# LCA for Mere Mortals

A Primer on Environmental Life Cycle Assessment

By Rita C. Schenck

# Table of Contents

*Chapter One*

# Introduction

*If you have just picked up this book and are asking yourself, "How about Life Cycle Assessment? What is it? Is it going to be useful for me?" then this book is for you. It will explain all about Life Cycle Assessment in two–syllable words (well, mostly). You will learn how to get a Life Cycle Assessment (LCA) done, how to influence the outcome of an LCA, and how to use the results of an LCA. You'll even learn a few tricks to tell when things are going wrong and some hints on how to fix them. So read on.*

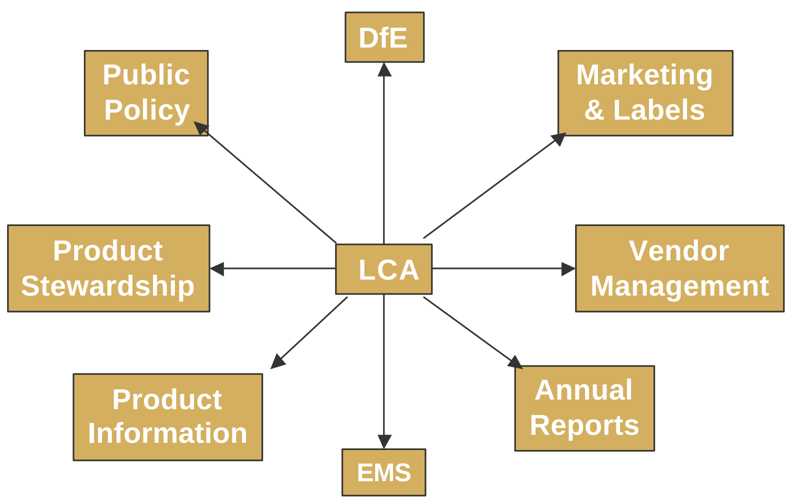
*First of all what is an environmental Life Cycle Assessment? A Life Cycle Assessment can be lots of different things—but all of them should include an attempt to evaluate the environmental aspects of a product or a service in a cradle–to–grave fashion. There are LOTS of things that have undergone Life Cycle Assessments: jet engines, diapers, drinking cups, computers, remediation techniques, trash disposal. You name it. If you can identify a system with a beginning and an end, you can look at what it does to the environment from beginning to end, and you can (in theory) do an LCA study.*

*As long as you are looking at the big environmental picture, you are doing a kind of Life Cycle Assessment. BUT (and this is important) there are now international standards that lay down rules about how to do an LCA. If you want to follow the international standards (ISO 14040 and others) you'll have pretty strict limits placed on what you can do. This book will explain most of that and will show you where to get more help if you need it.*

*Environmental Life Cycle Assessment is based on the very logical concept that if we knew all the environmental impacts of a product or service, we could make good environmental decisions about that product or service. The way you do an LCA (as described in ISO 14040) is you look at all the mass and energy flows from the time you extract the raw materials from the environment, through the product manufacture, its use, and its final disposal. Following all that mass and energy should tell you what the product is doing to the environment.*

*Some proactive companies such as AT&T and Volvo are placing LCA at the heart of their environmental strategy. You can use an LCA framework for identifying environmental aspects and impacts. LCA makes an excellent tool for communicating to management and engineering and operations inside the corporation, too. Life cycle indicators are almost tailor–built for environmental performance evaluation (the ISO 14030 series of standards). And they make a good basis for communicating to stakeholders and customers.*

The Many Uses of LCA



*Actually doing an LCA and understanding the results is another kettle of fish, as we'll explain later. But mere mortals (like YOU) can and have gotten very useful LCAs done, with the help of LCA practitioners. Very few organizations actually perform LCA's solely with in-house talent, for the same reason that few organizations perform their own remedial work. The focussed technical ability needed to perform an LCA is not a core competency of most organizations, and therefore is outsourced. Nevertheless, you need to understand the ins and outs of LCA's in order to manage the consultant doing the work, and this book is aimed primarily at helping you do that.*

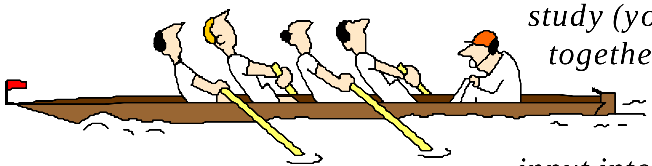
*What kinds of questions does LCA answer, and what can you use it for? Lots of different kinds of things, including:*

- ✓ *Marketing (does this product have less impact than others?)*
- ✓ *Purchasing (which product has the least impact?)*
- ✓ *Design (what should we change to make our product more environmentally friendly?)*
- ✓ *Benchmarking across an industry or across divisions of a corporation (who is best/worst; where are we?)*
- ✓ *Year to year tracking of environmental performance (are we getting better or worse?)*
- ✓ *Benchmarking between industries (can my product/service accomplish the same goals with lower environmental impact?)*
- ✓ *Policy (where should we have regulations to get the biggest benefit?)*

*The most common reason that people do LCAs is for market advantage for environmentally preferable products. LCAs document the performance of* *products, and so they can be used for top-line advantage. Of all environmental techniques, LCA is unique in this respect. Because LCA's can influence the financial success of a company, they provide an excellent wedge for the integration of environmental systems with other systems.*

*One new use of LCIA's is in validating greenhouse gas emissions to have marketable credits under the Kyoto Protocol. Although the markets for carbon credits (as they are known) is just in its infancy, the opportunity for selling them is considered to be very large.*

*LCA has the potential to provide a new model for regulations; one based on a synoptic view of environmental impacts rather than focusing on chemical risk management. This can give us a chance to address issues like species diversity on the same page as toxic effects.*



*The outcome of an LCA depends to a large extent on the people involved in the study (you and your peers and your LCA consultant) and how they work together. Besides the practitioners of LCA, there are the commissioners of a study, the experts reviewing the study and the interested parties (or stakeholders inside and outside of an organization) who can have input into the study. Usually, when a study is commissioned, a team works together to decide the goals of the study and who should perform it. In the very common case where the commissioning body is a large firm, a team will manage the project. The team is usually cross–functional and includes people from engineering, manufacturing or operations, environmental, marketing, and purchasing functions. The knowledge embodied in these different groups is essential to assure a successful outcome of the study.*

*Most LCA's are done using outside experts (consultants). This is because to be an LCA practitioner, you need a special set of skills, including:*

- ✓ *Understanding of industrial processes in several industries*
- ✓ *Knowledge of data sources both public and private*
- ✓ *Understanding of fate and transport modeling*
- ✓ *Understanding of human and ecological toxicity*

*In addition, doing an LCA is time consuming, and the pace of action in most organizations means that staff does not have enough time to devote to these studies. Some organizations do perform LCA's internally, especially after they have had thorough LCA's done and have developed some internal expertise. This is most common for simplified LCA's that look at only a few issues or for partial assessments looking at only a one life cycle stage.*

*One of the results of the thousands of LCA's that have been performed over the last few decades is that the accumulated knowledge has made it easier and therefore cheaper to do an LCA. Early on, LCA's could take millions of dollars and years to perform. Now, depending on the scope of the project, the cost of has dropped to a few to tens of thousands of dollars to perform, and they can be completed in a matter of months.*

*Depending on the intended use of the study, you may or may not want to include outside stakeholders in its design and review. When studies are published and a claim that one product or service is better than another, outside review is required. If studies are intended to be internal and limited in scope, outside review is not appropriate or needed. Some studies are short engineering exercises that answer minor questions about design choices. It is just not reasonable to expect much stakeholder input in this kind of study. In between, consultation with stakeholders may or may not be a good idea.*

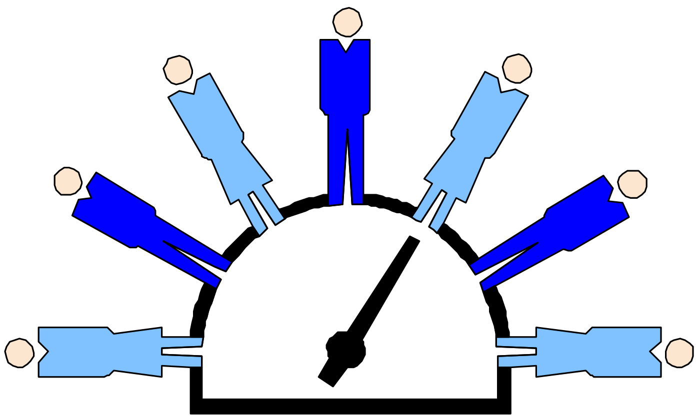
*How much stakeholders are included will depend on how confidant you are that you know which issues are the important ones, and how much of the results of the study will be made public. Publication is the key issue, but remember that if you plan to use LCA as the organizing concept for your EMS, you want to make* *sure you aren't leaving out anything important. Consultation with stakeholders can help you think of issues that you might otherwise miss.*

*If you have decided to include stakeholders, the very beginning of a study is the best time to identify stakeholders to the study. They may include vendors, customers, and competitors as well as environmental groups and academics. For potentially controversial studies, consulting with the stakeholders during the design of the study is a good idea. You have a better chance of including all the right questions, and the right data get collected when you ask everyone's opinion up front. It is less likely that the study will be discredited afterwards. You really want to avoid this very expensive and embarrassing outcome.*

*Each person involved in a study has a different role to play. That role will depend upon the scope of the study, but will mostly be driven by the specialized knowledge each possesses and what the job duties are. You need to decide what your role will be so you can do a good job—and also so that you can find the most important parts of this text, which will make separate recommendations for different roles.*

*Here are some of the roles that may play a part in an LCA study.*

***The environmental expert** within an organization is typically the leader of the internal team managing the study. He or she serves as a technical resource, but the primary role will be coordinating the project overall. That means:*



- ✓ *Scheduling and coordinating all internal meetings*
- ✓ *Providing minutes of the meeting to all participants*
- ✓ *Developing internal communications as necessary*
- ✓ *Following up on assigned tasks*
- ✓ *Smoothing away problems which come up during the course of the study*
- ✓ *Being the primary point of contact with the LCA practitioner*
- ✓ *Coordinating meetings with stakeholders*

*This book is largely aimed at the person coordinating the project. He or she will be the person most responsible for the completion of a useful LCA. We also include some tips for others participating in the study.*

***The engineer** within an organization supports the study by:*

- ✓ *Being an expert on the engineering management systems in the organization*
- ✓ *Coordinating access to engineering data for the study*
- ✓ *Assuring the data and data format is useful for internal organization use (if the study is primarily oriented towards design issues).*

*If the engineer does a poor job of linking the data collectors (LCA practitioners) with the data sources, the study will have a poor or incomplete data set. It is VERY hard to draw legitimate conclusions from an incomplete data set.*

***The manufacturing/operations function** on the team:*

- ✓ *Provides important information about the manufacturing or operations*
- ✓ *Coordinates getting the operational information for the study*

*This role is essential to assure that the operations studied are representative of the normal operations yielding the product or service being studied. Otherwise the conclusions of the study may be plain wrong.*

***The purchasing representative** on the team will:*

- ✓ *Support the team in choosing a practitioner to perform the study*

*If the study compares one vendor's products to another's, the purchasing representative will:*

- ✓ *Coordinate with vendors*
- ✓ *Make sure that the data collection and data format can support purchasing decisions*

*Needless to say, LCAs that help make a purchasing decision can be a touchy subject. It is in the best interest of the vendors to work closely with their customers to make sure a fair and high quality assessment is done. Some LCA's are actually initiated by vendors, and they provide an opportunity to improve relationships with customers.*

***The marketing representative** will play an important role if the study is being performed to support public statements about the environmental status of the product or service. He or she can also be very helpful in identifying and contacting potential stakeholders for the study.*

***The outside expert*** *(sometimes an academic) provides a disinterested review of the study. This means:*

- ✓ *Reviewing the study to assure that it conforms to current best practice*
- ✓ *Checking that the study format is appropriate to the goal and scope of the study*
- ✓ *Checking that the assumptions and methods of the practitioners were correct and properly executed*

*Typically, a panel of outside experts reviews LCA studies that are disclosed to the public. In essence, the outside expert performs the role of an auditor.*

*Outside experts are sometimes used during the performance of the study if some aspects of the study are considered to be unusual or controversial. In this case, the role is to assure that the methods being used are the best available. Here the expert adds credibility to the results of the study.*

***A representative of the public*** *or stakeholder (usually a non–profit (NGO) or a community group) is most likely to be interested in a study when it supports decisions that can have a local impact, for example the choice of a cleanup technique, or the installation of a power plant. The commissioner of the study solicits sometimes stakeholders, other times they have to volunteer themselves. In either case, a stakeholder should:*

- ✓ *Provide information on the concerns of the stakeholder*
- ✓ *Participate in scoping*
- ✓ *Provide technical review*

*A positive stakeholder relationship greatly strengthens the quality of the study. The earlier this participation occurs, the better will be the outcome.*

***Vendors*** *are an important stakeholder in two scenarios: when purchasing decisions are being supported by the study, and when the study encompasses the environmental impacts of parts or subassemblies of a given product or service. It is clearly in the best interest of the vendor to assure that an equitable and appropriate analysis is made of its own products and services. To do this, the vendor:*

- ✓ *Offers advice in the scoping stage*
- ✓ *Provides technical data*
- ✓ *Coordinates vendor's internal resources with the customers'*
- ✓ *Participates in data quality review (if possible)*

*Be aware that vendor management is one of the purposes of many LCA studies. Organizations seeking to meet the requirements of other ISO standards to minimize the environmental effects of their vendor chain often use LCAs as a tool to accomplish this task. If you can support the data collection exercise of an LCA well, you have a competitive advantage versus other potential vendors. This advantage is even greater if you can show that your product has a lower overall impact.*

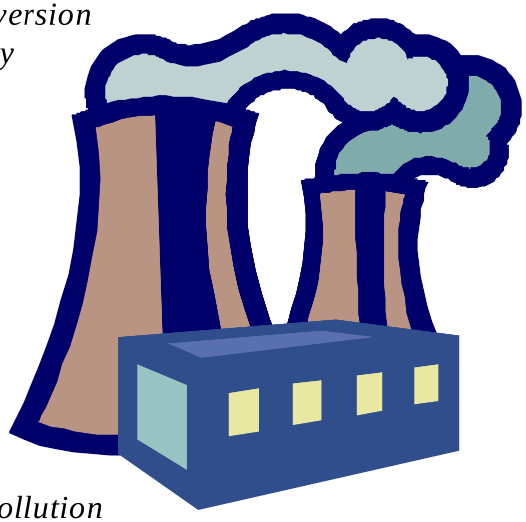
*That about covers it. You should fit into one of these roles if you are actually participating in an LCA. If you are only reviewing the data from an LCA to see if you can use it for something else, you should be aware that a whole group of people with different agendas worked together to produce the final product. Make sure that you understand who commissioned the work and why, and pay close attention to the data quality program embraced in the study.*

*Chapter Two*

# History

*Life cycle assessment came into being in the 1970s, during the oil crisis. As people were waiting in line for gasoline, and energy costs were going through the roof, companies were looking for ways to save on their energy bills. Their customers were asking for energy efficient products. And voila! Energy inventories came into being.*

*The energy sector was the first to get on the bandwagon. Hardly anything has been studied as intensively as the efficiency of conversion of energy from fossil fuels to electricity. The primary consumers of electricity (heavy industry) soon followed suit, and they paid attention to things like line loss and waste heat reuse. Finally, industry responded to consumers with more energy efficient light bulbs, for example.*



*Pretty soon, people figured out that there was a close link between energy production and consumption and pollution. The EPA starting doing pollution assessments and high fuel efficiency fleets came into being, not without some grief in the U.S. car industry. Of course, what the pollution assessments and subsequent regulations didn't take into account is the use part of the life cycle—more on this later.*

*Finally life cycle inventories for energy AND mass began to be done in the late 80s, and in 1990, SETAC (The Society of Environmental Toxicology and Chemistry) began its ongoing series of workshops and monographs on Life Cycle Assessment. The first workshop was held in 1990 at Smuggler's Notch, Vermont. The meeting resulted in a monograph "A Technical Framework for Life Cycle Assessment" which based the Life Cycle Assessment framework on Life Cycle Inventory, an engineering input–output technique that was based on mass and energy balances of life cycle stages, identified as:*

- ✓ *Raw Materials Acquisition*
- ✓ *Manufacturing, Processing, and Formulation*
- ✓ *Distribution and Transportation*
- ✓ *Use/Reuse/Maintenance*
- ✓ *Recycle/Waste Management*

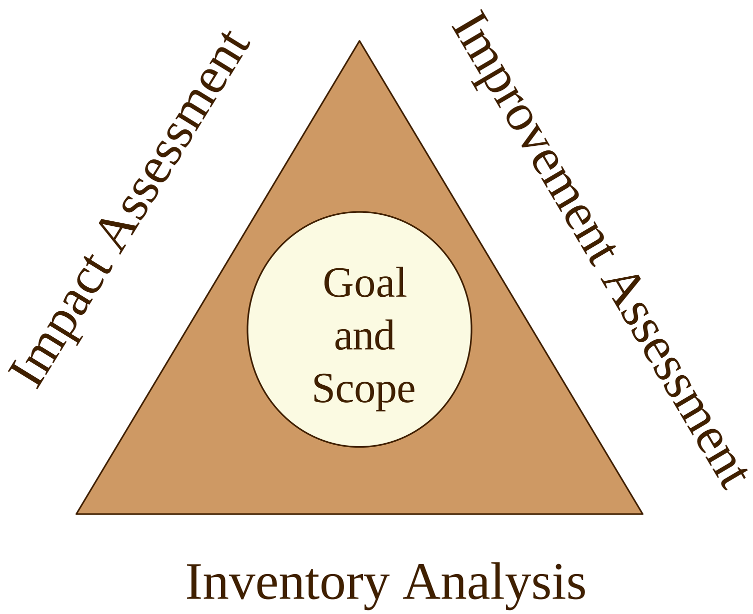
*These life cycle stages were considered to be the system under study.*

*Life cycle assessment was conceived to be a triangle, with inventory at the base, and impact analysis and improvement analysis as the other sides.*

*In 1992, a second workshop was held in Sandestin, Florida, on the role of Life Cycle Impact analysis. The topics covered in this workshop included:*

- ✓ *Ecological Health Assessment: chemical stressors*
- ✓ *Ecological Health Assessment: non–chemical stressors*
- ✓ *Human Health Impact Assessment*
- ✓ *Resource Depletion*
- ✓ *Valuation*
- ✓ *Integration*

*The Framework of LCA was reviewed, and goal and scoping was identified as central to Life Cycle Assessment, and formulated as below:*



*The monograph coming from the Sandestin workshop, A Conceptual Framework for Life Cycle Impact Assessment, identified the steps of impact assessment as classification, characterization and valuation.*

*Classification is the assignment of data from the life cycle inventories into stressor categories (such as greenhouse gases). A stressor category is a kind of environmental impact. Characterization is the estimation of the magnitudes of the impacts for each category. Valuation is a weighting exercise to explicitly combine the impacts across stressor categories.*

*To a large extent, the framework developed in this workshop continues to be used around the globe for Life Cycle Impact Assessments.*

