 and ending in 1997

Company Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
British Telecommunications plc (BT)	1	0	0	http://www.bt.com BT's Response to the Government's Consultation Paper Opportunities for Change, ISO 14401
Canadian Microelectronics Corporation	0	1	0	http://www.cmc.ca
Chartered Semiconductor Manufacturing Pte. Ltd			0	http://www.csminc.com lifecycle analysis and lifecycle assessment returned lots of results, but it was not for the entire phrase enclosed in parentheses, so none of the results were environmentally related.
Cirrus Logic	0	0	0	http://www.cirrus.com
Dow	3	3	0	http://www.dow.com link to ESH on home page, mentioned commitment to LCA, but not much information
DVIJF Consultancy BV				went out of business, involved with Eco-It
EMAX Solution Partners	n/a	n/a	n/a	http://www.emax.com found nothing relevant by clicking on links
Entegris, Inc.	0	0	0	http://www.entegris.com
Environmental and Occupational Risk Management, Inc. (EORM)	n/a	n/a	n/a	http://www.eorm.com no mention of LCA in ESH link
Electric Power Research Institute (EPRI)	2	1	0	http://www.epri.com environment link on home page, cost, plans for LCA, California assessment
Epson Electronics America (EEA)	0	0	0	http://www.eea.epson.com looked around website to find environmental information, but only found information on recent ISO 14001 certification and energy savings technology
Ericsson	8	68	53	http://www.ericsson.com report on LCA
ESEC Group				http://www.esec.com

Company Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
Ford	0	1	0	http://www.ford.com performed LCA
Franklin Associates				cannot access the web page
Fujitsu	0	11	12	http://www.fujitsu.com introduced LCA internally in 1997, provided total support for environmental activities by corporations and local government through introductory-level consultation and with LCA support software: **Green design support package (FJVPS/ECODESIGN)** supports the design of green products through LCA, **LCA support package (LCASLIM)** supports product assessment
General Semiconductor Inc.	n/a	n/a	n/a	http://www.gensemi.com only a product search is available, site index had a link to environmental policy, but did not have a lot of information and did not mention LCA
GM-Hughes Electronics	n/a	n/a	n/a	http://www.hughes.com
Hitachi	0	0	0	http://www.hitachi.com
Hitachi Semiconductor	0	0	0	http://semiconductor.hitachi.com
Holtzmann, Wise, Sheppard				cannot find a web page
Intersil	0	0	0	http://www.intersil.com looked around web site and could not find any environmental information
Jacobs Engineering Group, Inc.	0	0	0	http://www.jacobs.com
J.M. Huber Corporation	n/a	n/a	n/a	http://www.huber.com environmental commitment link had no mention of LCA.
KLA-Tencor Corporation	179	44	0	http://www.kla-tencor.com results did not include entire phrase, so none of the results were environmentally related
Kokusai Semiconductor Equipment Corporation	n/a	n/a	n/a	http://www.ksec.com
Lam Research	0	0	0	http://www.lamrc.com

Company Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
Linear Technology Corporation	0	0		http://www.linear-tech.com LCA had results, but were not environmentally related
Lucas Automotive Electrons				cannot find a web page
Lucent Technologies	4	1	15	http://www.lucent.com
Maxim Integrated Products	0	0	0	http://www.maxim-ic.com
MCG & Associates				cannot find a web page
Microelectronics & Computer Technology Corporation (MCC)				http://www.mcc.com company no longer exists
Micron Technology, Inc.	0	0	0	http://www.micron.com looked at site map and found link to environmental policy. ISO 14001 certified, but no mention of LCA
Mitsubishi	0	11	13	http://www.mitsubishi.com environmental link on web page, but no individual search, LCA for waste at refuse incineration power plants, commitment to LCA whenever possible, LCA of electrical appliances and electronic equipment and containers and packaging
Mitsubishi Electric	3	6	7	http://www.mitsubishielectric.com promoting LCA to reduce negative environmental impacts from products, commitment/work on LCA
MKS Instruments	0	0	0	http://mksinst.com
Nanya Technology Corporation	n/a	n/a	n/a	http://www.nanya.com looked at sitemap and found environmental management policy, but no mention of LCA
NEC	0	11	77	http://www.nec.com LCA software (“LCA Support”, JEM-LCA) for PC LCA, annual report, lots of environmental information and large LCA commitment
NedCar				http://www.nedcar.nl search function temporarily unavailable

Company Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
Nikon Precision Europe GmbH	n/a	n/a	n/a	http://npeurope.com
Nokia	247	154	2	http://www.nokia.com environment website shows commitment to LCA and analyzing ways for improvement
Novellus Systems, Inc.	0	0	0	http://www.novellus.com sitemap did not provide a link to environmental information
Oce	0	0	0	http://www.oce.com
PRé Consultants	n/a	n/a	n/a	http://www.pre.nl information on general LCA, SimaPro, Eco-Indicator, ECO-It, Ecodesign, good information with demonstrations
PricewaterhouseCoopers (Ecobilan Group in France, Ecobalance in UK and US)	5	4	5	http://www.pwcglobal.com software: TEAM/DEAM
Quantum Corp.	0	0	0	http://www.quantum.com
RF Micro Devices, Inc.	n/a	n/a	n/a	http://www.rfmd.com
Robert Bosch GmbH	n/a	n/a	n/a	http://www.bosch-pt.com/en
Roy F. Weston, Inc.	0	0	0	http://www.rfweston.com thought for sure that there would be some information at this website, but nothing.
Samsung	0	4	4	http://www.samsung.com LCA of microwave ovens, DRAM chips, TVs, monitors, refrigerators, air conditioners, washing machines, desktop PCs, laptop PCs, laser printers, vacuum cleaners; LCA software—Simplified LCA Program for Effective Eco-Design (SPEED); ISO 14000
Schuurink				cannot find a web page
SEMITOOL	0	0	0	http://www.semitool.com
Silicon Laboratories	n/a	n/a	n/a	http://www.silabs.com
SiRF Technology Inc.	0	0	0	http://www.sirf.com

