

Guidance on Life-Cycle Thinking and Its Role in Environmental Decision Making

Sustainable Materials
Management Coalition

MARCH 2014



Table of Contents

1. What Is Life-Cycle Thinking?.....	1
2. What Is a Life-Cycle Assessment?	10
Full LCAs: Process-Based Assessments	10
Input-Output Life-Cycle Assessments.....	14
Focused LCAs and “Back-of-the-Napkin” Evaluations	14
3. Communication of LCA Results	16
4. Conclusions	18
5. End Notes	19
6. References	20
7. APPENDIX 1 – Examples of Life-Cycle Assessments	21
Oregon Department of Environmental Quality Shipping-Container Study.....	21
Procter & Gamble Laundry Detergent Inventory	22
Oregon Department of Environmental Quality Drinking Water Study.....	23
8. APPENDIX 2 – Sustainable Materials Management Coalition	24

1. What Is Life-Cycle Thinking?

OUR ACTIONS AFFECT THE ENVIRONMENT IN WAYS WE MAY NOT UNDERSTAND WHEN WE DECIDE WHAT PRODUCTS TO USE AND HOW WE USE THEM. WHICH PRODUCTS DO WE BUY? WHAT ARE THEY MADE OF AND HOW ARE THEY MADE? HOW DO WE USE THEM? WHAT DO WE DO WITH STUFF WHEN WE'RE THROUGH WITH IT?

In making these choices, we may think about their environmental ramifications, but in doing so we're often swayed by conventional wisdom that's misleading, by incomplete information, and by a limited understanding of the full effects of our choices. When we do consider environmental effects, we often look narrowly, focusing on one or two concerns, and we are often guided by generic labels like "recyclable," "recycled content," "biodegradable," "organic," or "zero waste" that don't really provide us much understanding of the broad range of impacts that the production, use, and end-of-life management of products can entail.

We can better inform our choices with what is often called "life-cycle thinking," which recognizes the importance of potential environmental effects at each stage of a product's life (that is, resource extraction, manufacture, use, and end-of-life management). Focusing on just one stage or one effect can be misleading. Instead, a broader look at life-cycle considerations can often illuminate unsuspected or surprising effects – such as the amount of energy, air emissions, solid waste, etc., associated with doing

your laundry with hot as opposed to cold water (since someone likely burned fossil fuels to make the energy that was used to heat the water). Life-cycle thinking can also show that the "obvious" answer isn't always the right one; for example, "non-recyclable" packaging can sometimes outperform recyclable packaging from an energy and resource perspective, if it's significantly lighter and occupies less space – in this case, the benefits of more efficiently transporting the product may outweigh the lost recycling benefits.

Life-cycle thinking can be particularly helpful to anyone comparing two or more options for product choice or deciding what to do with a product at the end of its life, because it allows a more complete assessment of environmental effects across the product's life cycle.

This guidance document attempts to provide government, private sector, community-based organizations, and the general public with some simple and non-technical guidance on how to apply life-cycle thinking to understanding and resolving product choice and end-of-life management issues.