*Other technical documents have been produced and continue to be produced as a result of the efforts of SETAC. However, the practice of LCA has spread out to a wider audience, and new developments in the field are documented through textbooks, and in many other publications, such as the International Journal of Life Cycle Assessment.*

*In 1992, as a result of the Rio World Environmental Summit, the U.N. asked the International Organization for Standardization (ISO) to evaluate whether any international environmental standards were appropriate. ISO formed the Strategic Advisory Group on the Environment (SAGE) to evaluate the issue and return recommendations. SAGE came back with the recommendation that an environmental management standard be written and that it parallel the ISO 9000 quality management standard in many respects. Thus ISO 14000 was born. ISO 14000 is a series of standards international environmental management standard with global scope.*

- *14001 and 14004, environmental management systems*
- *The 14010 series on auditing*
- *The 14020 series on eco–labelling*
- *The 14030 series on environmental performance evaluation*
- *The 14040 series on life cycle assessment*
- *The 14050 series, which collects terms developed in all the different standards*

*Of all these standards, only the 14040 series (Life Cycle Assessment) explains how to integrate what we know about the science of the environment into environmental management. Much of the debate on life cycle analysis has moved from the SETAC venue to the ISO venue. The ISO 14040 series has four separate standards:*

- *14040: LCA framework*
- *14041: scoping and Life Cycle Inventory*
- *14042: Life Cycle Impact Assessment*
- *14043: Life Cycle Assessment interpretation*

*An additional standard on data transfer is currently in development.*

*If you want to publish your LCA study, you will likely wish to look into these standards and decide whether you wish to follow them. The World Trade Organization views ISO standards as the accepted international consensus, and following these standards when making environmental claims will protect you from the accusation that your claims and practice are effectively a trade barrier. Even if you are not planning to publish your study, the standards offer valuable guidance about how you might wish to format your study.*

*The bottom line, though, is that the ISO standards are all voluntary—you don't have to use them if you don't want to, and many LCAs (especially those done for*

*Lots of times, you don't want to do a full blown Life Cycle Assessment. Instead, you may follow life cycle management principles, or "life cycle thinking." All of which really means that an attempt is being made to look at environmental issues from a system–wide perspective. And that is a good thing, too.*

### International Organization for Standardization (ISO)

*The (non–profit) International Organization for Standardization (ISO) was formed right after the Second World War. Its purpose is to provide standardization to facilitate international trade. The way it works is that different countries participate through their national standards organizations, which call on the (volunteer) work of the interested parties to form consensus standards. Technical groups within countries meet and develop their country's positions, and delegates from these groups meet together internationally to hammer out language acceptable to all parties.*

*Most of the standards developed through ISO are physical or chemical standards. For example, there are ISO standards for photographic film and for credit cards. These standards allow you to use your credit cards and get film for your camera anywhere in the world. Conformance to the standards is completely voluntary. But following those standards means that your business can sell goods all over the world, so most industries are eager to do so.*

*About 15 years ago, ISO developed its first management system standards, the ISO 9000 series. These standards tell companies what they have to do to provide a consistent product, and companies all over the globe have become certified to ISO 9000.*

*When ISO 14000 was first envisioned, it was decided to follow the same format as ISO 9000, and there is an ongoing effort to harmonize these two standards.*

*Deciding the scope of your study is where you begin. Scoping is not a one-time event, but something that is revisited over and over during the study. It is the most important thing you will do during the entire study. Why? Because how you scope your project determines what you will get in the end. Even though this chapter is titled scoping, expect to hear more about this topic throughout this book— it really is the key to a successful study.*

*Begin with the most basic questions. What you are trying to accomplish with your LCA? What questions are you answering? What decisions are you trying to support? Who will read the study? Who will read the study summary? Who will use the results?*

*You may be saying to yourself, "that's obvious—I just want this study to tell me where the environmental problems are. That's easy!" Think again.*

*A lot of LCA studies fail because critical questions remain unanswered. Mostly, they fail because there never was a clear statement of the question or questions being asked. Define your questions carefully and scope your study carefully. Don't spend time and money on a study that will end up gathering dust on a shelf.*

*But don't worry: you already have the skills to do a good job scoping your LCA, because scoping exercises are something that you do all the time. We'll prove it with an example.*

*Suppose you decide one day that you want to redecorate your living room. Your first thought is that you want to redecorate. The place looks dingy to you. You're tired of looking at those old drapes. The carpet color looks like it belongs in a homeless shelter. It has paths worn into it. You have made a first scoping* *decision. You are going to do something about a particular problem—your living room.*

*Later on, you have more detailed decisions to make. Some of the things that will guide your decisions will be whether you do a lot of entertaining, and the size of your budget, and who lives with you (kids and pets, as well as your mate). So you will decide things like:*

- ✓ *What color scheme you want*
- ✓ *What style or feel you want in the room*
- ✓ *Whether you are going to do the design work yourself or hire an interior decorator*
- ✓ *Whether you will do any of the physical work yourself*

*Once you decide these, you've made your second set of scoping decisions.*

*Of course, if you redecorate the living room while your mate is out of town, you might find that you have fireworks when they get back. Or if you decide on a motif of white silk while you kids are still spreading blenderized carrots across the landscape, you might not be happy with the result. So you need to be practical and realistic.*

*Your final scoping for your living room re–do covers all the details. Unless you are Bill Gates, you will be making some trade–offs. You probably won't be able to buy customized Bokara rugs AND that hand–carved chestnut wainscoting. You will make final decisions about the material for the drapes, the carpeting, the shade of the walls, and so forth. You will hire contractors as necessary, and get the job done.*

*In the end, your living room makeover should take care of the problems that bothered you in the first place—that dingy look should be gone. If you did it right,* *the whole household as well as your guests should be pleased to spend time in the room.*

*Scoping an LCA is just like scoping your redecorating. You do it in phases, each more detailed than the last. You decide on boundaries. You are constrained by finances, and by your stakeholders. The end results will depend on how well you did your decision making up front. If you do a good job, lots of people will find the results to be useful.*

## Preliminary Scoping

*If you are in charge of the project, sit down by yourself or with a few people and develop a preliminary scope for the study. Don't invite the guy down the hall who is totally detail–oriented. You'll need that help later on, but right now too much detail will probably just muddy the water.*

*This first LCA scope should say what it is you are studying (what room you are fixing), what environmental aspects of the system you will be studying (carpeting, walls and curtains, or only walls), who you expect to use the results, and a short list of questions you want to answer. Most important, develop a list of the people who should be helping with the more detailed scoping exercise.*

*Perhaps the most confusing issue is the one of what it is you are studying. In LCA, this is called the system function. It is the subject of the entire study, but is an elusive concept starting out. LCAs are studies of the environmental impacts of products and services that perform a useful function. The concept of system function is at the heart of the LCA study. It is what allows you to compare really disparate things to see tradeoffs. For example, you can compare the impacts of videoconferencing versus face–to–face meetings. Videoconferencing has a certain infrastructure (cameras, screens, cabling and electrical consumption). Face–to–face meetings have another (car and plane environmental impacts, primarily).*

*Both systems can have the same function: to permit an exchange of verbal and non–verbal communication.*

*So think about what it is your organization sells. If you are selling carpeting, the system function is to cover the floor, for a certain period of time. Your study should look at everything from growing or manufacturing fiber, to manufacturing the carpet, to transporting and installing the carpet, to cleaning the carpet, and finally to disposal at end of life. You will want to compare your results to competing products, such as wood flooring, which has a very different set of environmental impacts.*

*Suppose your company makes garments, and you are interested in choosing between making jackets out of either wool or cotton. An example of a first scoping exercise can be seen in the sidebar. Here we are comparing the production of cotton and wool cloth. Don't try to be detailed at first: the point is to get the main ideas down. You are putting on paper the first outline of the study so that you can take it to a larger group for a second scoping. The idea is to put down enough information so that the bigger group understands what it is you are trying to get at. After that, you will probably be hiring a contractor to perform the study itself. They will step you through a very detailed scoping exercise that will put very clear boundaries on the technical aspects of the study.*

### First Scoping

**Example: A life cycle assessment of cotton and wool cloth**

***Questions to be answered***

- *What are the major environmental impacts of cotton versus wool production and use*
- *What parts of the life cycle have the greatest impacts?*
- *Does it matter where the cotton or wool is grown/manufactured?*
- *Can we show that cotton is more environmentally friendly than wool or vice–versa?*

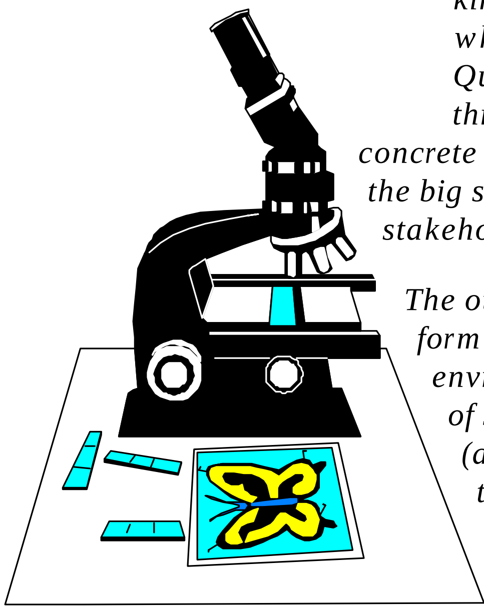
***System Boundaries***

- *The whole life cycle included*
- *Need to look at the major sources of cotton and wool*
- *Need to look at the major manufacturing sites*
- *Need to decide about disposal/recycling issues*
- *Want to publish*

*Talk about what you want the study to do for you. LCAs have been done on all kinds of things: building materials, power installations, paper cups, jet engines. Decide what exactly you are going to study. Remember, LCA is about a cradle–to–grave look at a product system. But be realistic. Some of the best studies have been done on a cradle–to–gate approach. The study stopped at the gate where the product was sent to the customer. If you are making a raw material, it may not be possible for you to know all the uses your customers may put that material to. The key is to evaluate the environmental aspects over which you have some control. After all, you are trying to understand the environmental impacts of the product, not just gather data into neat piles.*

*Another approach to LCAs is the gate–to–grave approach. You look at the environmental impacts of your product from the time that raw materials (or components) come into your possession, through the transportation, use and* *disposal stages. This works well for complex consumer goods whose main impact is expected to occur mostly during use and disposal. For example, consumer appliances or services fall into this category.*

## Second Scoping



*The biggest reason for LCAs to fail is that the stakeholders were not identified and talked to. So after spending big bucks, someone says "But you didn't look at ___," (fill in the blank) "and that is the only thing that is important." An example of this kind of mistake was made by the James Bay Power Company, (James Bay), which looked at the Life Cycle Inventory of the hydroelectric dams in northern Quebec—but excluded any consideration of the impact of flooding of land. Since this project flooded thousands of acres of tundra, the impact in terms of tons of concrete poured (a major impact measured in the study) was really not very important in the big scheme of things. The second stage of scoping is about LISTENING to your stakeholders.*

*The other big reason for talking with stakeholders is that LCAs yield results in the form of apples and oranges—you can't really add them up. That is because different environmental impacts really are different from each other, and it takes some kind of social exercise to determine how to convert a basket of apples and oranges (and pears and bananas) into a basket of fruit. An example of a study that had this problem was the one that compared disposable and cloth diapers. Basically, cloth diapers use lots of water, and disposable diapers use up landfill space. Without some input from stakeholders about whether landfills or drinking water were most important, there was no way to claim one kind of diaper is better than the other.*

*The problem with both these studies can be tracked down to scoping. James Bay should have listened to their stakeholders (including the Indian tribes whose hunting grounds were being flooded) and included that impact in their study.*

*Proctor & Gamble (the commissioner of the diaper study) should have sat down with their stakeholders and developed some agreement on the relative importance of landfills versus drinking water before the study started. Then they could have applied the stakeholder's weightings to the results, and been able to state the relative (social) importance of the impacts they measured.*

*Of course, tracking down those stakeholders and asking them what they think is expensive—but not as expensive as doing a life cycle study that has no conclusions, raising more questions than it answers.*

*So, if you are starting up a life cycle study, you need to ask yourself a few questions.*

*First—What are you trying to use this study for? The most common use of LCA's is to support market claims, but many organizations also use them for internal reasons only, such as:*

- ✓ *To provide a logical and consistent framework for the Environmental Management System (EMS),*
- ✓ *To identify environmental aspects and impacts,*
- ✓ *To measure performance,*
- ✓ *To communicate progress internally,*
- ✓ *To support Design for Environment (DfE) needs, telling the engineering department where they should be focusing efforts for design improvement.*
- ✓ *To manage vendors' environmental performance*

*Second-- Who is the audience for this study? How you collect, analyze and present the data will be very different if your audience is the engineering department versus if it is the management team.*

*Third--is this study (or its results) going to be published? If so, now is the time to bring on the whole gang to look at how you are going to do the job. It will be frustrating— and you may decide that you don't want to follow through and do the study after all. But that is a good, not a bad outcome. At least you didn't waste time and money on something no one can agree on. Which brings us to*

*Fourth-- How much time and money can you spend on this study? Data collection is difficult and time consuming, and even a small study can suck up an inordinate amount of time. For this reason, we recommend that you look into designing the study for multiple uses. It might take a bit more work, but you'll get a bigger bang for your buck.*

*OK, now you are doing your second phase of scoping. You have identified your stakeholders (inside and, if necessary out) and gotten them all in one room. What happens in that room?*

*The first item on the agenda is to tell everyone what they are there for—what a Life Cycle Assessment does, and what your preliminary scoping exercise concluded. Remember the thing you did all by yourself? Copy it off the back of the envelope and onto something that looks more official. If you are not publishing your study and have only internal stakeholders, you may wish to talk about the budget. Judicious financial limitations can also be useful for scoping with external stakeholders. Most people understand the tradeoff between data collection and analysis and dollars.*

*Back to your wool versus cotton comparison. At this meeting, you will probably have issues of functional equivalency brought up: is cotton as warm as wool? Does it last as long? Can it be used to make the same kind of jacket? It is important that you identify the function that the cotton or wool performs. Cloth alone serves no useful function. It is only when it gets turned into something that can be directly used that it is possible to identify the function. In this case, you can identify the weights of material necessary to provide equivalent protection to the wearer, and you can choose the particular model of jacket you intend to* *study, perhaps medium weight jackets, which have the most opportunity to be made by both kinds of cloth. Your functional unit may be the material needed to produce 100,000 jackets which last for at least 75 wearings. But it really is not necessary to pick out your functional unit just yet. It is more important to identify the function (protection at a certain level for a certain amount of time) rather than the units you will use (amount of protection for a specified period of time).*

*Besides asking the system function questions, your team may help you identify some of the things that may be concerns in the study, for example:*

- *The use of pesticides in the production of cotton*
- *Allocation of impacts for wool between wool, lanolin and meat production*
- *Land use and land degradation (intensive agriculture vs. grazing)*
- *Fuel used by agricultural practices*
- *Different methods of cleaning, carding and spinning the two fibers*
- *Different sources of the fiber (e.g. Egyptian vs. Georgian cotton; New Zealand vs. Montana wool)*
- *Different efficiencies of cutting of the different cloths*
- *Ease of recycling of the different waste fibers*
- *Different dyeing methods and impacts of the two fibers*

- *Previously unidentified issues: global warming due to grazing animals*
- *New technology to decrease energy usage in production of garments*
- *Data sources internal and external*

*The main thing the stakeholders (inside and outside) are there for is to help you design the study to be useful—to answer as many questions as well as possible for the smallest amount of money. If your LCA is small and is only being used for internal purposes, there is no need to bring in outside stakeholders, unless you need additional technical help about a particular technical challenge.*

*Regardless of whether your stakeholders are internal or external, Make sure that you explain to them exactly what you want from them—written or oral feedback, ongoing or a one–time input, advice or permission. Probably different stakeholders will contribute different levels of effort. Decide about any further meetings: who, when, where, and the topic.*

*After the meeting, send a copy of the minutes to all attendees (and anyone else who needs to be in the loop). Don't forget to thank all the stakeholders—after all, they have other important things they could be doing besides helping you with your study. Your minutes should provide a summary of the scoping exercise you just performed.*

*By the way, you should expect to pay travel costs for the external stakeholders you invite to your meetings. A small honorarium is not unusual, either, but you want to make it small-- otherwise you may have the appearance of having "bought" your stakeholders.*

*The sidebar below shows the outcome of a second scoping exercise: We have a better handle on that wool versus cotton cloth study, and can now pick out a consultant to do the study.*

## Second Scoping

**Example: A life cycle assessment of cotton and wool cloth**

***Questions to be answered:***
***What are the major environmental impacts of cotton vs. wool production and use***

- *What parts of the life cycle have the greatest impacts?*
- *Does it matter where the cotton or wool is grown/manufactured?*
- *Can we show that cotton is more environmentally friendly than wool or vice–versa?*

***System function and functional unit:***

*Wool and cotton cloth needed to make 100,000 jackets, with a lifetime of 75 wearings.*

***System Boundaries***

- *Will look at cotton grown in the American South vs. Egypt*
- *Will look at wool grown in New Zealand vs. Montana*
- *Will look at cotton and wool mills in the American South and in Great Britain*
- *Will supplement information with industry–wide data from the International Cotton Association and the International Woolen Products Association*
- *Will gather inventory information on land use, pesticide application, agricultural runoff pollution and fossil fuel use in the production phase*
- *Will use database information for transportation impacts*
- *Will gather inventory information on raw materials use and emissions from manufacturing*
- *Will gather inventory information on recycling/reuse of fibers, and average useful life.*
- *Will gather information on the washing vs. drycleaning of jackets made of cotton vs. wool (will use database information to evaluate inventories for these operations).*
- *Will estimate landfill impacts for disposal*

***Items not in the system***

- *Buildings, equipment and machinery*
- *Employee travel impacts*
- *Non–fiber uses of sheep*

***Second Scoping: Impacts to be evaluated***

- *Land use*
- *Fossil fuel depletion*
- *Aquatic and terrestrial toxicity*
- *Eutrophication*
- *Global Warming*
- *Water resource depletion*
- *Ground level ozone*
- *Acidification*
- *Acute health impacts from air emissions*

## Outside Experts and NGOs

*The main job of outside experts and NGOs is to think about the big picture. Are there other, similar projects that have been done, and what worked and didn't for them? Academic peers and outside constituencies may have information that could be useful here. Where the constituency is focused (say, on water issues), bringing that perspective and those issues to the table can be helpful. It can assure that those important environmental issues are addressed. Outside experts with special technical knowledge should share it! One shouldn't assume that the commissioner of the study knows everything about the environmental implications of their products and services.*

*On the other hand, one can assume that the commissioner of the study knows a great deal about the relevant industrial processes, much more than any outside stakeholder. Pumping study commissioners for information about how products are made, transported and sold, used and recycled is appropriate behavior. That information will make NGO's much more effective participants in discussions. If one doesn't know or understand the technical issues, asking questions and following up on advice on how to learn more about them improves ones effectiveness.*

*Experts and NGO's knowing of significant environmental issues related to the product under study should bring them up! If some environmental concern will be excluded, there should be a good reason to exclude it. A legitimate reason to exclude an environmental issue is that no one knows enough to develop a numerical model of it. The life cycle study will be strengthened by stakeholders' thoughts. Realize however, that the study can't do everything. Sometimes the cost of pursuing some issues is so high that it just isn't worth it.*