Company Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
SLDRAM	n/a	n/a	n/a	http://www.sldram.com international consortium of synchronous-link DRAM producers
Sun Microsystems, Inc.	0	4	2	http://www.sun.com Sun does not support the European Commission's Working Paper for a Directive addressing the impact on the environment of Electrical and Electronic Equipment (EEE), whatIf?^{R} is a suite of software tools (from Robbert Associates Ltd.) for the design, documentation, implementation and use of quantitative decision support systems and simulation models for applications including urban planning, demography, financial analysis, product and process lifecycle assessment and energy analysis
Sony	0	1	0	http://www.sony.com ISO 14000
SP Swedish National Testing and Research Institute	2	8	13	http://www.sp.se/eng incorporation of fire in LCA (TV case study), building LCA
Sylvatica	n/a	n/a	n/a	http://www.sylvatica.com had information on the following tools: **PTLaser**, **LCNetBase**, **Baseline Green** , **TCAce**, **SimaPro**, **Athena**, **Lifecycle Explorer**
Synergy	n/a	n/a	n/a	http://www.synergyservices.com
Telecom Italia Lab S.p.a (CSELT now a part of Telecom Italia Lab)	2	11	13	http://www.telecomitalialab.com most of the information was in Italian
Telecordia, Research Division (formerly Bellcore)	0	0	0	http://www.telcordia.com/research/index.html
Teradyne Inc.	0	0	0	http://www.teradyne.com
Toshiba	0	0	0	http://www.toshiba.com
Tower Semiconductor Ltd.	0	0	0	http://www.towersemi.com
United Microelectronics Corp. (UMC)	0	0	0	http://www.umc.com sitemap did not provide a link to environmental information

Company Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
Varian Semiconductor Equipment Associates, Inc.	n/a	n/a	n/a	http://www.vsea.com
Vignes Consulting				cannot find a web page
Vishay Intertechnology, Inc.	6	4	8	http://www.vishay.com results did not include entire phrase, so none of the results were environmentally related
Xerox	0	0	<1,000	http://www.xerox.com nothing found during LCA search that was relevant to lifecycle analysis

Table 7 ISMT and Member Companies

Company Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
Advanced Micro Devices, Inc. (AMD)	0	0	0	http://www.amd.com
AMD ESH	n/a	n/a	n/a	http://www.amd.com/about/ehs/index.html
Agere Systems	0	0	5	http://www.lucent.com/micro
Agere Systems ESH	n/a	n/a	n/a	http://www.lucent.com/micro/ehs/index.html
Conexant Systems, Inc.	0	0	0	http://www.conexant.com/cnxt/index.html
Hewlett-Packard Company (hp)	2	0	1	http://www.hp.com
hp's environmental program	n/a	n/a	n/a	http://www.hp.com/hpinfo/community/environment good website for environmental information, but nothing about lifecycle analysis
Hynix Semiconductor Inc.	0	0	0	http://www.hynix.com/eng/index.html
Hynix ESH	0	0	0	link on home page
IBM	6	0	41	http://www.ibm.com nothing environmentally related
IBM's environmental program	n/a	n/a	n/a	http://www.ibm.com/ibm/environment good website for environmental information, but nothing about lifecycle analysis
Infineon Technologies AG	0	0	2	http://www.infineon.com
Intel Corporation	0	0	0	http://www.intel.com
Intel ESH	n/a	n/a	n/a	http://www.intel.com/intel/other/ehs/index.htm good website for environmental information, but nothing about lifecycle analysis
International SEMATECH (ISMT)	0	0	1	http://www.sematech.org/public/index.htm
Motorola, Inc.	0	1	1	http://www.mot.com/home ISO 14000

Company Name	Lifecycle Analysis (# of results)	Lifecycle Assessment (# of results)	LCA (# of results)	Comments
Motorola, Inc. ESH	n/a	n/a	n/a	http://www.mot.com/ESH/environment Green Design Advisor (GDA)—design for environment—partnered with University of Erlangen in Germany; German Product Environmental Template (PET)
Philips Semiconductors	37	4,048	110	http://www.semiconductors.philips.com mention the use of LCA and Eco-Indicator
Philips Semiconductor's environmental program	n/a	n/a	n/a	http://www.semiconductors.philips.com/aboutus/env good website for environmental information, and lifecycle analysis was mentioned a few times throughout
Royal Philips Electronics	1,328	1,047	1	http://www.philips.com/indexie4-5.php use of LCA
STMicroelectronics	0	0	0	http://us.st.com/stonline/index.shtml
STMicroelectronics' environmental program	n/a	n/a	n/a	link on home page
Taiwan Semiconductor Manufacturing Company (TSMC)	0	0	7	http://www.tsmc.com/index.html
Texas Instruments (TI) Incorporated	0	0	8	http://www.ti.com

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e-mail: info@sematech.org