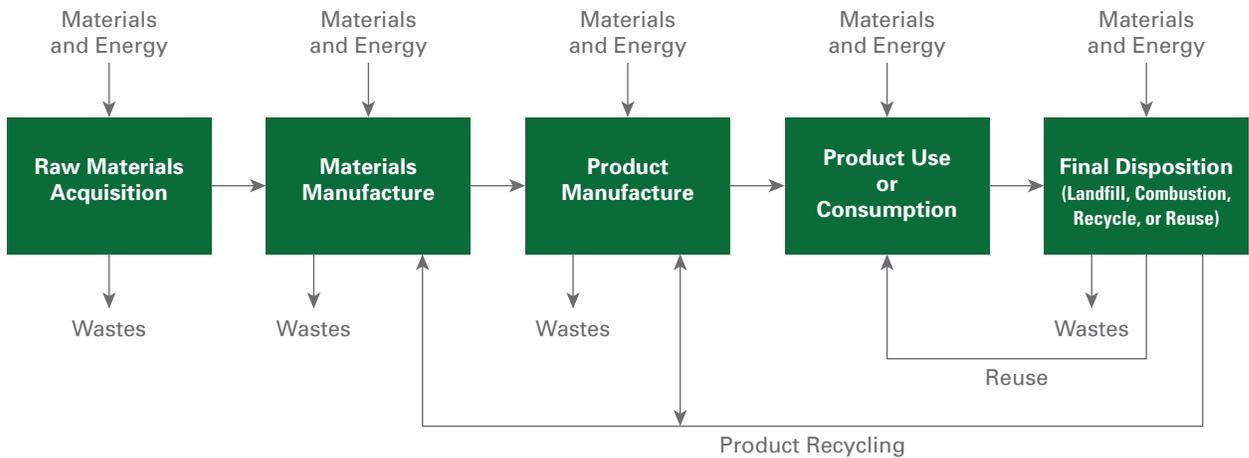


FIGURE 1: The Product Life Cycle

How Life-Cycle Thinking and LCAs Are Used

- Life-Cycle Thinking and Life Cycle Assessments have numerous applications in real life for government officials, industry, environmental and citizens' organizations, and others.
- Government officials use LCAs in developing public policy, e.g., "waste" management strategies, national energy policies, procurement, and resource management.
- NGOs and public organizations use LCAs in comparing products and processes, identifying priorities, and evaluating broad public policies.
- Members of the public can use the results of LCAs in making personal choices about the products they buy, how they manage discards, and other day-to-day choices.
- Industry regularly uses LCAs in product development, particularly in product stewardship reviews to assess the environmental sustainability of a product and in supporting environmental claims.
- Retailers increasingly use LCA approaches in "greening" their supply chain, i.e., to improve products provided by their suppliers; academics and NGOs often participate in these efforts.
- Life-cycle thinking and LCAs increasingly underlie environmental product declarations by industry and third party standards like Green Seal and LEED building standards

The key to life-cycle thinking is to consider the impacts of a material throughout its full "life cycle" – from the extraction of the raw materials used to make the product through the product's manufacture, use, and waste management. It looks at a range of inputs and effects, such as energy use and related emissions, water use, and the potential for human toxicity and ecological effects. A product's full life cycle is illustrated in Figure 1 above.

Each of the stages, as illustrated in Figure 1, has its own set of potential inputs (such as energy, water, and chemicals) and environmental impacts (such as toxic releases, ecological effects, and greenhouse gas emissions). Of course, we can't expect a full analysis of all factors for every decision we make in day-to-day life. However, if we consider issues through the lens of life-cycle thinking, we can better inform our choices and decisions. If we focus on one attribute or one life-cycle stage, we may miss the big picture; if we look at the full life cycle, we can make better informed choices.

Within the last several decades, scientists have developed detailed and formal procedures to assess life-cycle effects – termed Life-Cycle Assessment (LCA). In the 1950s, US companies began to look at the full life cycle of their products as part of cost-accounting exercises; in the late 1960s, The Coca-Cola Company commissioned what is often considered the first life-cycle-based environmental analysis to help it review soft-drink container options. During the

1970s, other companies followed suit, typically with proprietary studies, and EPA conducted materials-flow studies to support the goal of diverting materials from landfills. LCA practices have advanced significantly since then, reflected in international protocols on how to conduct LCAs, improved data inventories, better understanding of environmental effects, and improved computing capacity. Many LCAs now also look beyond choices involving particular products or processes, and take on system-wide assessments with large policy and social implications. These include analyses of the environmental impact of large systems across the overall economy – such as recent LCAs on the food system, which take a broad look at world-wide food production, processing, consumption, etc.¹

While one can perform a very detailed and rigorous analytical LCA, it is not always necessary to do so. One of the goals of this guidance is to help you think about how to best apply life-cycle thinking, and LCA concepts, to the particular decision or choice you need to make.

LCAs and life-cycle thinking does not replace the basic principles underlying EPA's materials or "waste" hierarchy, especially the importance of source reduction and waste prevention in sustainable materials management. The hierarchy provides a conceptual framework that has proven very useful, and indeed it reflects a life-cycle perspective. The hierarchy was never intended, however, to provide prescriptive answers applicable to any particular situation or choice, and life-cycle thinking can provide significant insight for specific decisions. In recent years, moreover, the nature of the products we use, as well as the tools we have to manage those products when we discard them, have become increasingly complex. The relatively general framework of the waste hierarchy can fall short in helping guide these more complex choices and decisions. Fortunately, life-cycle thinking and this guidance can help.