*One way of figuring this out is by making a list of issues that one's organization thinks are important, then prioritizing them. Combine that with a guesstimate of the cost of getting the information (high/medium/low), will yield a picture of* *which issues are going to be easy to get through, and which are not. The table below illustrates this approach to negotiation planning. Note that the ratings will be project specific, and will also reflect the opinions of those filling in the matrix.*

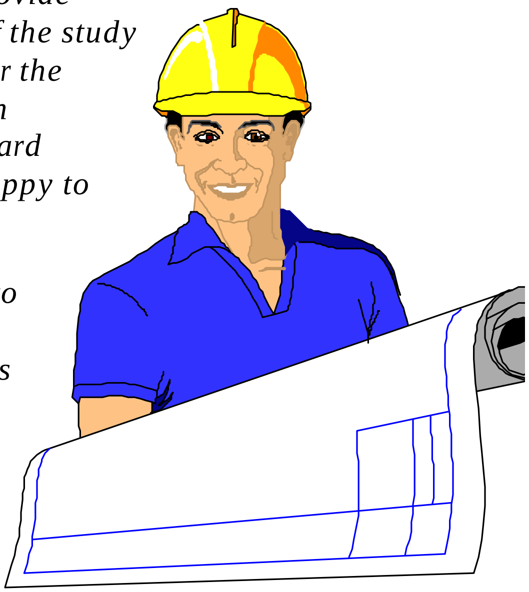
| ***Issue*** | ***Importance*** | ***Cost*** | ***How Hard to Win*** |
|---|---|---|---|
| *Biodiversity* | *Medium* | *V. High* | *Hard* |
| *Water use* | *Medium* | *Medium* | *Medium* |
| *Fossil fuels* | *High* | *Low* | *Easy* |
| *Aquatic toxicity* | *Medium* | *High* | *Hard* |
| *Acidification* | *Medium* | *Low* | *Easy* |
| *Noise* | *Low* | *Medium* | *Medium* |
| *Human Health* | *High* | *V. High* | *Medium* |
| *Mineral Resources* | *Medium* | *Low* | *Easy* |

*In this particular analysis, issues of Human Health and Fossil fuels are rated as of high importance. Fossil fuels information is cheap, and therefore it will be easy to get that kind of information into the study. Human health information is much more expensive to obtain, and therefore more effort will have to go into getting those issues included in the study.*

*The real decision points come in the medium importance group. One will have to decide which things to let ride and which are worth fighting for. Realize, too that there is plenty of room for compromise on most of these issues. For example, biodiversity measurements are very expensive to obtain. But one may be able to get a handle on biodiversity through estimates of land cover, which is very cheap. As an outside expert, being patient but firm while keeping upbeat make one an effective participant in the discussions.*

*This kind of prioritizing exercise can also be helpful for the entire team to look at, to help scope the project. Separating the importance discussion from the discussion of costs helps make the decision process easier.*

## Engineering and Production



*The engineering and production staff will be called upon to provide production data. The better the data is, the better the results of the study will be. And the more statistically treated the data, the cheaper the study will be. That means, if lots of data that has already been collected over the past year or years, and the mean and standard deviation of the numbers are known, the consultant will be happy to take the "massaged" data rather than the raw data.*

*The kinds of production data that will be requested will have to do with the mass and energy balances of the processes. That means how much electricity, fuel, metal, plastic or whatever is used to make the product. And how much waste is produced.*

*Engineering and manufacturing or production staff can help in the scoping exercise if they know immediately what the products are made of—and the relative amounts of each thing. Say the product is integrated circuits. The staff knows that they are made from backing material, copper, lead, silver, and gold, as well as plastic resins, and a bunch of other material in resisters and so forth. Probably the resins are the biggest waste stream—and lead is the nastiest waste stream. The precious metals are probably well recycled—and perhaps they should be left out of the data collection exercise as not environmentally important.*

*The company may make comparable items in different places. Manufacturing and engineering can suggest which and how many facilities should be looked at. It usually isn't necessary to study all the facilities. In fact, many (if not most) LCAs are based on looking at just one or a few examples of each life cycle stage. The trick is to find the best examples for getting the answers to your questions.*

*Most studies choose one of two approaches: either they look at the best case example, or they look at a representative example. No one looks at the worst case. You need to decide which approach to take. A best case has the advantage of acting as a spur for the less–than–best examples to get moving on their improvement plans. It also is less likely to cause embarrassment if published. And you can count on finding a wide range of environmental performance at different facilities.. A few studies have tried to capture ALL facilities. This is clearly the most representative data. This approach is useful, because it gives you a snapshot of the "real" picture: on average, what are the impacts of a product? Which brings us to the other approach, selecting representative facilities If you want to make claims of environmental superiority, you had better use representative data. Otherwise you may well be accused of having cooked the numbers.*

Don't Cook Your Numbers!

*If you are trying to get at the representative numbers, you will also want to gather data that you can do statistical analysis on (actually, you want to do this no matter how you set up your study). The reason for this is that the environmental performance of (supposedly identical) processes varies all over the block. This is true for ALL life cycle stages. You really do want to know if your numbers are significantly different from zero—and if different examples of your processes are different from each other.*

*One of the problems with using surrogate data (or data from databases) is that you rarely get any information about the statistical variability of the data. This is not too important, if the majority of the impacts of concern come from the processes you gather your own information on. If you are using database information to evaluate your primary environmental impacts, you may wish to re–evaluate that* *decision.*

*Another of the problems you are probably going to have to deal with is the issue of DATA GAPS. This problem raises its ugly head in every LCA known to man (or woman). There is bound to be someplace in your analysis where you just don't have the information you need to figure out what is going on. Either the information is at too high a level (the whole planet, or the whole country) or in the wrong format or just too hard to get in time for the study. What do you do then?*

*Basically there are only a few things you can do.*

- ✓ *First, decide how important that data is to the whole study. Is having not–so–good (or absent) numbers going to make a big difference?*
- ✓ *Then, if the numbers are not critical, use published data, or engineering estimates, or information from another, similar process (this is called surrogate data), or even seat–of–the–pants estimates (these are called "professional judgement" if you have a PE)*
- ✓ *If the data is critical to your analysis, then you have three choices:*
  - ➨ *Get the data by shelling out big bucks*
  - ➨ *Re–evaluate the scope of the project (there's that S word again)*
  - ➨ *Call a screeching halt and stop spending time and money on something that's not going to work*

.

## Marketing and Purchasing

*The role of the marketing and purchasing functions in scoping are sometimes opposed to each other. The purchasing guy or gal tries to keep the costs down, while the marketing guru wants to get as much good material as possible. Together, they can strengthen the study by providing balance.*

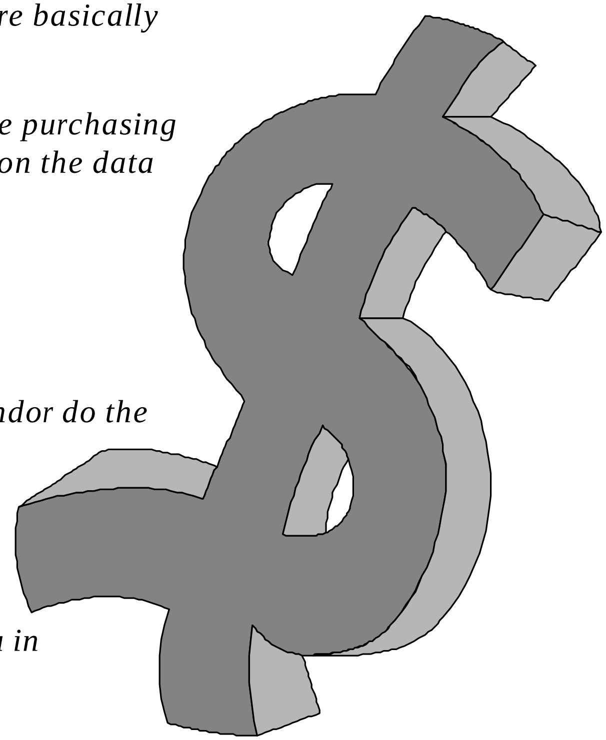
*Of course, sometimes (often!) life cycle studies are done at the request of one of these functions. Then the work has to be focused on the needs of that function.*

*When using a life cycle study for supply chain management, there are basically three ways to go about funding the work.*

1. *You can make life cycle information requests a requirement of the purchasing contract, and then pay someone to do the life cycle study based on the data from the vendors, or*

2. *You can require that vendors do life cycle studies themselves, or*

3. *You can partner with the vendors to do the work together.*



*There are pros and cons in each of these approaches. Having the vendor do the work means that you need no outlay of resources. But every vendor will do it his or her own way, and you may have difficulties comparing apples and oranges at the end. And if you are a small part of their business, they may simply refuse your request and let you find another vendor. On the other hand, if you are their biggest customer, the vendor will probably pass the whole cost along to you in product cost.*

*Life cycle studies can be expensive. If marketing and purchasing are your goals, recognize that you need a payback to your life cycle studies.*

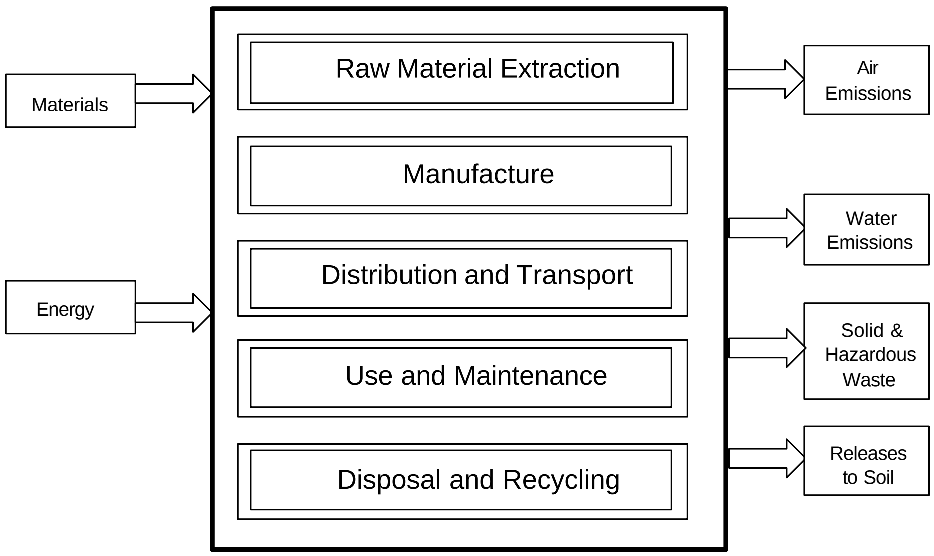
*All this means that you should be careful selecting your LCA Practitioner. Make sure that you have picked a firm with experience in the Life Cycle Assessment field—you don't want to pay them to gain expertise! They should be familiar with software and international standards on Life Cycle Assessment.*

*If you are planning to use your LCA for marketing purposes, you will be doing an impact assessment, too. Make sure that your consultant knows how to do Life Cycle Impact Assessment, which is quite different from standard environmental impact assessment. Note, too, that many life cycle practitioners are really only experienced in developing inventories. Your consultant should have experience with both. See chapters four and five to get a better idea about what this means.*

*Chapter Three*

# Life Cycle Inventory: The Engineer's Dream

*The Life Cycle Inventory (LCI) is a funny beast. You do it by breaking your product system into five boxes:*




*Then you try to figure out how much energy and material is moving into and out of these boxes. That's it.*

*Of course, it's lots more complicated than that, and there are lots of places where you are going to have to make decisions. For example, although we have these neat little boxes we are putting everything into, where are the edges of those boxes? Say you are looking at the extraction box. If you are making sheet metal, it is pretty clear that your extraction box will include the mining of the metal. On the other hand, if you are making computers, it is not likely that you will want to go all the way to the mining of the fifty or so elements that are found in your hundreds of components. You may not even want to look at the manufacturing of your components, but just consider them as raw material coming to your door.*

*Deciding where the lines of these different boxes should be placed is part of the scoping of the project, and is called setting the boundary conditions.*

*You have lots of flexibility to set your boundaries wherever you like, but it will always be a balancing act that looks at:*

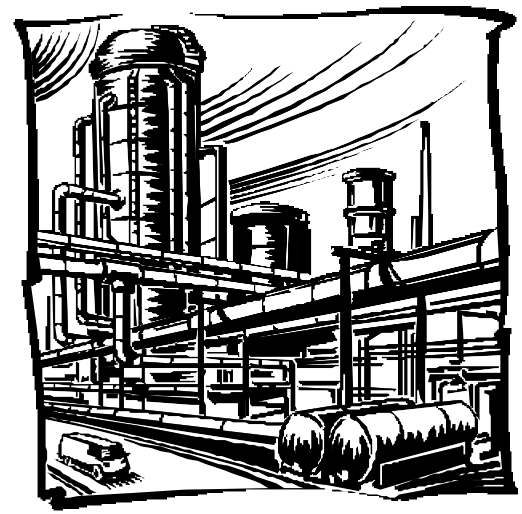
- ✓ *The questions you are trying to answer*
- ✓ *How much time you have to put into the project*
- ✓ *The cost of getting the data*

## Information Sources for Inventories

*Remember the telephone game, where one person whispers a message to another, and so forth around the room? Remember how the message got garbled in translation? The same thing happens with Life Cycle Inventory information.*

*You can get information about processes from primary, secondary, or tertiary sources. The primary data comes from the people who collected the data. For example, the results of a stack test or a discharge monitoring report or purchase records are primary data. This data is the best kind (highest quality) you can get.*

*Secondary data comes from someone who has assembled the data. So, if your discharge monitoring report results are summarized by the EPA (trust us, they are), and you use that data for your inventory, you are using secondary data. If someone has taken data from secondary sources and further assembled it, you have tertiary data. An LCI report is tertiary data.*



*Every time you transfer data from one person to another you get a chance to degrade it. On the other hand, the more aggregated the data, the cheaper it is to get.*

*One cheap source of estimates for life cycle inventories is the large and proliferating databases available commercially. These databases are a collection of the data collected by consultants over several or many years, and are either secondary or tertiary data. Many of the databases are available as part of a computer model—some of them are only available as part of a model (you can't see the data itself, only the output of your calculations). Cheap, of course, is a relative term. These databases usually come with an annual licensing fee of up to $20,000. On the other hand, the cost of collecting the primary data is enormous. The same $20,000 will buy you one stack test, out of which you get perhaps a half dozen inventory emission numbers. Since literally thousands of data points are needed for an LCI, you can see how the cost can escalate if you use only primary data.*

*Another thing you might want to think of is the problem of aging data. Most manufacturing sites work hard to decrease their emissions all the time. The result is that three year old information may show processes to be twice as dirty as they actually are today. The same kind of thing goes on with resource use—think of how soda bottles and cans have gotten thinner and thinner—using fewer resources than ever before. At the very least, the age of your data should be known, and if trends in the data are clear, they need to be reported in your final report.*

### Examples of Sources of LCI data

**Proprietary Databases**
- *The Boustead Model (a proprietary database)*
- *The Ecobilan Database (a proprietary database)*
- *LCAdvantage*

**Private Information**
- *Business confidential data*
- *Vendors data*
- *Data from industry associations such as the American Forestry and Paper Association and the Chemical Manufacturer's Association*

**Public Data**
- *EPA compliance databases*
- *USGS databases*
- *BUWAL database (available as a book and on disks)*
- *Satellite photos*
- *Published reports*

*What all this is saying is that you will need to make some decisions about the kinds of information you will need, to get to the answers you want. Deciding which information is most important in getting to your results is called sensitivity analysis. The concept is that you think about how variations and errors in the data will affect the end result, and then you get better data for the parts of your system where variation can have the greatest impacts on your results.*

*For example, fuel consumption is almost always a big impact in industrial systems, either from the point of view of operations or of transportation or power generation. But energy impacts have been studied to death—you can get good estimates of your* *emissions without doing any stack tests. What you might want to be careful to collect, then, is really good information about actual fuel consumption or electricity use. And you want to know what your electrical grid looks like, too.*

*The table below is an example of the level of data collection detail that usually goes into Life Cycle Inventory studies.*

## Partial Inventory Data Collection Table

| **Site:** | | | | | |
|---|---|---|---|---|---|
| **Process** | | **Process Number** | | | |
| Fuel Type | Usage | Dates covered | Data Source | Data Type/Units | Error Estimate |
| 1. | | | | | |
| 2. | | | | | |
| 3. | | | | | |
| Air emissions | Amount | Dates | Data Source | Data Type/Units | Error Estimates |
| 1. | | | | | |
| 2. | | | | | |
| 3. | | | | | |
| Water emissions | Amount | Dates | Data Source | Data Type/Units | Error Estimates |
| 1. | | | | | |
| 2. | | | | | |
| 3. | | | | | |
| 4. | | | | | |
| Solid Waste emissions | Amount | Dates | Data Source | Data Type/Units | Error Estimates |
| 1. | | | | | |
| 2. | | | | | |
| 3. | | | | | |
| 4. | | | | | |
| Materials Usage | Amount | Dates | Data Source | Data Type/Units | Error Estimates |
| 1. | | | | | |
| 2. | | | | | |
| 3. | | | | | |

*This is only a taste of the kind of information that needs to be gathered—a lot more detailed information is usually gathered for an LCI.*

*Once all this data is gathered about processes, the information is allocated and normalized to the functional unit.*

*The concept of the system function and the functional unit is at the heart of Life Cycle Assessment. It is what makes LCA different from all other environmental techniques. The system function is the reason why a product or service is purchased. For example, e-mail and surface mail both provide the same function: transfer of written and graphical materials between distant locations. The functional unit is a convenient way to compare different products and services. For example, you might want to use one thousand document pages of letter size as your functional unit. All your results would be expressed as the amount of matter and energy used or released in transferring one thousand pages of copy.*

*Industrial processes are complex, and often produce many different products from the same manufacturing processes. If you doing a study of carpeting versus wood flooring, for example, you will have to allocate the inventory data to the products you are concerned with. That means that if you are looking at forestry or agricultural practices, you will have to decide what proportion of the inventory data belongs to your product. How many acres of land did it take to grow just the cotton fiber used in making the carpeting? How many acres of forest production went into making your flooring?*

*The next step is the LCI is aggregation. That means that you add up the inventory across all sources. Thus, if your company has factories in Japan, the U.S., Latin America, and Australia, you will add up things like total $SO_2$ emissions or total water consumption in all these different places. Note, however, that some LCA studies leave the data dis-aggregated, so that better impact assessment can be performed.*

*Finally, the inventory data has to be normalized to the functional unit. That means that if you are studying flooring, you will have to choose an amount of flooring that you wish to work with (say, 100 square meters for 20 years). Then you divide your allocated, aggregated data by the functional unit. You end up with units of mass and energy per functional unit. The table below shows the results of one such study.*

*The study evaluated the production of steel in the United States, and the functional unit was the total annual output of the largest steel mill in the country. The production of steel requires large quantities of metallurgical coal and other energy. Only the energy and fossil fuel balance is shown here. You can imagine what the entire inventory looked like (it was a small book all on its own, and the life cycle study ran to hundreds of pages).*

## Energy Balance, Steel Production
## (Courtesy Steel Recycling Institute)

| Process | Production | | Coke Ton | | Electricity kWh | | Steam 1000 MJ | | BF gas 1000 MJ | | COG Gas 1000 MJ | | Natural gas 1000 MJ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | *units / year* | *unit* | *input* | *Output* | *Input* | *output* | *input* | *output* | *input* | *output* | *Input* | *output* | *input* | *output* |
| **Coking** | | | | | | | | | | | | | | |
| *Coking* | *4,160,494* | *ton* | | *4,160,494* | *576,490,299* | | *5,527,968* | | | | *10,595,272* | | | |
| *COG Gas prod. 1)* | *41,862,808* | *1000 MJ* | | | *199,554,334* | | *1,913,527* | | | | *3,667,594* | *41,862,808* | | |
| *By–products* | *15,901,671* | *1000 MJ* | | | *75,801,111* | | *726,857* | | | | *1,393,143* | | | |
| *Power plant* | | | | | | *206,508,059* | | *8,168,353* | | | *11,535,529* | | | |
| **Coking Total** | | | | **4,160,494** | **851,845,744** | **206,508,059** | **8,168,353** | **8,168,353** | | | **27,191,539** | **41,862,808** | | |
| | | | | | | | | | | | | | | |
| **Steel Production** | | | | | | | | | | | | | | |
| *Blast Furnace* | *2,026,754* | *ton* | *911,315* | | *76,800,000* | *285,078,053* | | *1,927,150* | | *9,501,638* | *5,304,800* | | *4,307,381* | |
| *BOF Steel making* | *2,543,123* | *ton* | | | *283,600,000* | | | | | | *141,765* | | *151,891* | |
| *Cont.casting/cutting* | *2,543,123* | *ton* | | | *69,600,000* | | | | | | | | | |
| *Other* | | | | | | | *11,929,079* | | | | | | | |
| *Power plant 1* | | | | | *3,708,000* | *155,504,541* | | *3,378,327* | *3,206,225* | | *629,759* | | *125,711* | |
| *Power plant 2* | | | | | *3,662,234* | *152,972,644* | | *3,323,523* | *3,199,662* | | *871,421* | | *173,913* | |
| *Power plant 3* | | | | | *3,654,096* | *151,867,816* | | *3,300,079* | *3,095,462* | | *1,046,925* | | *210,874* | |
| **Steel Production Total** | | | **911,315** | | **441,024,330** | **745,423,054** | **11,929,079** | **11,929,079** | **9,501,349** | **9,501,638** | **7,994,670** | | **4,969,770** | |
| | | | | | | | | | | | | | | |
| **Steel Forming** | | | | | | | | | | | | | | |
| *Hot strip mill* | *2,396,124* | *ton* | | | *262,700,000* | | | | | | *4,712,424* | | *1,077,162* | |
| *Pickling* | *1,305,075* | *ton* | | | *13,100,000* | | *190,056* | | | | | | | |
| *Cold rolling* | *1,121,247* | *ton* | | | *109,500,000* | | | | | | | | | |
| *Ann. & tempering* | *762,485* | *ton* | | | *43,800,000* | | | | | | *555,669* | | *111,176* | |
| *Hot–dip galvanizing* | *239,990* | *ton* | | | *8,760,000* | | | | | | | | *240,494* | |
| *Other* | | | | | | | *355,734* | | | | | | | |
| *Power plant 4* | | | | | | | | *190,013* | | | *213,107* | | *24,463* | |
| *Power plant 5* | | | | | | | | *252,636* | | | *284,023* | | *31,772* | |
| *Power plant 6* | | | | | | | | *54,316* | | | *60,415* | | *7,480* | |
| *Power plant 7* | | | | | | | | *48,825* | | | *55,422* | | *5,609* | |
| **Steel Forming Total** | | | | | **437,860,000** | | **545,790** | **545,790** | | | **5,881,060** | | **1,498,155** | |
| | | | | | | | | | | | | | | |
| **Total Steel System** | | | **911,315** | **4,160,494** | **1,730,730,074** | **951,931,113** | **20,643,222** | **20,643,222** | **9,501,349** | **9,501,638** | **41,067,268** | **41,862,808** | **6,467,925** | |
| *External import (+)/export (-)* | | | | *3,249,179* | | *778,798,961* | | *0* | | *-289* | | *-795,539* | | *6,467,925* |

*Chapter Four*

# Life Cycle Impact Assessment: Getting to the Science

*OK, are we doing all right now? Take a deep breath, because here is where thing start getting complicated. You might want to read this over a gin and tonic, or at least when you are feeling pretty relaxed.*

*Say you have your inventory in hand. You know how many pounds of material you used to make the product. You know how many gallons of oil you burned to heat the building where you made the product. You know how much nasty stuff went into the air and water to transport the product to the customer. You know how much cleaner and lubricant the customer used to keep the product clean and happy while it was in use. You even know how much of the product ended up in a landfill, how much was recycled, and how much was burned. You have lists of hundreds of chemicals that were used or released over the life of the product. You know a lot!* ***But you don't know what any of it means.***

*Life Cycle Impact Assessment poses the questions: how much of that material that went into the environment actually did anything bad? How important was it that the product used up coal, and oil and other natural resources? What is the environmental impact of your product?*

*To answer these questions, Life Cycle Impact Assessment (LCIA) develops* **indicators** *for all the important categories of environmental concerns, based on*

*your LCA inventory. An indicator is not a measurement of actual environmental effects. Instead, it is a measurement of something that most environmental scientists believe will correlate well with the actual effects. It is a simplification of the real world.*

*For example, let's look at global warming. As you probably know, the earth is expected to warm up over the next century or so, because one result of human activities has been to increase pollutants in the atmosphere. Many of these are known to trap heat heading for space and send it back to the earth's surface (the greenhouse gases). Many people believe that the El Niño/La Nina effects we have been seeing over the last few years are at least partly caused by the greenhouse gases in the atmosphere. Many other alarming things have been measured that indicate that the earth may be warming up.*

- ✓ *Large pieces of the Antarctic ice shelf have broken off and drifted North.*
- ✓ *Songbirds in Great Britain are nesting seven to ten days earlier than they were a hundred years ago.*
- ✓ *Tornadoes have become more common and stronger over the last decade in North America.*

*To top it off, scientists have developed models that predict contradictory things. For example, some predict sea level rising a couple of meters (enough to drown most coastal cities and to submerge 80 percent of the area of many Pacific Island States) and great desertification happening in Asia, Africa and elsewhere, while floods happen in other parts of the world. Other models predict cooling in some areas, possibly even another ice age. All in all, it is a pretty horrific vision. The predictions are so variable, that many people have taken to calling the predicted phenomena global climate change, rather than global warming, and there is an Intergovernmental Panel on Climate Change (IPCC), a group of (mostly) scientists that tries to make sense of what is known.*

*With all this uncertainty about effects, LCIA looks for an indicator of change, without predicting what that change might be. We know that the impact of greenhouse gases is based on the amount of radiation that they can capture and send back to earth, so LCIA typically measures an indicator called radiative forcing potential. This is the sum of all the radiation capture of all the greenhouse gases emitted over the lifecycle of a product.*

*But wait. The important greenhouse gases (carbon dioxide, nitrous oxide and methane) all have different lifetimes in the atmosphere. Methane has a half–life of about 12 years, then it breaks down to carbon dioxide ($CO_2$). Carbon dioxide stays around for about 150 years, but only about 5 years if you are just looking at its cycling in and out of plants. Nitrous oxide (yes, laughing gas) has a half–life of about 150 years. They all have different absorption abilities and they all last different times. So how do you go about figuring out how much greenhouse effect is caused by your product?*

*All of this just illustrates how complicated it is to get a handle on the environmental science that supports impact assessment. But don't get discouraged. People have been doing environmental impact assessments since 1970, and lots of these problems have been worked out already. The trick is to have a good SCOPING for the project. (We warned you that this topic would come up again!)*

*Doing the Life Cycle Impact Assessment scoping is actually something that should be done before you ever gather your first inventory data. Why? Because most of the inventory data you MIGHT collect about your process isn't important. For example, you might collect data about the types and amounts of lubricating oil used on machinery. It is a lot of work to track all the different lubricants used in your average manufacturing facility. There could be 30 or 40 different types (or even more!) and you would also be looking at where those oils are used and disposed of. Most waste oils are burned for heat recovery, yielding greenhouse gases and other air pollutants.*

*But if you start your study asking what are the environmental impacts of your facility, you would look at issues such as the resource depletion for petroleum, and any impacts of transport and disposal. No matter how much oil you are using as a lubricant or in hydraulic systems, it will be tiny compared to the amount used to run boilers and heat a facility, and the kinds of impacts are the same: petroleum depletion and air pollution. So, just gathering information on heating oil usage will give you enough information (probably at least 95 percent of the usage of petroleum) to model the impacts from the use of petroleum products.*

*The same concept applies to other inventory numbers. Rather than get 100% of the data on every chemical used, manufactured, or disposed of, you can get perfectly good estimates by just looking at the "big hitters" in your unit operations. The reason why this is OK to do is that the errors in making estimates of all your indicators are at least 10 percent, and are probably lots higher—perhaps as high as 50 to 75 percent. So leaving out 5 percent of your inventory (or estimating it instead of measuring it) will not have an important effect on your results.*

*Doing a Life Cycle Inventory is something you do from the inside out. You are looking at the unit processes—a factory or a transportation system—and figuring out all the resources used and all the emissions released. This information is important if your goal is to understand and control all aspects of a process, but there is lots of information that doesn't affect the environment very much. Life Cycle Impact Assessment, on the other hand, looks from the outside in. It says "Hey! You're using up lots of resources and polluting a lot to make these widgets." So you are really only interested in things that could have a MEASURABLE EFFECT ON THE ENVIRONMENT.*

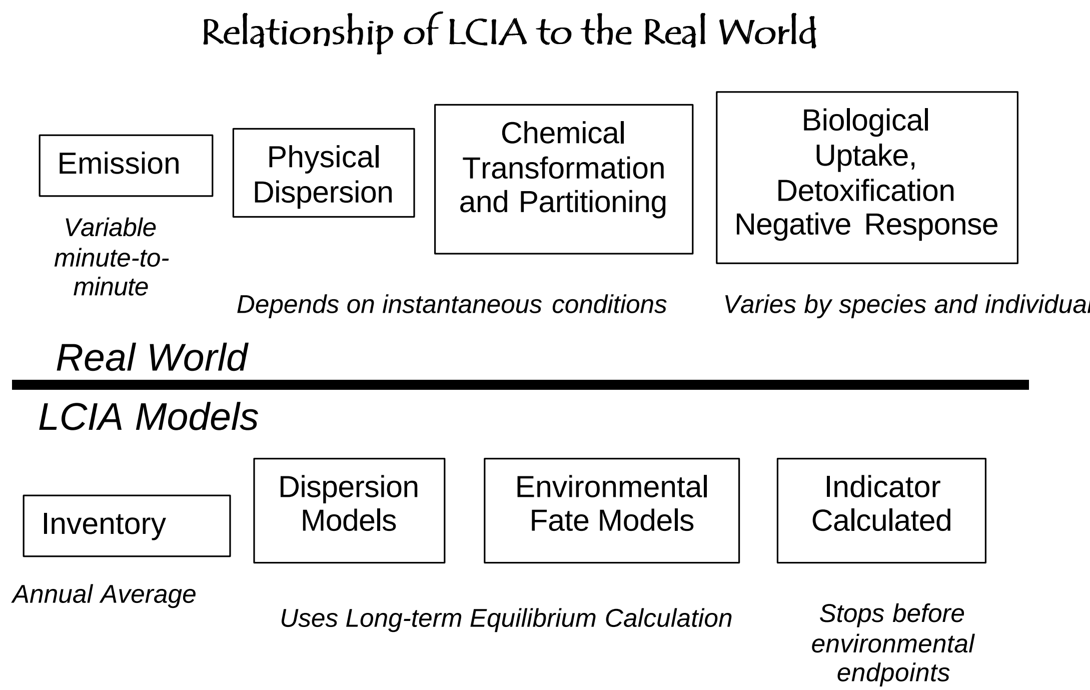
*If you have an effectively unlimited resource (say, seawater), you don't pay attention to it. On the other hand, if you have a limited resource (say, groundwater in the desert), you pay lots of attention to it.*

*The same thing goes for pollution. Just because pollution is coming out the stack does not mean that bad things are happening in the environment. For example, there isn't any acid rain in Texas, even though there are oil refineries and other industries that make lots of acid gases. Why? Because there are so many dust storms coming up from Mexico and so much sea spray from the Gulf of Mexico that all those acid gases are neutralized.*

*Now, you could just look at what was coming out the stack, and say that acid rain was a problem, but if you did, you could just be hiding what was the real problem for that product, which could be any number of things. Petroleum resource depletion and global warming both come to mind. The whole point of doing an LCA is to look at the big picture.*

*LCIA helps you look at something closer to reality, and when you do that kind of analysis, you can get "environmentally relevant indicators" as described in the ISO 14042. Having environmentally relevant indicators is always a good idea, but it is essential if you want to make a claim in the marketplace. The World Trade Organization (WTO) and the Federal Trade Commission (FTC) both rely on international consensus standards such as the ISO standards to tell them if the analysis was done using good science. And ISO says that you must use environmentally relevant indicators in an LCIA to make a "comparative assertion disclosed to the public". That means if you are going to say, "my product is better than their product" you had better have all your ducks in a row.*

*An LCIA is really just a modeling exercise. It doesn't get you to real impacts, but you measure something that you think is related to the real impacts. The real impacts of acid rain are dead fish and trees, but you measure how much un–neutralized acid gas might be deposited. It definitely is not real world you are looking at, as the figure below points out.*




## Transforming and weighting the indicator results

*Lots of times, you will want to look at your results in relationship to outside concerns. For example you might want to know what proportion of the total global warming coming from your country is associated with your product. Or you might want to know how much global warming from your product compares to global warming from a natural source.*

*For example, the average adult human body generates about 250 pounds of $CO_2$ per year. This is about the same amount of $CO_2$ that is generated when you burn a tank of gasoline. That kind of puts your trips to the grocery store in perspective. If you divided the amount of gasoline $CO_2$ per year by the amount of human body $CO_2$ per year, you would get a measurement of body–equivalents.*

*Or, you could divide the domestic global warming (used for cars and for heating and lighting homes) by the industrial global warming (used for running trucks and factories). This would let you identify where the problem is. In most industrialized countries, domestic and industrial global warming potential is about the same size.*

*Dividing one indicator number by a reference amount is called Normalization, and it is very useful for communicating the importance of certain results. Normalization puts results into perspective. But you have to be careful using this technique, because you can use a reference that conceals the importance of the results, too. Your reference tells you what your perspective is.*

*Another way to transform results is multiply the indicator results by weighting factors. Weighting factors are a way to explicitly apply the value system of a person or group. Say, for example, your organization thinks that acidification is not important and that global warming is. You could weight global warming by 100 and acidification by zero. Essentially, you would "throw" the results to get the answer you wanted.*

*Of course, not all weighting is bad. In fact lots of times it is essential. If you are a purchasing agent and you get LCIA profiles like the ones below, you need to get some kind of weighting scheme to help you decide which one to purchase.*

| *Indicator* | *Widget A* | *Widget B* |
|---|---|---|
| *Global Warming* | *100* | *75* |
| *Acidification* | *20* | *10* |
| *Ground Level Ozone* | *1* | *25* |
| *Stratospheric Ozone* | *1* | *2* |
| *Fossil Fuels* | *45* | *25* |
| *Water Resources* | *10* | *10* |
| *Land Use* | *1* | *0.5* |

*You could weight everything equally, but it is more likely that you will weight them according to something like your organization's environmental policy or goals. It is your organization's values or your stakeholders' values that will drive the data transformation.*

*If you are using an LCIA for a label, you will probably not be able to use normalization or weighting methods in making that label, with the exception of comparison to industry averages. This way everyone discloses their LCIA results on a level playing field.*

## Stakeholders

*So what does this mean to stakeholders, or those who represent the public interest? Stakeholders want to make sure that their environmental issues are represented. If one's primary concern is land use, or the preservation of green spaces, then one had better make sure that the study addresses land use. If biodiversity is important, then again, land use will matter, for protection of the habitats important to endangered species or populations.*

*One way of getting an indicator of habitat effects is to measure the area of different habitats affected by a product system. Then deciding if that habitat is important to threatened and endangered species. The indicator ends up being the* *area of endangered species habit that is disrupted and the area of non–endangered species habitat that is disrupted. There are other methods to address ecological issues in an LCA. Collecting the data for this kind of analysis is not difficult, but it is much easier to do if it is planned for in the initial stages of the study. Stakeholders won't make any friends if they bring this issue up in the final weeks of the study.*

*On the other hand, if one's primary concern is air toxics, then one should be asking to see risk assessment analyses in the study. This kind of assessment is common in the framework of LCAs. The data is usually (though not always) readily available and the analysis is straightforward.*

*A stakeholder should keep in mind that the nature of LCAs is to look at all issues on a more–or–less level playing field. If one currently represent a single issue, one has the opportunity to expand horizons to the whole range of environmental issues. Also, note that according to the international standards, issues that have no biological, physical or chemical mechanism supporting them (e.g., esthetic considerations) cannot be used to support claims in the context of a Life Cycle Assessment disclosed to the public. Since claims are one of the biggest reasons people do LCAs, it will be very difficult to get most study commissioners to consider them in any depth, if at all.*

*Stakeholders also want to make sure that any normalization or weighting schemes don't conceal the importance of the important issues.*

## Project Manager

*If you are managing an LCIA, you need to be aware of the concerns of your stakeholders. The best way to understand their concerns is to talk with them, ASAP in your planning process. Knowing what their concerns are will allow you to include them in the scope early on, and determine whether it will be possible to model the impacts of concern.*

*So what kinds of things to people usually include in a study? The table below shows one approach.*

| ***Life Cycle Impact Category*** | ***Results, Units*** |
|---|---|
| *Global Warming* | *Tons $CO_2$ Equivalents* |
| *Stratospheric Ozone Depletion* | *Tons Halon Equivalents* |
| *Ground Level Ozone* | *Tons Projected Ozone* |
| *Acidification* | *Tons $SO_2$ Equivalents* |
| *Eutrophication* | *Tons Phosphate Equivalents* |
| *Aquatic Toxicity* | *Tons of Toxic Equivalents* |
| *Human Health* | *Equivalent tons of toxics* |
| *Fossil Fuel Depletion* | *Tons of Oil Equivalent* |
| *Mineral Depletion* | *Tons of Mineral Equivalent (by Mineral)* |
| *Water Depletion* | *Cubic Meters of Water Equivalent, (surface & groundwater)* |
| *Landuse* | *Equivalent hectares of endangered species and non–endangered species habitat* |
| *Wood Resources* | *Equivalent tons of wood* |