One good illustration of this point is how Procter & Gamble (P&G) used the LCA process to markedly reduce the environmental footprint of household laundry detergents. This effort also illustrates the sometimes surprising insights LCA can provide.

■ Early in the 2000s, Procter & Gamble scientists inventoried the life-cycle effects of household laundry detergents, looking at all life-cycle stages and a full suite of environmental attributes. They determined that 80% of the energy use, 70% of the greenhouse gas (GHG) burden, and over 60% of toxic emissions associated with the use of the product's full life cycle came from its use in the home – more specifically, from the energy required to heat the water in washing machines. It was far from immediately evident before this study that the overwhelmingly dominant impacts associated with laundry detergents arise not from resource extraction, product and packaging manufacture, transportation, or disposal but from hot water! To address this issue, P&G developed a reformulated detergent that could clean laundry in cold water as effectively as the earlier generation of detergents could clean in hot water. (See Appendix 1 for more detailed description.)²

What's instructive about this example is that P&G didn't start with the answers. They started instead by compiling a detailed life-cycle inventory of the product, carefully identifying inputs and outputs throughout the product's life cycle, and quantifying impacts on a full range of environmental concerns. In the end, the analysis pointed toward an improbable strategy for improving the product's environmental performance that would likely have been missed by a narrower analysis (or by an analysis that focused on more "visible" impacts, such as packaging waste). The study was thorough enough and convincing enough to persuade P&G to pursue a multi-year R&D project to reformulate its detergent.

Another illustration of the informative value of life-cycle thinking is in the area of food. People today frequently express concern about the GHG and energy costs associated with the transportation of food products, and they frequently advocate buying locally produced food. There are many good reasons to buy local, but, if energy use and greenhouse-gas emissions are of interest, LCAs have shown that transportation represents a relatively small part of the global food system's GHG, energy, and other burdens. Reducing transportation isn't the place to start if GHG reduction is the goal – and buying local is not necessarily reducing your carbon footprint.

■ In 2008, researchers at Carnegie-Mellon reported a detailed life-cycle inventory of GHGs associated with foods, looking at eight different standard food categories. The study showed that 83% of the average U.S. household's annual carbon footprint for food consumption comes from producing the food (such as from the energy used to power farm equipment and the use of fertilizers that derive from natural gas). Transportation represents only 11% of life-cycle GHG emissions. And more than half of those transportation-related GHG emissions occur before the food reaches the final food producer, as fertilizers, raw ingredients, and packaging move through the supply chain. These emissions can occur whether the consumer "buys local" or not. The authors concluded that, for the average American household, "buying local" could achieve, at maximum, only a 4-5% reduction in GHG emissions due to the CO₂ and non-CO₂ emissions that occur in food-related transportation, and this assumes that the local food has production-related emissions that are comparable to non-local food, an assumption that is often not valid.³

Understanding how an assessment is scoped is important in understanding the results of the assessment. The Carnegie-Mellon study looked only at GHG emissions, not other issues like water use, ecologic effects, and human toxicity, and it did not consider food loss or wastage by the consumer. Thus, while this LCA can inform decisions regarding greenhouse gas emissions, it would not provide any insights into issues such as water use, human toxicity, or food wastage by consumers. More recently LCAs have looked specifically at food loss and have shown its impact is significant. For example:

■ A 2011 study by Clean Metrics in Portland, Oregon, looking specifically at food losses, calculated that for the U. S. "avoidable" food loss accounted for nearly 29% of annual food production by weight; the authors also concluded that 60% of the avoidable food loss occurred at the consumer stage. According to the authors, "the production, processing, packaging, distribution, retail and disposal" of wasted food at the distribution, retail, and consumer levels lead to annual CO₂ emissions equivalent to 2% of US national

emissions – a meaningful element of the greenhouse-gas footprint of the food-value chain that the original Carnegie Mellon study did not capture because of its more narrow scope.⁴

Thus, wasting less food is a relatively easy step a consumer could take with a significant potential to reduce the environmental impact of their food choices. These results indicate how important the scope of an LCA is, and how the choice of scope influences the result. It is important that the boundaries and limitations of any given LCA are clear so that they can properly be taken into account when the results of the LCA are used.