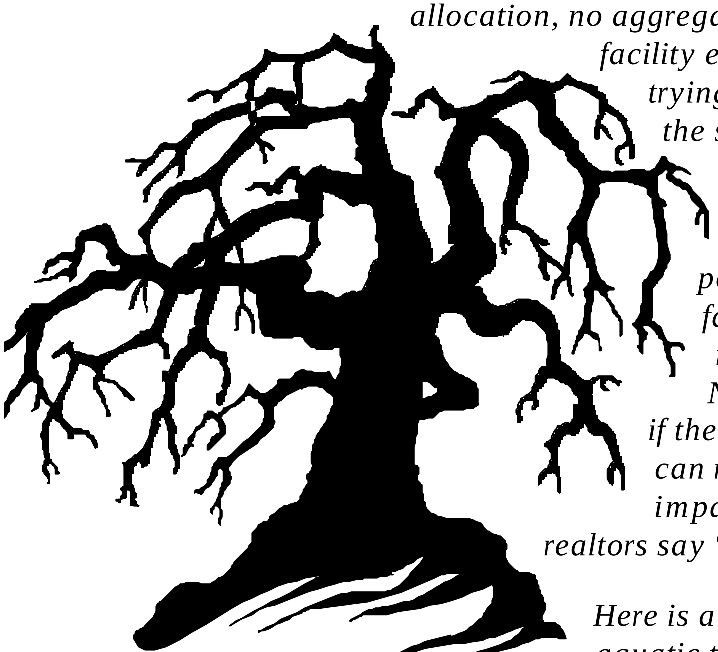
*This list could be longer or shorter, depending on the scope of the study. For example, if you are comparing Widget A with Widget B, and they are much the same except for the amount of energy they use, you might only look at the energy related issues: Fossil Fuel Depletion, Acidification, Eutrophication, Global Warming, Ground Level Ozone, and possibly, Human Health.*

*Or you might be interested in terrestrial toxic effects, and you would develop an indicator that looks at risk assessment for animals and plants. You could also try to get different units of your measures, ones based on the natural scale of the environment.*

*For example, some people have developed indicators based on the amount of land that is potentially affected by emissions. That way, you can look at most of the indicators on the same scale. For example, global warming affects the entire surface of the earth, while land use and acidification affect only regional portions of the earth. Thinking about environmental impacts in this fashion helps put things in perspective.*

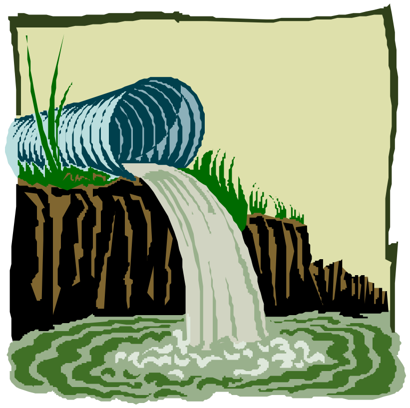
## Engineering

*The biggest issue for engineers in doing an impact assessment is going to be gathering the data in a site–specific manner. For most indicators, one needs regional and local information to figure out what is going on. That means no allocation, no aggregation, and there is going to be a bigger focus on whole–facility effects. The reason is that what an impact assessment is trying to change the focus from the inputs and outputs of the system under study to the environmental impacts of the system under study.*



*Let's take an example. Suppose acid rain is a big potential problem in the study system. Where the facilities are tells all. Most of the U.S. is relatively insensitive to acid rain, with the exceptions being the Northeast, the Southeast and the Pacific Northwest. So, if there are facilities in Denver, Albuquerque, and Ohio, one can right away guess that the first two facilities have no impacts on acid rain, while the one in Ohio does. As the realtors say "location, location, location."*

*Here is another example. Suppose there is the potential to cause aquatic toxicity. Usually, this is evaluated by calculating whether concentrations in natural waters exceed some standard. Let's suppose*



*that one of the facilities does indeed emit enough nasties into the water to exceed some standard. But suppose one has only reported the allocated emissions in the study, which are only 3 percent of the total. A calculation based on this 3 percent would probably show no effect, while the environment is actually suffering. A legitimate look at the situation is to look at the total emissions at that location, calculate some impact, and THEN allocate that IMPACT to the product system.*

*Imagine that you were producing and manufacturing cotton exactly the same way in two different locations. You might get quite different profiles of their environmental impact, as shown here.*

| **Indicator** | **Cotton in Georgia** | **Cotton in Egypt**[1] |
|---|---|---|
| Global Warming | 100 | 100 |
| Acidification | 20 | 0 |
| Ground Level Ozone | 1 | 25 |
| Stratospheric Ozone | 2 | 2 |
| Fossil Fuels | 45 | 45 |
| Water Resources | 0 | 10 |
| Land Use | 1 | 1 |

## Purchasing

*The purchasing department will probably want to keep a rein on how many indicators are being evaluated, and how complicated the assessment becomes. There are two reasons for this: to control the cost of the study, and to simplify the purchasing decisions that might be made.*

[1] *These figures are purely imaginary, and do not reflect the results of an actual LCA*

*In preparing a purchase order or contract, specifying that only previously collected and public data may be used is a good way to keep the cost of a study down. Another cost control strategy is to coordinate the collection of data with vendors, thus sharing costs of the study with those vendors. It can be a good idea to let vendors know what kind of weighting scheme will be used to help make purchasing decisions. Then they can focus their environmental improvements where it matters to the purchaser.*

*Focusing on only the most important environmental impacts helps purchasing agents make decisions more quickly.*

## Marketing

*As mentioned above, the really big reason to perform an LCIA is for market advantage. While one can make single claims in the marketplace ("our product has less phosphates!"), these will always be open to stakeholders saying things like "Yeah, you have less phosphates, but you use phosphates more in the manufacturing." Or, "Yeah, but now the product relies on cutting down old growth forests." A full Life Cycle Impact Assessment is the only way to be sure claims will stand up in the marketplace.*

*Several countries require "environmental declarations" for their products, especially in the European Union and Canada. Although different countries and different industries may have somewhat different disclosure requirements, they typically include such information as content declarations and some Life Cycle Impact information. The content information is sometimes in the format of: the product has so much of this and so much of that, while the life cycle information is in terms of global warming acidification potential and the like.*

*In the U.S., such product declarations are not currently required. However, some states are developing a content label on the electrical power being marketed in the state. In this case the content label says the relative percentage of hydro* *versus coal versus nuclear versus natural gas or other source. In addition, these states typically require information on selected emissions, such as $SO_2$ emissions.*

*The U.S. Federal Government has an "environmentally preferable program" (EPP, for short), which is intended to force the use of more environmentally desirable products by government agencies. The guidance from the EPA on this program suggests that Life Cycle Impact Assessments make a good proof of preferability. However, not all purchasing agents are interested in getting the full story an LCIA provides, and before embarking on an LCIA for marketing to the U.S. Government, it would be wise to be certain what the customer would accept.*

*The key thing to remember is that an LCA performed according to the international standards is likely to hold up in court, and one that is not performed this way is likely to get people in hot water.*

## Environmental Management

*If you are in charge of environmental programs, you have lots of reasons you might want to use an LCIA. The biggest items are measuring and reporting performance and managing a Design–for–Environment (DfE) program. Because LCIAs focus on what is happening in the environment, they are the perfect measuring sticks for your environmental performance. And because much of environmental performance is driven by engineering decisions, LCIAs can help focus engineering improvements on the most important environmental issues first.*

*What this means is that you have to make sure to scope the study so that you get the information you need. You want to know not only your overall environmental impacts, but also exactly where they come from, so that you can go after the sources of those impacts. The unit processes you use are going to be crucial to this assessment, because the information you get will not describe any lower level than the unit process.*

*Reporting performance using the environmental indicators in an environmental annual report can be very helpful, too. Your stakeholders may not be impressed at first at how you came about getting these indicators, but if you explain it clearly, in the end, they will like that you looked at all the system impacts, not just those that were easy to measure. And of course, what gets measured gets done, so you can expect that those indicators will improve—and your stakeholders will like to see this, too.*

*There is a school of thought that full disclosure of environmental impacts is crucial to assuring environmental performance. That concept is embodied in EMAS, the Environmental Management and Audit Standard, a voluntary standard in the European Community. Organizations certified under EMAS provide annual reports of performance: LCIAs are an excellent source of the information for such reports.*

## Critical Review

*Under the ISO standards, LCIAs disclosed to the public must undergo critical review. That means that enough technically qualified and interested people review the document and assure that it is valid and correct.*

*The job of the reviewers is not only to check the numbers and assumptions. It is to make sure that all important issues were included and the analysis was legit. Because LCA's are very broad-based analyses, this can be hard to do, so usually review panels have a person with special knowledge about the industry, another who is an LCA expert, and another who is a scientific expert about the thorniest issue in the report. Panels can also have stakeholders or more than one person in each role.*

*Once the review is complete (and any outstanding issues are addressed), the LCIA is ready for prime–time. The outcome of the analysis is called an environmental profile—just a collection of the results for all the indicators.*

*The ISO standards require that published LCAs include the report of the critical review team, along with the report on the actions taken to address them.*

*Chapter Five*

# Life Cycle Interpretation: What does it all mean?

*We are getting close to the end here. Life cycle interpretation is the part of an LCA that connects the results of your work to the real world.*

- ☞ *What matters?*
- ☞ *Are the numbers consistent?*
- ☞ *Are they realistic?*
- ☞ *What can you use them for?*
- ☞ *Did the study do a good job?*

*You need to interpret your results so you can apply them to your problems and make decisions with them.*

*Typically, an interpretation section of an LCA report will discuss the assumptions and value choices that were made, and will talk about two major types of quality tests that are made: sensitivity analyses and error analyses. Sensitivity analyses look at what effect different assumptions have on the final results. Error analyses tell you how well you know the numbers (plus or minus 10 percent, 25 percent, or even 100 percent).*

*The interpretation phase is where you had better get your stakeholders' opinions in play. If you think your study indicates your product is better than competing products, you had better let your competitors know about that conclusion, and you had better have VERY good data to back that up. Of course, that is what we have been talking abut all along, making sure that you have a strong and useful study in the end.*

*Most of the interpretation section is about making sure that your data is good, consistent and easy to understand. But the other thing you are doing with the study is saying what that data means.*

- *Did you fulfill the goal of the study?*
- *Did your stakeholders participate meaningfully?*
- *What future actions should you or could you take?*
- *How does your product look in the marketplace?*

*In your interpretation section you may be making extensive comparisons to other studies. Or you may be normalizing your data to the total number of humans in the world in the year 2050, or you may be just looking at ways to improve your product to be more environmentally friendly.*

*Whatever the outcome of your study, the purpose of the interpretation is to link the model world to the real world and help you make decisions. Once again, the goal and scope of your project will determine what kinds of things end up in your interpretation.*

## Outside experts

*If outside experts have been part of the team from the beginning, they won't have much to say at this point. If not, then they will have a lot of catching up to do. At* *the least, though, they need to look at the results: have the important issues been addressed? How? Is the data believable, based on what is known from other sources? Are there opportunities at the last moment to fill in data gaps?*

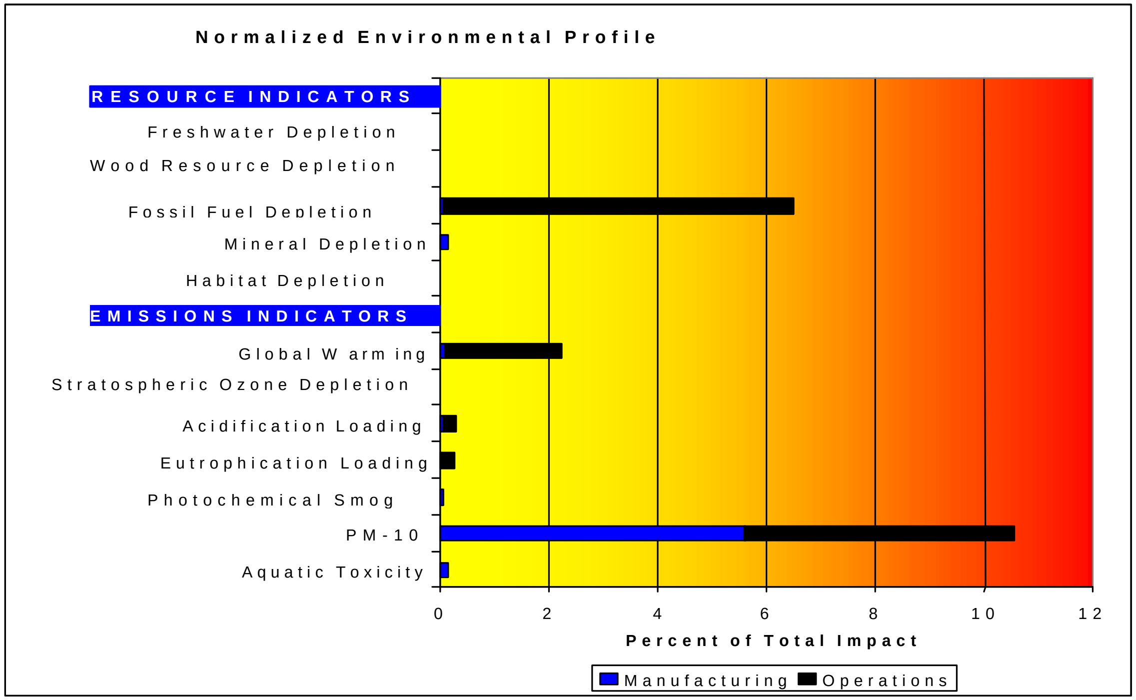
*For experts with particular skills, such as statistical expertise, this is the place to use them.*

*Finally, and perhaps most important, are the data and analysis strong enough to support the conclusions? Are there other conclusions that need to be stated?*

## Marketing

*Here is the place to make sure the data is presented in a useful fashion. Presenting data is not a trivial exercise. The figures below show some potential ways to show the data. Notice that the graphical methods are all easier to understand immediately—but that they all contain a spin. One has to walk a fine line between communicating clearly and communicating the wrong or misleading information. Good communication gets kudos. Deliberately misleading information can get one in trouble with the Federal Trade Commission (FTC) or the World Trade Organization (or both). You can rely on your competitors and on consumer groups to point out the frailties of your study to these bodies.*

*The figure below shows the output of a life cycle study where the percentage of the impact of a product due to its manufacture and operation are shown. This format was chosen because the client wanted to know for its internal audience where it should direct its efforts in design for the environment. Unfortunately, relatively little of the impacts of the product were under the direct control of the company. Just knowing that fact is useful, as was the information that a significant proportion of the particulate matter was under their control. Particulate matter is an important human health concern, as well as an aesthetic concern due to loss of visibility.*




## Engineering and Environmental Functions

*Hopefully, what comes out the end of this report will be useful to the engineering group. They should get data that can help with the design for environment program. However, although many LCAs include improvement opportunities in this section, it is wise to modulate those conclusions so that the report does not make commitments that are impossible to reach. This would just raise expectations among stakeholders both inside and outside the organization that could lead to a perception of bad faith.*

## Showing Results

*One of the important things you do with the interpretation phase is show your results so people can understand them. Of course, this depends on who is going to use them, but there are some things that you want to consider.*

*First, the most straightforward way to show results is simply to make a list of them, with a table like below for product XYZ. This gives you the information about the outcome of the study, but gives you no clue as to what it means.*

### Environmental Profile, Product XYZ

| ***Impact Category*** | ***Units*** | ***Result*** |
|---|---|---|
| *Global Climate Change* | *Tons of $CO_2$ equivalents* | *200* |
| *Stratospheric Ozone Depletion* | *Tons ofCFC–11 equivalents* | *1* |
| *Acidification* | *Tons of $H^+$ equivalents* | *4* |
| *Eutrophication* | *Tons of carbon equivalents* | *10* |
| *Photochemical Smog* | *Tons of ozone equivalents* | *0.5* |
| *Human Toxicity* | *Tons of benzene equivalents* | *.005* |
| *Ecotoxicity* | *Tons of benzene equivalents* | *.0008* |
| *Fresh Water Depletion* | *Tons of water equivalents* | *20* |
| *Fossil Fuel Depletion* | *Tons of oil equivalents* | *50* |
| *Mineral Resource Depletion* | *Tons of mineral equivalents* | *5* |
| *Land use* | *Hectares of land used* | *25* |

*Well, what does this mean? Without context it is difficult to say. However, look at the same kind of data when done in comparison with another product.*

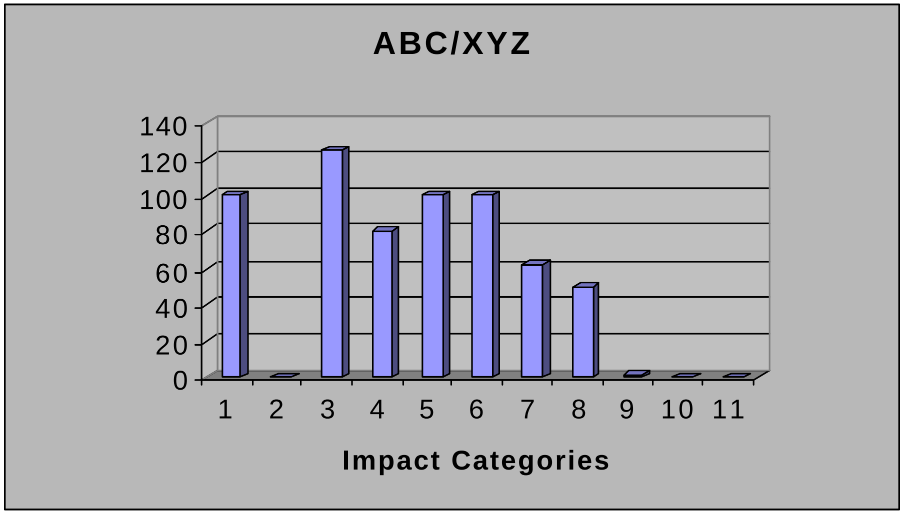
## Environmental Profiles, Products ZXY and ABC

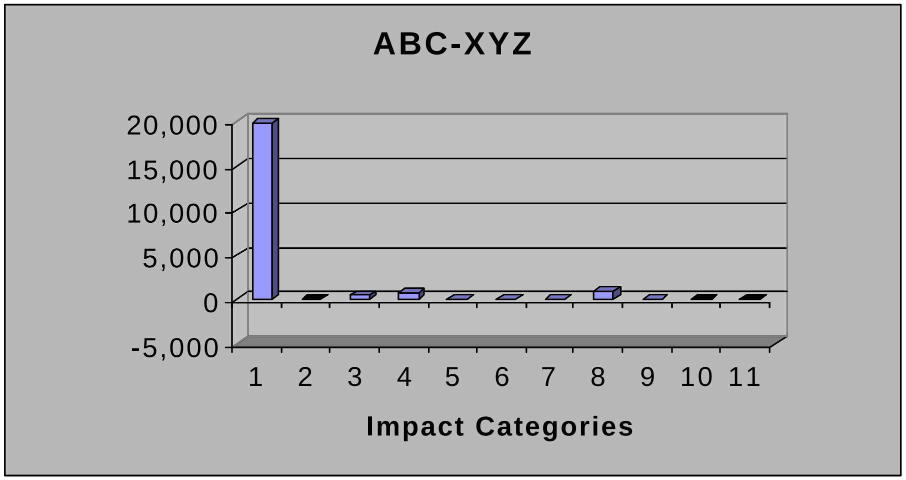
| ***Impact Category*** | ***Units*** | ***Result*** | |
|---|---|---|---|
| | | ***XYZ*** | ***ABC*** |
| *Global Climate Change* | *Tons of $CO_2$ equivalents* | *200* | *20,000* |
| *Stratospheric Ozone Depletion* | *Tons of CFC–11 equivalents* | *1* | *.01* |
| *Acidification* | *Tons of $H^+$ equivalents* | *4* | *500* |
| *Eutrophication* | *Tons of carbon equivalents* | *10* | *800* |
| *Photochemical Smog* | *Tons of ozone equivalents* | *0.5* | *50* |
| *Human Toxicity* | *Tons of benzene equivalents* | *0.005* | *0.5* |
| *Ecotoxicity* | *Tons of benzene equivalents* | *0.0008* | *0.05* |
| *Fresh Water Depletion* | *Tons of water equivalents* | *20* | *1000* |
| *Fossil Fuel Depletion* | *Tons of oil equivalents* | *50* | *80* |
| *Mineral Resource Depletion* | *Tons of mineral equivalents* | *5* | *.5* |
| *Land use* | *Hectares of land used* | *25* | *.05* |