The above examples illustrate a critical point for decision makers conducting an LCA: you should clearly identify the question that you are trying to answer with the assessment, so that the work can be properly scoped. The scope should be broad enough to address the question at hand, while avoiding analysis of factors that add work, but do not contribute to better understanding of the potential activity under consideration. You should acknowledge any limitations in scope, so that all limitations are clearly understood.

Consistent with EPA's waste hierarchy, LCAs generally show that the bulk of a product's environmental effects occur earlier rather than later in its life cycle. By the time a material is ready for discard, it has already incurred most of its environmental burden. Thus, choosing preferable material – or using less material to begin with – is often a more effective strategy than optimizing end-of-life management. Understanding this point can help to guide consumers in buying products with smaller environmental footprints across their life cycles.

■ A study by the Oregon Department of Environmental Quality (DEQ), looking at a full suite of environmental impacts, showed that delivery of drinking water through the tap was preferable to the use of single-use bottles or home/office delivery systems, regardless of whether or not the bottles were recycled. This is because of the emissions, resource use, and energy use associated with manufacture of single-use bottles (and - for longer shipping distances - energy and emissions associated with transportation). Recycling the bottles provides important benefits, but the impacts of manufacturing the

bottles and transporting the bottled water far outweigh the benefits of recycling for all environmental effects considered, including energy, global warming emissions, potential for human health effects, and ecotoxicity.⁵ See Appendix 1 for more detailed description.

If the consumer does choose to rely on single-use bottles as a water source, the DEQ study showed that recycling the bottles is important (because they replace virgin plastic in the manufacture of new bottles). But the DEQ study also showed that it is far preferable to reduce the use of the bottles in the first place. While bottled water producers have made meaningful improvements by reducing the amount of materials used in bottles (light-weighting) as well as in secondary packaging (packaging crates for the bottles) and recycling does provide measurable benefits compared to disposal, the DEQ study showed that tap water is clearly preferable from a life-cycle perspective. DEQ conducted its study on water delivery systems in part to address questions it was hearing from the public, asking: “Isn’t recycling enough?” The study makes clear that the answer is “no.”

Another recent Oregon DEQ study illustrates the importance of source reduction in packaging, in this case by showing that “recycled content” and “recyclability” aren’t necessarily the most important considerations in any given situation. A lighter and smaller volume packaging material that isn’t recycled may be preferable to heavier packaging material that is recycled.

■ In a 2004 study on packaging for non-breakable material shipped by mail, DEQ showed that flexible shipping bags (paper or plastic) were almost always preferable to boxes with filled void space, regardless of recycling or recycled content. In the study, shipping bags that, as a practical matter, could not be recycled and that had no post-consumer content were shown to have lower energy, solid waste, and GHG burdens than did cardboard boxes with fill material that had significant post-consumer content and that could be recycled. This result applied to almost all environmental burdens reviewed. Because shipping bags contain less material and are more compact than boxes, less material has to be produced up front and the product could be shipped

more efficiently, reducing the energy intensity of both manufacturing and shipping.⁶ See Appendix 1 for more detail.

Similarly, “compostable” isn’t always better.

■ Some companies promote the use of plant-derived plastics in snack packaging on the grounds that they are “compostable” and therefore consistent with principles of “zero waste.” However, many of these packaging materials are not separated from the rest of the waste stream for composting and end up in landfills. Even when some of these plastics are put into a compost pile, they decompose into carbon dioxide and water. No organic compost is actually produced and so all of the resources that went into making the package in the first place are not recovered or reused in any meaningful way. If the plastics are placed in a landfill and degrade, they will produce methane, a powerful greenhouse gas. If the compostable snack packaging turns out to be preferable in some ways, it will be for reasons unrelated to the fact that it is potentially compostable, but rather because of what materials it is made from and/or how it is made. This illustrates that buying products based on generic label claims and attributes such as “compostable” can lead to unintended consequences and may not even be the best choice for the environment. Single attributes such as “compostable” and “recyclable” often do not correlate with lower-impact choices.