*Now we have something to talk about. XYZ is a lot better than ABC for all but the stratospheric ozone depletion and the mineral resource depletion and the land use.*

*You can present the same data graphically as shown below. But you have to be careful how you present it, so that the pictures show a realistic view of the two systems you are comparing.*

*This graph shows the* **ratio** *between ABC and XYZ. The graph below it shows the* **difference** *between the two products.*




*It is hard to believe that we are looking at the same data, isn't it? But you'll note that in both cases, product XYZ looks mostly* **lower** *than product ABC.*

*So what is the right way to look at the results? We prefer the ratio method, because it is the least statistically biased. The real answer is that there is no right way. There are many elaborate schemes used to weight and display numbers and the "right" answer is the one that appropriately reports the data for the audience. In the end, it all goes back to your scoping exercise (again!).*

## Where do we go from here?

*One of the functions of the interpretation phase is to make suggestions for improvement. This can be either very simple, for example pointing out that better housekeeping would lead to a better environmental profile (if that is the case), or it could suggest sweeping changes in technology across an entire industrial* *system. We have been involved in LCA's whose outcome has been accelerated plans to eliminate an entire product line, because it carried too high an environmental burden.*

*In writing conclusions and recommendations can be a tightrope between offering useful advice and documenting problems that have significant economic implications for the study commissioner. Outside of the technical reviews described above, the interpretations phase is the place where the commissioner of the report needs to be really on top of what is being written.*

*Chapter Six*

# Other Things to Do With Your LCA

- ✓ *Use it to prop up the table leg*
- ✓ *Start fires with it*
- ✓ *Make paper airplanes out of it*
- ✓ *Recycle it*

*No, not really. You remember from chapter one that most LCAs are done for marketing purposes. Even if you can't prove that your product is environmentally superior, you have a nice clean way to disclose to your stakeholders exactly how you are doing. LCA is a good way to track environmental performance within an organization, so that you actually will get to be an environmentally superior provider.*

*What we want to talk about here is the other things that people do together with LCAs that work to produce more useful results. The most obvious ones are financial studies like life cycle costing, or activity–based costing. But people have also done detailed risk assessments for each life cycle stage, and have made policy decision models for government requirements.*

*Life cycle costing and total ownership costing are techniques used to figure out what are the best choices for buying big capital items. Like buildings or battleships. In fact, it was the military that dreamed up life cycle costing as part of government procurement policy, and in the last few years, the military has been looking closely at environmental costs as part of their life cycle cost. In fact* *the military has even done LCAs on ammunition, to support environmentally friendly bombs and the like. (If this seems absurd to you, you are not alone!)*

*Anyway, life cycle costing is a bit different from LCA. Its primary goal is to account for depreciation and the cost of money over time. For example, if you buy a car, you probably pay for the car over three or four years, and drive it for 10 years. Life cycle costing will figure out the capital cost (the car sticker price) and spread it over the useful life of the car. It will also look at inflation, and figure out the net current worth of the car. For example, if you are looking at a car that costs $10,000, you will say that the cost of the car itself is $1,000 per year. But if you have a 2% inflation rate, that means that the money you pay next year is worth less than this year's money. And the following year's money is worth even less. So in the tenth year, your $1,000 is really worth $817 in today's dollars. Adding up all the years' inflated dollars gets you the net present value of the car. This number can tell you whether the purchase is a good investment or not.*

*Another way to evaluate cost is to make assumptions about the opportunity costs of the investment. If I just put my money in the stock market, I can expect an average rate of return of 10%. Subtracting inflation (2%) I get an average annual rate of return of 8%. That means if I spend $10,000 now on an investment in the stock market, I can expect to earn $8,000 on that investment over the next ten years. You can say that the money is really worth $18,000 in present worth. From the point of view of an organization investing in environmental improvement, any $10,000 investment should have a payback greater than you would expect by investing in the stock market or in other organization improvements.*

*In practice, people usually use much simpler rules when deciding to invest in environmental improvements. Of course, the first thing is that, if you are required by law, you have to do it. But that doesn't mean you have to buy a Cadillac to do the job of a Volkswagen. But it is probably better to buy a Cadillac once than to buy ten Pintos. Figuring out how long the solution has to last is an important part of life cycle costing.*

*Most people make investment decisions based on simple calculations like pay back time. If an investment saves money, payback time is the length of time it would take to save as much money as the cost of the investment. Some pollution prevention payback times are as short as two months, while a payback of two years is still going to be a good investment. If payback will take longer than two or three years, you probably want to look closer at the investment.*

*All of that is great, but there is also another source of cost, and that is the operating cost of the investment. For a car, you have to buy insurance, gasoline, oil, new tires and the like over the life of the car. The table below shows a theoretical simple example.*

### The Cost of Car Ownership

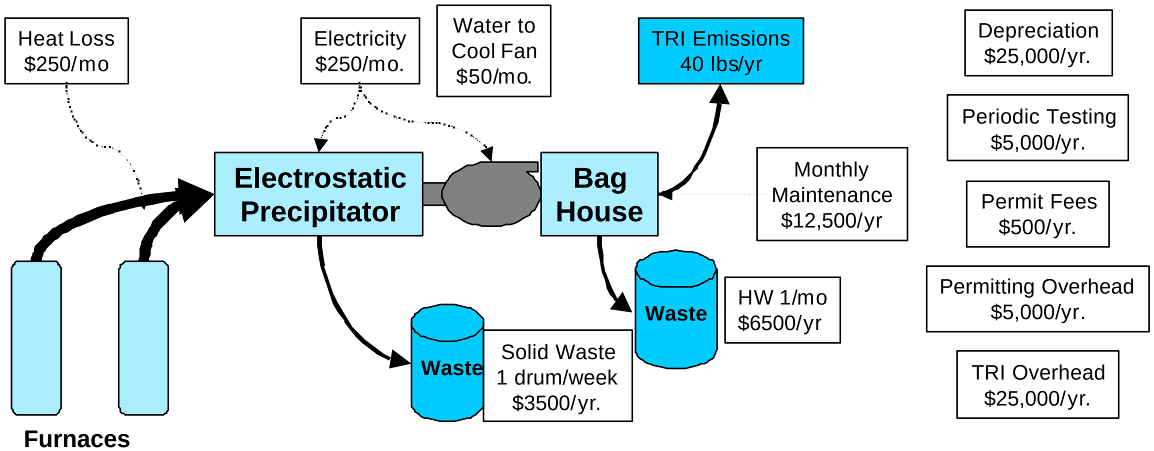
| ***Cost item*** | ***Frequency*** | ***Cost*** | ***Annual Cost*** |
|---|---|---|---|
| *Car* | *1/10 years* | *$10,000* | *$1,000* |
| *Insurance* | *Annual* | *$300* | *$300* |
| *Gasoline* | *Weekly* | *$10* | *$520* |
| *Oil Change* | *Quarterly* | *$25* | *$100* |
| *Inspection* | *Annual* | *$25* | *$25* |
| *Tires* | *1/5 years* | *$600* | *$125* |
| *Shocks* | *1/5 years* | *$500* | *$100* |
| *Battery* | *1/5 years* | *$70* | *$14* |
| *Brakes & Pads* | *1/5 years* | *$250* | *$50* |
| *Registration* | *Annual* | *$50* | *$50* |
| **Total** | | | **$2,284** |

*As you can see, the cost of owning the car is a lot bigger than the cost of buying the car. This example left out several of the operating expenses of owning a car, too, like lubrication and replacing windshield wipers and antifreeze. I'm sure that you can think of several things we forgot here, too. The point is that for a big* *capital item like owning a car, the operating costs are usually bigger than the capital costs, and in industry, a rule of thumb of two to three times higher is a pretty good one.*

*Figuring out these costs from an environmental point of view is not as easy as falling off a log. Most of the information you need to understand the costs of environmental management or pollution control is hidden in overhead accounts. Like the maintenance costs for pollution control devices. Or the raw material costs for material that is wasted.*

*Fortunately, there is a way to get at these costs. It's called Activity Based Costing or ABC for short. Doing activity based costing is a lot like doing a Life Cycle Inventory. You flow chart the activity, and figure out the costs associated with that activity (or Unit Process) all along the way. If you are interested in those costs associated with environmental impacts only, you only look at those costs, but you can use ABC to get at the true costs of making a product, so that you can price it appropriately.*

*The figure below shows an example of an environmental activity–based costing exercise for a small glass manufacturing plant. The study evaluated the costs associated with end–of–pipe glass furnace air emissions only. A similar approach might uncover other costs at other parts of the manufacturing process.*




*The EPA is currently using activity–based accounting as a basis for a model of regulatory cost–benefit. They are evaluating the financial cost of modified regulations compared to the standard regulations, to see whether the net effect is cost improvement to all the parties involved: industry, regulators, and the public sector. An advantage to such a cost model is that it will allow the EPA to predict the new programs that are most likely to be successful in financial terms.*

*This kind of study has perfect linkages to LCA—you have the full financial situation and the full environmental situation and you have just about everything you need to know to develop good environmental management programs in industry, government and in the non–profit sector.*

## Federal Environmentally Preferable Purchasing

*The federal government is required to purchase goods and services that are environmentally preferable, where such goods can be shown to provide an equivalent function. EPA views Life Cycle Assessments as a good way to prove* *environmental preferability, and is creating guidance on how to perform LCAs to that end.*

*The new guidance called FRED (Framework for Responsible Decision–making), is based on a Life Cycle Assessment that covers the following environmental issues:*

- ✓ *Global Climate Change*
- ✓ *Stratospheric Ozone Depletion*
- ✓ *Eutrophication*
- ✓ *Photochemical Smog*
- ✓ *Acidification*
- ✓ *Human Toxicity*
- ✓ *Ecotoxicity*
- ✓ *Resource Depletion*

*Following this guidance permits vendors to claim that their products are environmentally superior to those of their competitors, and this provides a wedge for getting the government to buy your goods and services.*

*There are other ways to claim environmental preferability, relating to recycled content claims, but LCA documentation is vastly preferable to those claims, because LCAs look at* **all** *important issues and they cover* **all** *the product's life. That means that we can look at the overall environmental performance, not just single issues, like phosphate content in detergent.*

*When developing the FRED methodology, three pilot LCAs were done. One of them, the comparison of two asphalt road maintenance products is shown in full in the next chapter.*

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*Chapter Seven*

# Appendix: An Example LCA

*This chapter contains a slightly edited example of an LCA study, so you can see what you can expect from what was in this case a very short study. It was prepared as a pilot study for the U.S.. EPA to help guide their development of FRED, the Framework for Responsible Environmental Decision–making, which is intended to be used for environmentally preferable purchasing by the U.S. Federal government. This example represents an extreme: the simplest possible type of analysis. Most LCAs are much more complicated, running to hundreds of pages. And you'll see the high "table density" of this kind of report: thousands of data points are common in LCAs.*

## Executive Summary

## Summary of LCA of Asphalt Emulsion and Thin Layer Asphalt Cement for Road Maintenance

*Asphalt Systems, Inc. provided data to assist the U.S. EPA develop its guidance on the use of Life Cycle Assessment to demonstrate the environmental preferability of products. The life cycle data were for its asphalt emulsion product GSB-88. This product is used to extend the useful life of asphalt pavements. It was compared to an equivalent product commonly in use, a thin layer of asphalt cement.*

*The two products were compared for a comprehensive set of environmental impacts, and the results are shown below. Of the 14 indicators evaluated, the GSB-88 was had superior environmental performance (at least twice as good) for nine, had equivalent performance for three, and was worse on only one parameter* *(water consumption). The water consumption was related to the use of water in the product itself, which is a water–based emulsion of asphalt.*

| ***Indicator*** | ***LCIA Totals*** | |
|---|---|---|
| | ***Asphalt Emulsion*** | ***Asphalt Cement*** |
| **Global Warming (kg $CO_2$ equiv)** | *20,000* | *40,000* |
| **Ozone Depletion (kg CFC–11 equiv)** | *0* | *0* |
| **Acidification (kg $SO_2$)** | *100* | *300* |
| **Eutrophication (kg $PO_4$)** | *0.007* | *0.02* |
| **Photochemical Smog (kg $O_3$)** | *40* | *80* |
| **Human Toxicity** | | |
| *Cancer (kg benzene equiv)* | *0.08* | *0.2* |
| *NonCancer (kg toluene equiv)* | *2* | *5* |
| **Ecotoxicity** *(dimensionless)* | *1000* | *2000* |
| **Resource Depletion** | | |
| *Fossil (tons oil equivalent)* | *40,000* | *90,000* |
| *Mineral (equiv tons)* | *0* | *0* |
| *Precious(equiv tons)* | *0* | *0* |
| **Other Indicators:** | | |
| *Land Use (ha)* | *0.6* | *0.6* |
| *Water Use ($m^3$)* | *80* | *2* |
| *Solid Waste (ton)* | *30* | *800* |

*It is unusual for a product to show such a clear pattern of environmental superiority when reviewed at a life cycle level. Here the tradeoff is clear: water use versus almost everything else. These results indicate that the use of GSB–88 is environmentally preferable to the use of thin layer asphalt cement for maintaining the usability of paved surfaces.*

*The U.S.. government (through the National Institute of Standards and Technology) has also developed a database on building products, which is based* *on LCA. It is called BEES (Building for Economic and Environmental Sustainability) and is expected to expand its scope beyond building products in the near future*

## Summary of LCA of Asphalt Emulsion and Thin Layer Asphalt Cement for Road Maintenance

*As part of the effort to develop LCA as a tool for environmental preferable purchasing, three pilots were undertaken to test how best to perform the analysis in order to make it:*

- *Easy to use*
- *Yield results in a timely manner*
- *Meet the needs of procurement officials and vendors*
- *Conform, as much as possible, to the requirements of ISO DIS 14042 for comparative assertions*
- *Support the needs of the EPP program*
- *Support the needs of the National Institute of Standards and Technology (NIST) in its goals relating to the Technology Transfer Act*

*Two of those pilots were based on the inventory data sets collected to support BEES. The final one was based on original data collection from a small asphalt emulsion vendor, and is reported here.*

## Goal and Scope Definition

### Goal

*An important goal of this study was to evaluate whether a small vendor would be capable of gathering the data necessary for a Life Cycle Assessment, in a timely fashion. If this proved to be impossible, the application of LCA for EPP would present a significant barrier for small businesses seeking to sell goods to the Federal government. Asphalt Systems, a small manufacturer of asphalt emulsions in Utah, participated in providing site specific information on the manufacture, application, and use of asphalt emulsions and hot mix asphalt.*

### Intended Applications and Audiences

*The LCA itself was intended to be used to support a comparative assertion of environmental superiority of a product over a competing product in the context of the Federal requirement for environmentally preferable purchasing. Audiences include purchasing agents as well as other federal and state officials. An ancillary use of the study is to support efforts towards environmental improvement.*

### Scope

### Description of the Product

*The products evaluated represented two methods of maintaining roads: applying a thin layer (1.5 inches thick) of asphalt cement and applying an asphalt emulsion containing a natural mineral product, gilsonite. Both of these products are applied to asphalt roads before significant deterioration has occurred (three to five years into the life of the road), and neither adds structural strength to the road. Each extends the life of the road considerably. In the case of the asphalt emulsion,* *for three to five years, and in the case of the asphalt cement thin layer, seven to nine years. There are some other specialized methods for maintaining asphalt cement roadways, but these tend to be based on trade secret chemical compositions, and were not included in this study.*

*Asphalt emulsion is applied by spraying diluted emulsion from a distributor truck that simultaneously spreads sand onto the emulsion. Application is at ambient temperature. Traffic can ensue one hour after application. Thin layer asphalt cement is applied by first spreading a tack coat (consisting of a simple asphalt emulsion) with a distributor truck, then applying a layer of asphalt, and finally rolling the layer of asphalt to assure a smooth surface. Typically, the asphalt cement is manufactured near the construction site at a hot–mix asphalt cement plant, which heats the asphalt and mixes it with aggregate, which is then trucked to the road site and applied as above. Asphalt cement must be applied at 165 degrees F or above. Traffic can ensue one to two hours after application is complete.*

## System Function and Functional Unit

*The function provided by the alternative products is the maintenance of good quality roads (five on a scale of ten). The functional unit is twenty years of one lane mile. The inventory includes two applications of the thin layer of asphalt cement, and five applications of the asphalt emulsion.*

## System Boundaries

*The system studied included all unit processes except those used for the production of hydrochloric acid. This material comprised less that one percent of the total mass of the products, and it was expected from the composition of the materials that the acid would be neutralized in use, and would not pose a significant toxicological threat.*

*All inputs and outputs were accounted for as long as they comprised at least:*

1. *One percent of the mass*
2. *One percent of the energy, or*
3. *One percent of the expected toxicity scores*

*Primary data was not available for the asphalt production, but was gathered from published sources. Information on the production of the asphalt emulsion and the tack coat was obtained from the manufacturer, as was information on the application of the asphalt emulsion, the tack coat and the thin layer of asphalt cement. The flow charts below identify the systems under study.*