Life-cycle thinking also shows the importance of recycling when a material has reached the end of its life, and it helps States and local communities make effective choices in their waste management and recycling programs. Numerous LCAs have shown the benefits of recycling common recyclables like metals, paper, glass, and plastics like PET and HPDE. While local officials, the press, and the public often focus on “landfill diversion” as the main benefit of recycling, LCAs show that its benefits instead come overwhelmingly from recycled materials replacing virgin materials and therefore avoiding the environmental footprint of producing those virgin materials. To take one example, the energy expended in recycling a kilogram of aluminum cans saves approximately 95% of the energy consumed in producing a kilogram of

virgin aluminum, and this figure doesn't reflect the other environmental effects of bauxite mining and primary aluminum production.⁷

LCAs and life-cycle thinking can help local communities and waste management officials overcome common misconceptions, such as the concern that the energy (and GHG) costs of collecting and transporting materials for recycling do not justify the recycling's environmental benefits. This misconception has even led some facilities to drop recycling programs, because they thought recycling was a waste of energy.

Cities, similarly, sometimes wonder if they can save energy by reducing the frequency of curbside recycling services or eliminating them altogether, reducing fuel and trucking costs. This strategy reduces the energy (and costs) directly expended by the recycling program (because fuel use and other transportation-related effects are lower) – but only if the program is looked at in isolation.

One important question is, what effect would reducing the frequency of curbside recycling have on recycling rates? Multiple studies have shown that cutting back curbside recycling collection indeed reduces recycling rates (assuming no other program changes are made at the same time). Decreasing the frequency of collection, therefore, means less recycled material available for producers of packaging, containers, office paper, electronics, etc., resulting in the extraction and production of more virgin materials such as glass, metal, plastic, and paper. Manufacturing virgin materials requires mining (or harvesting) and transporting the raw materials and then processing them into finished products. LCAs generally show that the energy use and greenhouse gas emissions associated with those upstream activities far exceeds the energy required for the various steps in recycling used glass, metal, paper, and plastic (for those plastics amenable to recycling). Thus, reducing recycling frequency in this situation does not reduce energy use overall, and in fact increases it; but it does so in a way that would not be visible without a life-cycle perspective – that is, by shifting it to other locales. This shows the power of life-cycle thinking as a way of effectively sorting through choices.

Several LCA examples follow.

■ Oregon DEQ evaluated curbside recycling for the city of Portland and found that, when residential curbside recyclables displace virgin feedstocks in manufacturing, the resulting reduction in greenhouse gases is approximately 38 times greater than the GHG emissions associated with extracting, refining, transporting, and burning the fuels used by the curbside collection trucks. Reducing the collection schedule from weekly to every other week, in this case, would reduce fleet-related emissions by approximately 3 metric tons CO₂e/100 tons of recyclables, but if this reduction in convenience caused even a tiny decrease in the quantity or quality of materials collected, the resulting reduction in “upstream” benefits (232 metric tons CO₂e/100 tons of recyclables) would lead to a net increase in greenhouse gases. The upstream benefits are primarily the GHG savings achieved by substituting recyclables for virgin raw materials.⁸

■ According to calculations by Oregon DEQ, aluminum scrap could be shipped by ocean freighter for more than 500,000 miles – farther than the distance to the moon – before the energy expended in transportation was more than the energy required to create similar amounts of virgin aluminum. Similarly, glass to be recycled into bottles can be shipped by rail about 5,000 miles before glass recycling consumes more energy than manufacturing virgin glass.⁹

The particular end use selected for a discarded material can also have a significant effect on environmental benefits, and LCA can help illuminate that.

■ Oregon DEQ estimates that if glass scrap collected on the Oregon-Idaho border is used locally as a replacement for road aggregate, approximately 0.2 million BTUs of energy are saved per ton of glass collected. But if the glass is shipped by truck all the way across the state to Portland for recycling into bottles, the net energy savings are 3 to 8 times higher (depending on how it is transported), even after subtracting the energy used in round-trip transport. This is because the recycled glass offsets the production of virgin glass, which involves energy use to mine the raw materials and make the glass.¹⁰ This point is illustrated

by Figure 2, which shows estimated energy savings per ton of discarded glass (in million British Thermal Units or MMBTU) depending upon the end use:

End Markets Matter! (sometimes)