**Figure 1**

***Asphalt Emulsion Coating***

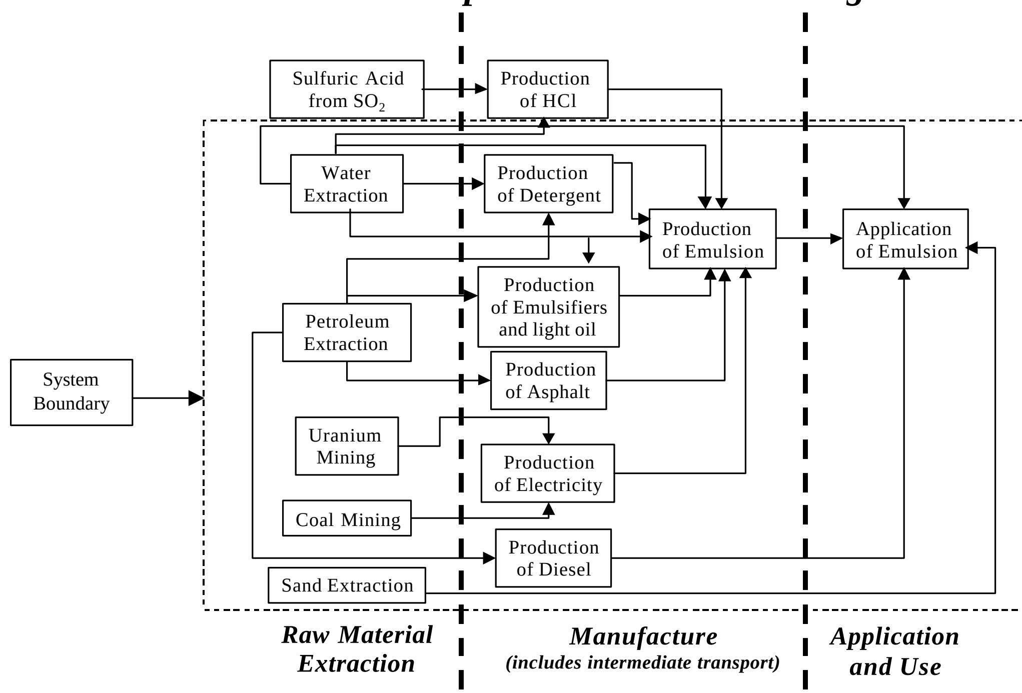
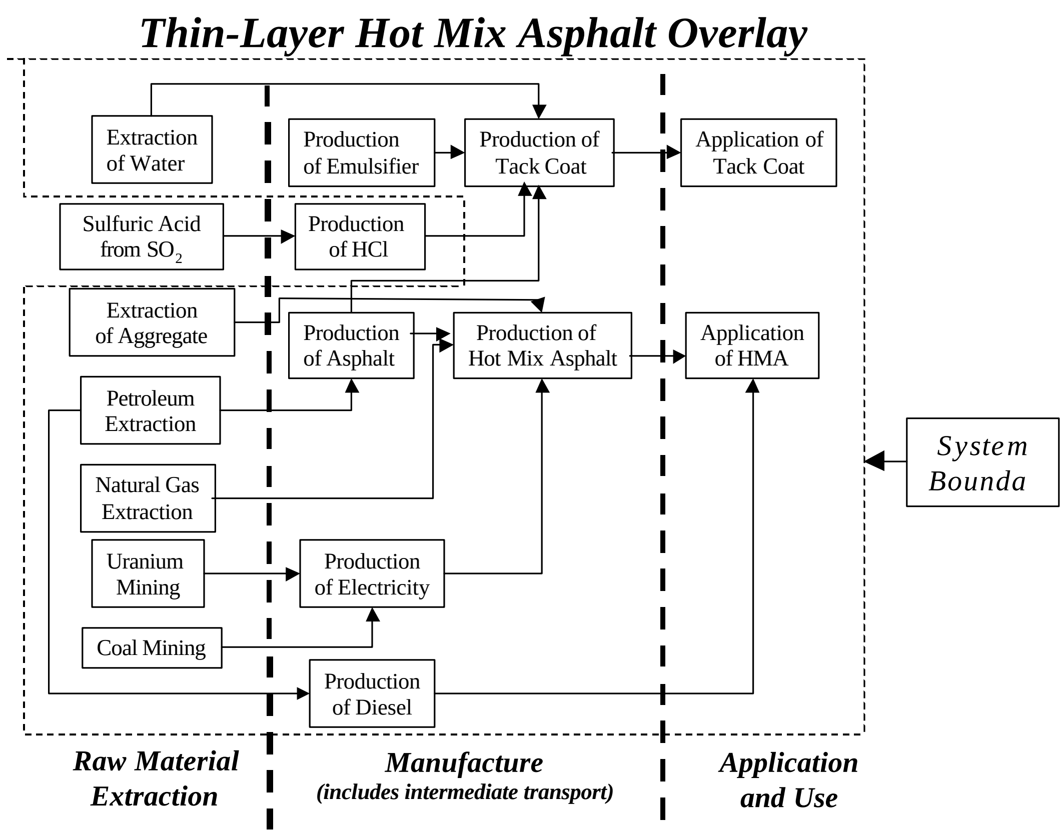


**Figure 2**




## Data Gathering

*The entire data gathering exercise for this project took place over two months (January–March 1999). Data was gathered using the data sheets in Appendix A. In general, data gathering was quite rapid. This situation was aided by the simple nature of the materials under study. However, there were some difficulties that were encountered. For example, the source of the asphalt in the emulsions and* *tack coat (a large refining company) was not willing to provide site–specific information to this small vendor. Consequently, industry average data, obtained from the American Petroleum Institute (API) was used for estimating the inventories of this material.*

*Secondly, it was not possible to obtain site–specific information from any vendor that was not a direct vendor to the manufacturer. Thus the inventory results from some products that were obtained from a distributor (e.g., HCl and some detergents) were derived from data bases.*

*Finally, the contents of some materials (emulsifiers) are considered to be trade secrets. The issue of trade secrets is a common one in LCAs, no matter what size of vendor one might be evaluating. Some of the trade secret materials are considered to be potentially ecotoxic, and that is reflected in the analysis reported here.*

## Allocation

*All allocation of emissions and resource use was performed based on a mass basis. This was required for the production of asphalt, and for transportation inventory results, but not for other inventory data.*

## Impact Assessment

*Impact assessment was performed based on the FRED indicators, as described in the body of this work. The assignment of inventory data to impact categories is shown in the table below.*

**Table 1 Assignment of Inventory Results to Impact Categories**

| *Inventory Result* | *Impact Category* | *Justification* |
|---|---|---|
| *Fossil Fuels and Uranium* | *Resource Depletion (Fossil Fuels* | *Although Uranium is not truly a fossil fuel, it is "used up" in a precisely comparable fashion* |
| *$CO_2$, $N_20$, Methane* | *Global Warming* | *These are important greenhouse gases which do not participate to a great extent in other impact categories* |
| *CO* | *Human Toxicity*<br>*Photochemical Smog*<br>*Global Warming;* | *CO is a human and animal toxicant, as well as a precursor to ozone formation and a greenhouse gas. It can participate in the first two of these environmental mechanisms without losing its potency for the others.* |
| *CFC's, HCFC's, Halons* | *Global Warming 100%*<br>*Stratospheric Ozone Depletion 100%* | *These substances participate fully in both of these parallel environmental mechanisms* |
| *$SO_2$,* | *Acidification 100%* | *Although SO2 contributes to visibility deterioration, and human health effects through the formation of Particulate Matter, these environmental mechanisms are not addressed by FRED.* |
| *HCl, HF* | *Acidification 100%*<br>*Human Health 100%* | *These acid gases have minor human health effects as well as contributing to acidification. It was thought that double counting would not significantly skew results.* |

| ***Inventory Result*** | ***Impact Category*** | ***Justification*** |
|---|---|---|
| *Toxic Air and Water Emissions* | *Human Toxicity 100%*<br>*Ecotoxicity 100%* | *Since it was not possible to evaluate the partitioning of these substances, they were double counted so as not to underestimate their impacts.* |
| *NOx* | *Acidification 100%*<br>*Eutrophication 100%* | *Since FRED does not currently evaluate the fate and transport of NOx, this emission was double counted.* |
| *VOC's, ROG's* | *Photochemical Smog* | *These are the essential precursors to photochemically produced ozone. Although some of them are also toxic, unspeciated data does not permit a toxic evaluation.* |
| $NH_4$ | *Eutrophication (water emissions); acidification (air Emissions)* | *Although* $NH_4$ *is not an acid gas, it undergoes changes in the soil leading to acidification effects.* |
| $PO_4$ | *Eutrophication 100%* | *Phosphate does not participate in any other environmental mechanism described by the FRED methodology.* |

*The table below shows the gross inventory for the two options, normalized to the functional unit. The functional unit is twenty years of one lane mile. The inventory includes two applications of the thin layer of asphalt cement, and five applications of the asphalt emulsion. Because the information about asphalt cement was obtained from published sources rather than from primary data, it was not possible to estimate the amount of land that was used to manufacture the asphalt. Since this product uses aggregate, it is likely that the mining of gravel/aggregate produced somewhat higher land use than the manufacture of the emulsion, perhaps ten times as much. However, the land use during manufacturing of materials is very small. Even assuming that the production of hot mix asphalt used ten times as much land, this would still be much smaller* *than the land use associated with the road itself. Thus, the land use difference between the two products is probably not significant.*

## Inventory

*The table below shows the summary inventory for the two products compared. A full inventory by life cycle stage can be found in Tables 6 and 7.*

**Table 2 Summary Inventory**

| ***System Description*** <br> ***Raw Materials*** | ***Asphalt Cement Thin Layer (2applic) lb/lane mile/20yr*** | ***Asphalt Emulsion GSB88 (5 applic) lb/lane mile/20yr*** |
|---|---|---|
| *Asphalt* | *122,621* | *47,790* |
| *Aggregate* | *2,181,960* | *0* |
| *Diesel (application)* | *3,063* | *15* |
| *Diesel to prep hotmix* | *884* | *0* |
| *Sand* | *0* | *17,600* |
| *Gilsonite* | *0* | *21,500* |
| *HCl* | *32* | *24* |
| *Water* | *4,779* | *173,317* |
| *NP–40 (Detergent)* | *0* | *285* |
| *Surfactant* | *156* | *29* |
| *Light Cycle Oil* | *0* | *585* |
| *Land use (road, m2)* | *5888* | *5888* |
| *Land use (mfg, m2)* | *???* | *2* |

## Indicator Results

*The table below shows the indicator results for the two systems studied.*

**Table 3 LCIA Results**

| | *LCIA Totals* | |
|---|---|---|
| ***Indicator*** | ***Asphalt Emulsion*** | ***Asphalt Cement*** |
| **GWP (kg $CO_2$ equiv)** | *16,547* | *44,368* |
| **ODP (kg CFC–11)** | *0* | *0* |
| **Acidification (kg $SO_2$)** | *145* | *344* |
| **Eutrophication (kg $PO_4$)** | *0.0065* | *0.0151* |
| **Photochemical Smog (kg $O_3$)** | *36* | *77* |
| **Human Toxicity** | | |
| *Cancer* | *0.0797* | *0.178* |
| *NonCancer* | *2.02* | *4.5* |
| **Ecotoxicity** | *1250* | *2260* |
| **Resource Depletion** | | |
| *Fossil (tons oil equivalent)* | *3.86E+04* | *8.55E+04* |
| *Mineral (equiv tons)* | *0* | *0* |
| *Precious(equiv tons)* | *0* | *0* |
| **Other Indicators:** | | |
| *Land Use (ha)* | *0.6* | *0.6* |
| *Water Use (kg)* | *76,982* | *2,292* |
| *Solid Waste (kg)* | *31729* | *816165* |

## Interpretation

*We can draw some conclusions about the two products based on the total indicator values noted in the table above. Of the 14 indicators or sub–indicators evaluated, the asphalt emulsion was significantly lower than the asphalt cement for 11, equal to the asphalt cement for two (Stratospheric Ozone Depletion and Land Use) and greater than the asphalt cement for one (Water Consumption). Overall, the asphalt emulsion product appears to be superior to the asphalt cement product for this application.*

*It is also possible to evaluate the sources of the various impacts in order to identify opportunities for improvements. The table below shows the asphalt emulsion and asphalt cement indicators in terms of percentage of the indicators in the different life cycle stages.*

**Table 4 Percentage of Indicator by Life Cycle Stage, Asphalt Emulsion**

| | Emulsion – by LC Stage | | | | |
|---|---|---|---|---|---|
| **Indicator** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **Disposal** |
| **GWP** | *12* | *34* | *54* | *0* | *0* |
| **ODP** | *0* | *0* | *0* | *0* | *0* |
| **Acidification** | *15* | *17* | *69* | *0* | *0* |
| **Eutrophication** | *0* | *91* | *9* | *0* | *0* |
| **Photochemical Smog** | *20* | *7* | *73* | *0* | *0* |
| **Human Health** | | | | | |
| *Cancer* | *13* | *78* | *10* | *0* | *0* |
| *NonCancer* | *10* | *81* | *9* | *0* | *0* |
| **Eco Health** | *21* | *14* | *63* | *2* | *0* |
| **Resource Depletion** | | | | | |
| *Fossil* | *85* | *6* | *9* | *0* | *0* |
| *Mineral* | *0* | *0* | *0* | *0* | *0* |
| *Precious* | *0* | *0* | *0* | *0* | *0* |
| **Other Indicators:** | | | | | |
| *Land Use* | *0* | *0* | | *100* | *0* |
| *Water Use (kg)* | *0* | *28* | *0* | *72* | *0* |
| *Solid Waste (kg)* | *0* | *0* | *0* | *0* | *100* |

*These results indicate that the majority of the environmental impacts for the material comes from transport and manufacturing. The vendor can improve these results through the use of lower impact transport mechanism of distributed manufacture of the product.*

**Table 5 Percentage of Indicator by Life Cycle Stage, Thin Layer Asphalt Cement**

| | Cement – by LC Stage | | | | |
|---|---|---|---|---|---|
| **Indicator** | **Raw Materials** | **Manufacturing** | **Transport** | **Use** | **Disposal** |
| **GWP** | *9* | *76* | *14* | *1* | *0* |
| **ODP** | *0* | *0* | *0* | *0* | *0* |
| **Acidification** | *13* | *66* | *19* | *2* | *0* |
| **Eutrophication** | *0* | *98* | *2* | *0* | *0* |
| **Photochemical Smog** | *20* | *20* | *59* | *0* | *0* |
| **Human Health** | | | | | |
| *Cancer* | *12* | *85* | *3* | *0* | *0* |
| *Non—Cancer* | *9* | *88* | *2* | *0* | *0* |
| **Eco Health** | *25* | *47* | *22* | *8* | *0* |
| **Resource Depletion** | | | | | |
| *Fossil* | *82* | *16* | *2* | *0* | *0* |
| *Mineral* | *0* | *0* | *0* | *0* | *0* |
| *Precious* | *0* | *0* | *0* | *0* | *0* |
| **Other Indicators:** | | | | | |
| *Land Use* | *0* | *0* | *0* | *100* | *0* |
| *Water Use (kg)* | *0* | *100* | *0* | *0* | *0* |
| *Solid Waste (kg)* | *0* | *0* | *0* | *0* | *100* |

*For the most part, the majority of the two products' indicator results can be found in the manufacturing and the transportation phases of the life cycle. This result supports the guidance of the FRED methodology, which recommends more intensive data gathering efforts in the manufacturing phase for products that are durable goods, which are not energy–intensive in the use phase.*

## Conclusions

*Although there were some issues around gathering primary data for the performance of this LCA, overall, the data gathering went quite smoothly. This was true especially for data gathered from the primary vendor and from one step up and one step down the vendor chain (i.e., from manufacturers of ingredients and from contractors/customers using the materials under study). For goods that have a very long or complicated vendor chain, (e.g., electronics) this may not be the case.*

*Overall, the environmental performance of the asphalt emulsion was superior to asphalt thin layers, with the exception that asphalt emulsion uses water and the thin layer of asphalt cement does not. If the vendor can incorporate this result for advantage in federal government purchasing, this will provide a significant market advantage to this small vendor.*

**Table 6 Life Cycle Inventory, Asphalt Emulsion**

| **Asphalt Emulsion** | | | **Sum** | **Extraction** | **Manufacture** | **Transport** | **Use** | **Disposal** |
|---|---|---|---|---|---|---|---|---|
| **Product** | *20 year–lane mile* | | *1* | *1* | *1* | *1* | *1* | *1* |
| **Inputs** | | | | | | | | |
| **Resources** | *Coal, Bituminous* | *Kg* | *430* | *167* | *170* | *93* | *1.34E–01* | *0* |
| | *Coal, Lignite* | *Kg* | *79* | *31* | *31* | *17* | *2.46E–02* | *0* |
| | *Coal, Subbituminous* | *Kg* | *235* | *92* | *92* | *51* | *7.32E–02* | *0* |
| | *Crude Oil* | *Kg* | *25,972* | *23,282* | *311* | *2,372* | *7* | *0* |
| | *Gilsonite* | *Kg* | *9,336* | *0* | *9,336* | *0* | *0* | *0* |
| | *Natural Gas* | *Kg* | *725* | *270* | *381* | *74* | *2.03E–01* | *0* |
| | *UO2* | *Kg* | *2.41E–03* | *9.43E—04* | *9.46E–04* | *5.25E–04* | *7.53E–07* | *0* |
| | *Fresh Water* | *Kg* | *76,982* | *0* | *21,845* | *0* | *55,136* | *0* |
| | *Land Use* | *ha* | *0.6* | | *.002* | | *0.6* | |
| | | | | | | | | |

| Asphalt Emulsion | | | Sum | Extraction | Manufacture | Transport | Use | Disposal |
|---|---|---|---|---|---|---|---|---|
| **Fuels** | *Coke, Petroleum* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Crude Oil* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Distillate Oil* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Distillate Oil, #1* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Distillate Oil, #2* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Electricity* | *kWh* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Fuel, Other* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Gasoline, Automotive* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *LPG* | **Kg** | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Natural Gas* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Residual Oil* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Steam, Low Pressure* | *btu* | *8.57E–01* | *3.96E–04* | *7.77E–01* | *7.92E–02* | *2.39E–04* | *0* |
| | *Still Gas* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | | | | | | | | |
| **Air Emissions** | *1,2,4—Trimethylbenzene* | *Kg* | *1.25E–02* | *5.79E–06* | *1.14E–02* | *1.16E–03* | *3.49E–06* | *0* |
| | *Aldehydes, Unspeciated* | *Kg* | *2.98E+00* | *4.12E–02* | *1.85E–03* | *2.94E+00* | *1.34E–05* | *0* |
| | *Ammonia* | *Kg* | *1.12E–01* | *5.16E–05* | *1.01E–01* | *1.03E–02* | *3.11E–05* | *0* |
| | *Benzene* | *Kg* | *7.97E–02* | *9.98E–03* | *6.21E–02* | *7.60E–03* | *2.22E–05* | *0* |
| | *Carcinogen, Unspeciated* | *Kg* | *6.91E–03* | *3.18E–06* | *6.27E–03* | *6.35E–04* | *1.92E–06* | *0* |
| | *CO* | *Kg* | *73* | *16* | *11* | *46* | *8.07E–03* | *0* |
| | *CO2* | *Kg* | *15846* | *1509* | *5421* | *8914* | *2.48* | *0* |
| | *Cyclohexane* | *Kg* | *2.52E–02* | *1.16E–05* | *2.29E–02* | *2.33E–03* | *7.01E–06* | *0* |
| | *Ethyl Benzene* | *Kg* | *2.47E–02* | *2.49E–03* | *1.99E–02* | *2.34E–03* | *6.90E–06* | *0* |
| | *Ethylene* | *Kg* | *3.04E–02* | *1.40E–05* | *2.76E–02* | *2.81E–03* | *8.46E–06* | *0* |
| | *HCl* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Iso–Octane* | *Kg* | *2.63E–03* | *9.78E–04* | *1.38E–03* | *2.67E–04* | *7.37E–07* | *0* |
| | *Methane* | *Kg* | *33.38* | *19.86* | *9.05* | *4.46* | *9.20E–03* | *0* |
| | *Methanol* | *Kg* | *1.19E–02* | *5.49E–06* | *1.08E–02* | *1.10E–03* | *3.31E–06* | *0* |
| | *MTBE* | *Kg* | *2.80E–02* | *1.29E–05* | *2.54E–02* | *2.58E–03* | *7.79E–06* | *0* |
| | *n–Hexane* | *Kg* | *1.71E–02* | *6.36E–03* | *8.99E–03* | *1.74E–03* | *4.79E–06* | *0* |