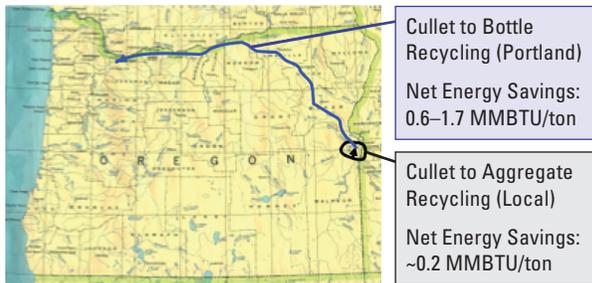


FIGURE 2: Transportation of Glass Cullet for Recycling

Personal communication from David Allaway, Oregon Department of Environmental Quality.

In this example, discarded glass used in a glass-to-glass manufacturing process is replacing a raw material in the glass value chain (cullet) with a material that has a higher GHG footprint than does the raw material (crushed gravel, etc.) it would displace in the aggregate value chain. The benefits are greater because the energy savings outweigh the effects of greater shipping distances.

Even the principle that less material is better may not always hold true, if the full life cycle is considered. As a simple example, food packaging plays an important role in protecting the product and reducing food spoilage; eliminating packaging may save material, but it can lead to more food loss. Sometimes more packaging is actually better. A 2010 DEQ study on residential housing, looking at multiple attributes and the full life cycle, reached similar conclusions. The study showed many opportunities to reduce the environmental impacts of home construction by reducing the materials used. In a few cases, however, using more material was better— for example, insulated concrete forms and double walls involved more material than other construction options - but they yielded greater GHG and other environmental benefits because they provided better insulation, which reduced lifetime energy use in the home. In this case, the energy use avoided because of better insulation outweighed the environmental costs from using more construction material.¹¹

As consumer goods and related packaging materials we use every day get more complex, LCA can help us think about the most effective management for these materials when they are discarded. For example, food packaging is increasingly asked to serve multiple functions in terms of protecting food, being very flexible in order to shape a product and printable with high-color high-quality graphics. These demands have led to a whole new class of packaging material called flexible multi-layer packaging. These materials do a great job keeping foods and other products safe and fresh and reducing food waste, and can lower the energy used in transport by the ability to move more product per vehicle and can reduce the space dedicated to packaged products in supermarkets (which need to be heated and cooled). Because they involve several different kinds of plastic that cannot be easily disaggregated, they are not well suited to traditional material-recovery recycling, and so LCA is also being used to help inform appropriate management of these materials at their end of life, with options under consideration as diverse as landfilling, combusting to produce electricity, and emerging technologies that use gasification to turn this packaging into a liquid fuel.

These examples show that we need to cultivate a life-cycle perspective, based on thoughtful analysis, to understand how our choices about the materials we produce and use affect the overall environmental system. Life-cycle thinking helps us to identify priorities, design and select products, and make sound environmental choices. It helps us get beyond one-dimensional goals like “zero waste” and automatic preferences for attributes like “compostable” or “recycled content,” and it allows us to identify the most effective strategies in specific situations.

LCAs, however, are only a tool; they can’t answer all questions, and the answers they give depend on how the questions are framed and what data they’re based on. For example, environmental LCAs are not suitable for answering questions about social or economic impacts. Practitioners of LCA are developing tools and guidelines for determining the social and socio-economic impacts of production and consumption

on workers, local communities, and consumers, but these tools and guidelines are not yet mature. Further, LCAs are limited by the availability and certainty of data – the less well defined or the more uncertain the available data (such as of predictions of crop yield and biodiversity), the less meaningful the results. LCAs do not typically quantify human risks (which might be separately addressed in a risk assessment), nor is it easy to balance broad geographic effects like climate change versus more local effects (e.g., effects of chemical emissions at a particular location); how to account for water use and water resources is still under debate, as is how to identify and account for the indirect effects of land-use changes.¹² These limitations should be recognized in understanding any LCA.

Given these cautions, it is important that all life-cycle studies, whether they're quick scoping analyses or

full LCAs meeting ISO standards, it is important to frame the question carefully, to clearly define the study's scope, to rely on sound data, and to draw valid conclusions without overstating them. The scope of the study may differ depending on its purpose, but it needs to be based on clear goals and sound analysis and to be clearly communicated.