| **Asphalt Emulsion** | | | **Sum** | **Extraction** | **Manufacture** | **Transport** | **Use** | **Disposal** |
|---|---|---|---|---|---|---|---|---|
| | *NOx* | *Kg* | *154* | *21.81* | *15.08* | *117.57* | *1.12E02* | *0* |
| | *Organic Acids* | *Kg* | *2.45E–03* | *9.56E–04* | *9.60E–04* | *5.33E–04* | *7.64E–07* | *0* |
| | *Organic Compounds, Unspeciated* | *Kg* | *9.25E–03* | *3.61E–03* | *3.63E–03* | *2.01E–03* | *2.89E–06* | *0* |
| | *Particulate* | *Kg* | *2.61E+00* | *3.42E–01* | *1.16E+00* | *1.11E+00* | *7.78E–04* | *0* |
| | *PM10* | *Kg* | *15.69* | *1.91E–01* | *5.77E–01* | *14.92* | *5.13E–04* | *0* |
| | *Propylene* | *Kg* | *9.75E–02* | *4.50E–05* | *8.84E–02* | *8.99E–03* | *2.71E–05* | *0* |
| | *SOx* | *Kg* | *35.66* | *5.65* | *13.45* | *16.55* | *6.02E–03* | *0* |
| | *TNMOC, Unspeciated* | *Kg* | *7.71E+00* | *1.56007433* | *3.81E–01* | *5.7682512* | *2.15E–03* | *0* |
| | *Toluene* | *Kg* | *1.55E–01* | *1.38E–02* | *1.26E–01* | *1.46E–02* | *4.31E–05* | *0* |
| | *VOC, Unspeciated* | *Kg* | *27.04* | *0.17414189* | *9.91* | *16.95* | *3.15E–03* | *0* |
| | *Xylene* | *Kg* | *1.00E–01* | *7.83E–03* | *8.29E–02* | *9.44E–03* | *2.79E–05* | *0* |
| | | | | | | | | |
| **Water Emissions** | *Ammonia* | *Kg* | *1.94E–02* | *8.9449E–06* | *1.76E–02* | *1.79E–03* | *5.39E–06* | *0* |
| | *BOD* | *Kg* | *5.32E–04* | *0* | *5.32E–04* | *0* | *0* | *0* |
| | *Carcinogen, Unspecia* | *Kg* | *2.71E–05* | *1.3144E–07* | *6.713E–07* | *2.625E–05* | *7.92E–08* | *0* |
| | *COD* | *Kg* | *6.83E–04* | *0* | *6.83E–04* | *0* | *0* | *0* |
| | *Dissolved Solids* | *Kg* | *3.55* | *1.32* | *1.87* | *0.36* | *0.000995* | *0* |
| | *Oil & Grease* | *Kg* | *0.56* | *0* | *0* | *5.59E–01* | *0* | *0* |
| | *Methanol* | *Kg* | *3.45E–04* | *1.7316E–07* | *3.10E–04* | *3.459E–05* | *1.04E–07* | *0* |
| | *MTBE* | *Kg* | *1.16E–03* | *5.4019E–07* | *1.05E–03* | *1.08E–04* | *3.25E–07* | *0* |
| | *Oil & Grease* | *Kg* | *5.91E–02* | *2.94E–04* | *1.59E–03* | *5.71E–02* | *1.72E–04* | *0* |
| | *Phosphate* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Produced Water* | *Kg* | *9,780* | *8,758* | *116* | *904* | *2.72* | *0* |
| | *Surfactant* | *Kg* | *3.51* | | | | *3.51* | |
| | | | | | | | | |
| **Solid Wastes** | *1,2,4–Trimethylbenzene* | *Kg* | *1.36E–04* | *5.9119E–08* | *1.24E–04* | *1.181E–05* | *3.56E–08* | *0* |
| | *Ammonia* | *Kg* | *1.50E–03* | *6.8698E–07* | *1.37E–03* | *1.37E–04* | *4.14E–07* | *0* |
| | *Ash, Bottom* | *Kg* | *13.87* | *5.42* | *5.44* | *3.02* | *4.33E–03* | *0* |

| **Asphalt Emulsion** | | | **Sum** | **Extraction** | **Manufacture** | **Transport** | **Use** | **Disposal** |
|---|---|---|---|---|---|---|---|---|
| | *Ash, Fly* | *Kg* | *44.21* | *17.26* | *17.32* | *9.61* | *1.38E–02* | *0* |
| | *Carcinogen, Unspeciated* | *Kg* | *6.18E–04* | *2.9683E–07* | *5.58E–04* | *5.928E–05* | *1.79E–07* | *0* |
| | *Cyclohexane* | *Kg* | *2.72E–04* | *1.1884E–07* | *2.48E–04* | *2.374E–05* | *7.16E–08* | *0* |
| | *Ethyl Benzene* | *Kg* | *4.08E–04* | *1.7735E–07* | *3.72E–04* | *3.543E–05* | *1.07E–07* | *0* |
| | *FGD Sludge* | *Kg* | *14* | *5.47* | *5.49* | *3.05* | *0.004367* | *0* |
| | *Solid Waste, Drilling* | *Kg* | *939* | *826* | *25* | *86.98* | *0.26* | *0* |
| | *Solid Waste, Hazardous* | *Kg* | *8.44E–01* | *3.90E–04* | *7.65E–01* | *7.78E–02* | *2.35E–04* | *0* |
| | *Solid Waste. Refiner* | *Kg* | *22* | *1.03E–02* | *20* | *2.06* | *6.20E–03* | *0* |
| | *Spent Fuel, Nuclear* | *Kg* | *4.21E–03* | *1.64E–03* | *1.65E–03* | *9.15E–04* | *1.31E–06* | *0* |
| | *Toluene* | *Kg* | *1.23E–03* | *5.582E–07* | *1.12E–03* | *1.11E–04* | *3.36E–07* | *0* |
| | *Xylene* | *Kg* | *1.64E–03* | *7.7116E–07* | *1.49E–03* | *1.54E–04* | *4.65E–07* | *0* |
| | | | | | | | | |
| | *Landfilled Waste* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Mining Waste* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Waste in waste roadway* | *Kg* | *31,729* | *0* | *0* | *0* | *0* | *31,729* |

## Table 7 Life Cycle Inventory, Thin Layer Asphalt Cement

| **AsphaltCement** | | | **Total** | **Extraction** | **Manufacture** | **Transport** | **Use** | **Disposal** |
|---|---|---|---|---|---|---|---|---|
| **Product** | *20 year–lane mile* | | *1* | *1* | *1* | *1* | *1* | *1* |
| | | | | | | | | |
| **Inputs** | | | | | | | | |
| **Resources** | *Coal, Bituminous* | *Kg* | *897* | *355* | *411* | *128* | *3* | *0* |
| | *Coal, Lignite* | *Kg* | *164* | *66* | *75* | *24* | *1* | *0* |
| | *Coal, Subbituminous* | *Kg* | *490* | *195* | *223* | *70* | *2* | *0* |
| | *Crude Oil* | *Kg* | *57,493* | *49,601* | *6,451* | *1,290* | *151* | *0* |
| | *Gilsonite* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Natural Gas* | *Kg* | *1,612* | *575* | *984* | *50* | *4* | *0* |
| | *UO2* | *Kg* | *5.04E–03* | *2.01E–03* | *2.29E–03* | *7.23E–04* | *1.59E–05* | *0* |
| | *Land Use* | *Ha* | *.6* | *NA* | *NA* | *NA* | *NA* | *NA* |
| | *Fresh Water* | *Kg* | *2,292* | *0* | *2,292* | *0* | *0* | *0* |
| | | | | | | | | |
| **Fuels** | *Coke, Petroleum* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Crude Oil* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Distillate Oil* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Distillate Oil, #1* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Distillate Oil, #2* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Electricity* | *kWh* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Fuel, Other* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Gasoline, Automotive* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *LPG* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Natural Gas* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Residual Oil* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Steam, Low Pressure* | *btu* | *1.92* | *0.001* | *1.87* | *0.043* | *0.005* | *0* |
| | *Still Gas* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Land Use* | *ha* | *0.6* | | | | *0.6* | |
| | | | | | | | | |
| **Air Emissions** | *1,2,4–Trimethylbenzene* | *Kg* | *2.80E–02* | *1.24E–05* | *2.73E–02* | *6.29E–04* | *7.35E–05* | *0* |
| | *Aldehydes, Unspeciated* | *Kg* | *1.88* | *0.087795277* | *1.53E–02* | *1.59* | *1.87E–01* | *0* |
| | *Ammonia* | *Kg* | *2.50E–01* | *1.10E–04* | *2.44E–01* | *5.61E–03* | *6.55E–04* | *0* |

| AsphaltCement | | | Total | Extraction | Manufacture | Transport | Use | Disposal |
|---|---|---|---|---|---|---|---|---|
| **Product** | *20 year–lane mile* | | *1* | *1* | *1* | *1* | *1* | *1* |
| | | | | | | | | |
| | *Benzene* | *Kg* | *1.78E–01* | *2.13E–02* | *1.52E–01* | *4.50E–03* | *4.69E–04* | *0* |
| | *Carcinogen, Unspeciated* | *Kg* | *1.54E–02* | *6.79E–06* | *1.50E–02* | *3.46E–04* | *4.04E–05* | *0* |
| | *CO* | *Kg* | *126* | *3.44E+01* | *6.22E+01* | *2.63E+01* | *2.86E+00* | *0* |
| | *CO2* | *Kg* | *42,793* | *3,215* | *32,956* | *6,106* | *516* | *0* |
| | *Cyclohexane* | *Kg* | *5.64E–02* | *2.48E–05* | *5.50E–02* | *1.27E–03* | *1.48E–04* | *0* |
| | *Ethyl Benzene* | *Kg* | *5.52E–02* | *5.31E–03* | *4.84E–02* | *1.37E–03* | *1.45E–04* | *0* |
| | *Ethylene* | *Kg* | *6.80E–02* | *3.00E–05* | *6.63E–02* | *1.53E–03* | *1.78E–04* | *0* |
| | *HCl* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Iso–Octane* | *Kg* | *5.84E–03* | *2.08E–03* | *3.56E–03* | *1.81E–04* | *1.55E–05* | *0* |
| | *Methane* | *Kg* | *75.00* | *42.32* | *29.05* | *3.39* | *2.44E–01* | *0* |
| | *Methanol* | *Kg* | *2.66E–02* | *1.17E–05* | *2.59E–02* | *5.97E–04* | *6.97E–05* | *0* |
| | *MTBE* | *Kg* | *6.27E–02* | *2.76E–05* | *6.11E–02* | *1.41E–03* | *1.64E–04* | *0* |
| | *n–Hexane* | *Kg* | *3.80E–02* | *1.35E–02* | *2.32E–02* | *1.18E–03* | *1.01E–04* | *0* |
| | *NOx* | *Kg* | *236* | *46* | *108* | *75* | *7.04* | *0* |
| | *Organic Acids* | *Kg* | *5.11E–03* | *2.04E–03* | *2.32E–03* | *7.33E–04* | *1.61E–05* | *0* |
| | *Organic Compounds, Unspeciated* | *Kg* | *1.93E–02* | *7.70E–03* | *8.78E–03* | *2.77E–03* | *6.08E–05* | *0* |
| | *Particulate* | *Kg* | *26.63* | *7.29E–01* | *23.92* | *1.96* | *1.64E–02* | *0* |
| | *PM10* | *Kg* | *210* | *4.07E–01* | *9.91* | *9.37* | *8.98E–01* | *0* |
| | *Propylene* | *Kg* | *2.18E–01* | *9.61E–05* | *1.90E+02* | *4.89E–03* | *5.72E–04* | *0* |
| | *SOx* | *Kg* | *176* | *12.04* | *151* | *11.46* | *9.54E–01* | *0* |
| | *TNMOC, Unspeciated* | *Kg* | *17.23* | *3.32* | *2.70* | *11.16* | *4.53E–02* | *0* |
| | *Toluene* | *Kg* | *3.45E–01* | *2.95E–02* | *3.07E–01* | *8.45E–03* | *9.09E–04* | *0* |
| | *VOC, Unspeciated* | *Kg* | *58.51* | *3.71E–01* | *47.87* | *9.19* | *1.08* | *0* |
| | *Xylene* | *Kg* | *2.24E–01* | *1.67E–02* | *2.01E–01* | *5.42E–03* | *5.89E–04* | *0* |
| | *Napthalene* | *Kg* | *4.72E–02* | *0* | *4.72E–02* | *0* | *0* | *0* |
| | *2–methyl napthalene* | *Kg* | *6.29E–02* | *0* | *6.29E–02* | *0* | *0* | *0* |
| | *Phenanthrene* | *Kg* | *3.88E–02* | *0* | *3.88E–02* | *0* | *0* | *0* |
| | *Fluoranthrene* | *Kg* | *2.52E–02* | *0* | *2.52E–02* | *0* | *0* | *0* |
| | *Pyrene* | *Kg* | *5.76E–02* | *0* | *5.76E–02* | *0* | *0* | *0* |
| | *Formaldehyde* | *Kg* | *3.35* | *0* | *3.35* | *0* | *0* | *0* |
| | | | | | | | | |

| AsphaltCement | | | Total | Extraction | Manufacture | Transport | Use | Disposal |
|---|---|---|---|---|---|---|---|---|
| **Product** | *20 year–lane mile* | | *1* | *1* | *1* | *1* | *1* | *1* |
| | | | | | | | | |
| **Water Emissions** | *Ammonia* | *Kg* | *4.33E–02* | *1.91E–05* | *4.22E–02* | *9.72E–04* | *1.14E–04* | *0* |
| | *BOD* | *Kg* | *2.13E–03* | *0* | *2.13E–03* | *0* | *0* | *0* |
| | *Carcinogen, Unspecia* | *Kg* | *8.79E–05* | *2.80478E–07* | *7.162E–05* | *1.43E–05* | *1.67E–06* | *0* |
| | *COD* | *Kg* | *3.85E–03* | *0* | *3.85E–03* | *0* | *0.00E+00* | *0* |
| | *Dissolved Solids* | *Kg* | *7.89* | *2.81* | *4.81* | *2.44E–01* | *2.10E–02* | *0* |
| | *Oil & Grease* | *Kg* | *1.19* | *0* | *0* | *1.19* | *0* | *0* |
| | *Methanol* | *Kg* | *7.75E–04* | *3.70E–07* | *7.53E–04* | *1.88E–05* | *2.20E–06* | *0* |
| | *MTBE* | *Kg* | *2.60E–03* | *1.15E–06* | *2.54E–03* | *5.87E–05* | *6.86E–06* | *0* |
| | *Oil & Grease* | *Kg* | *1.92E–01* | *6.27E–04* | *1.56E–01* | *3.15E–02* | *3.62E–03* | *0* |
| | *Phosphate* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Produced Water* | *Kg* | *21,861* | *18,658* | *2,652* | *494* | *57.34* | *0* |
| | *Surfactant* | *Kg* | *19.78* | *0* | *0* | *0* | *19.78* | |
| | | | | | | | | |
| **Solid Wastes** | *1,2,4–Trimethylbenzene* | *Kg* | *3.03E–04* | *1.26E–07* | *2.96E–04* | *6.42E–06* | *7.51E–07* | *0* |
| | *Ammonia* | *Kg* | *3.36E–03* | *1.47E–06* | *3.27E–03* | *7.47E–05* | *8.73E–06* | *0* |
| | *Ash, Bottom* | *Kg* | *28.94* | *11.54* | *13.16* | *4.15* | *9.12E–02* | *0* |
| | *Ash, Fly* | *Kg* | *92.22* | *36.77* | *41.93* | *13.23* | *2.91E–01* | *0* |
| | *Carcinogen, Unspeciated* | *Kg* | *1.38E–03* | *6.33E–07* | *1.35E–03* | *3.23E–05* | *3.77E–06* | *0* |
| | *Cyclohexane* | *Kg* | *6.07E–04* | *2.54E–07* | *5.92E–04* | *1.29E–05* | *1.51E–06* | *0* |
| | *Ethyl Benzene* | *Kg* | *9.09E–04* | *3.78E–07* | *8.88E–04* | *1.93E–05* | *2.25E–06* | *0* |
| | *FGD Sludge* | *Kg* | *29.22* | *11.65* | *13.28* | *4.19* | *9.20E–02* | *0* |
| | *Solid Waste,Drilling* | *Kg* | *2,098* | *1,760* | *284* | *47.92* | *5.51* | *0* |
| | *Solid Waste,Hazardous* | *Kg* | *1.89* | *8.31E–04* | *1.84* | *4.23E–02* | *4.95E–03* | *0* |
| | *Solid Waste. Refiner* | *Kg* | *49.84* | *2.20E–02* | *48.57* | *1.12* | *1.31E–01* | *0* |
| | *Spent Fuel, Nuclear* | *Kg* | *8.78E–03* | *3.50E–03* | *3.99E–03* | *1.26E–03* | *2.77E–05* | *0* |
| | *Toluene* | *Kg* | *2.75E–03* | *1.19E–06* | *2.68E–03* | *6.07E–05* | *7.09E–06* | *0* |
| | *Xylene* | *Kg* | *3.68E–03* | *1.65E–06* | *3.58E–03* | *8.38E–05* | *9.79E–06* | *0* |
| | | | | | | | | |
| | *Landfilled Waste* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Mining Waste* | *Kg* | *0* | *0* | *0* | *0* | *0* | *0* |
| | *Waste Roadway* | *Kg* | *816,165* | *0* | *0* | *0* | *0* | *816,165* |

*Chapter Eight*

# More Reading Material

*The list here is far from exhaustive, but it can get you into more of the technical aspects of LCA.*

*Ciambrone, David F. Environmental Life Cycle Analysis. 1997. Lewis Publishers Boca Raton.*

*Curran, Mary Ann.1996. Environmental Life Cycle Assessment. McGraw–Hill. New York*

*ISO 14042 Environmental management–Life Cycle Assessment–Impact assessment.*

*ISO 14043. Environmental management–Life Cycle Assessment–Life cycle interpretation.*

*ISO 14040 First edition 1997–06–15. Environmental management–Life Cycle Assessment—Principles and Framework.*

*ISO 14041 First Edition 1998–10–01. Environmental management–Life Cycle Assessment–Goal and scope definition and inventory analysis.*

*U.S. EPA (1999) Framework for Responsible Environmental Decisionmaking (FRED): Uning Life Cycle Assessment to Evaluate Preferability of Products. (Draft).*

*Wenzel, Henrik, Michael Hauschild and Leo Alting. 1997. Environmental Assessment of Products. Chapman and Hall, London.*

## Who Are We?

**Rita Schenck** *is the executive director of the Institute for Environmental Research and Education (IERE), a non–profit dedicated to encouraging the use of facts in environmental decision making. She is on the SETAC LCA Advisory Board, and is one of the U.S. international experts negotiating the ISO life cycle standards for the U.S. Rita has a doctorate in Oceanography.*

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