Highlights of Full Life-Cycle Assessment Process

- Life-cycle thinking describes a way of considering the environmental impacts of products or processes – it takes account of their environmental impacts throughout their life cycle, from raw materials extraction to end of life. Take the simple case of a glass bottle: To understand its true environmental burden, you need to understand the resources and emissions involved in mining the sand, soda ash, etc.; smelting the glass; manufacturing the bottle; transporting it, using and washing it, recycling or disposing of it, etc. – rather than just looking at the properties of the glass bottle in isolation. The results of this way of looking at impacts can be surprising and counterintuitive.
- Life-Cycle Assessments (LCAs) are formalized studies based on the perspective of life-cycle thinking; LCAs are conducted according to recognized protocols and aimed at evaluating a product or process's life-cycle impacts. LCAs are quantitative while life cycle thinking can be semi-quantitative or qualitative.
- The question an LCA is intended to address needs to be clearly framed, and its scope and boundaries need to be carefully selected. Leaving key considerations “out of boundary” or scope can lead to misleading results.
- Full LCAs typically look at multiple process stages and multiple attributes (e.g., toxic emissions, water use, global warming emissions, etc.); important results can be missed if a study is not fully and carefully scoped.
- Data gathering can be the most difficult and resource-intensive aspect of an LCA evaluation; some data may not be readily available, or it simply may not exist; careful use of data is essential, and judgment is required. Data limitations and uncertainties need to be recognized and explained.
- Assumptions need to be used carefully; where they would affect critical results, sensitivity analyses of assumptions are appropriate.
- External review is important, especially where LCAs are used for public purposes.
- Results need to be communicated clearly; scope, data, and underlying assumptions need to be transparent.
- LCAs are only tools; they generally assess environmental matters and don't address social and economic issues; they don't substitute for risk assessments; and some areas of application are still under development.

2. What Is a Life-Cycle Assessment?

LIFE-CYCLE THINKING DESCRIBES A WAY OF LOOKING AT THE ENVIRONMENTAL IMPACTS OF A PRODUCT OR PROCESS BY LOOKING AT ITS POTENTIAL EFFECTS AND THE RESOURCES IT USES ACROSS ITS LIFE CYCLE. EVALUATIONS BASED ON THIS PERSPECTIVE COME IN MANY DIFFERENT SIZES AND SHAPES, WITH LIFE-CYCLE ASSESSMENTS (LCA) BEING A FORMALIZED APPROACH ESTABLISHED UNDER INTERNATIONAL PROTOCOLS AND WELL RECOGNIZED IN SCIENTIFIC LITERATURE.

An LCA typically includes several key steps, regardless of the breadth or scope of the particular assessment:

- Clearly define the question to be answered so that the scope of the assessment can be focused.
- Establish boundary conditions that are relevant to the assessment; if the boundaries are too narrow, the assessment may fail to provide important information; if too broad, it can lead to unnecessary work and complication.
- Find the data sufficient to complete the assessment.
- Clearly communicate the nature of the assessment, including the question it is addressing, the boundaries of the assessment, the assumptions and data used, and their strengths and weaknesses (including limitations).
- Communicate the results of the assessment and how it informs (or has informed) particular decisions.

It is also important to recognize that LCAs, no matter how detailed, are limited in their focus – they do not address social issues (like equity) or economic issues, which of course are important in any decision; these concerns must be considered separately, in addition to the LCA results. And, given current limitations in data and methodologies, they are better at addressing some questions rather than others. At the same time, they represent the best tool we have for addressing the full environmental effects of society's materials management choices.

The following sections discuss different levels of LCAs.

Full LCAs: Process-Based Assessments

Process-based Life-Cycle Assessment is a systematic way of assessing materials flows and environmental impacts across the life-cycle stages of a product or process. As described earlier, the term "life cycle" refers to the major activities across the life-span of

a material, product, or service, beginning with the extraction or harvesting of raw materials (mining, logging, extraction of oil or natural gas) to processing of raw materials into feedstocks (smelting, pulping, production of plastics, etc.) and manufacture of products (containers, furniture, detergents), transportation and delivery to markets through use of the products, and end-of-life management (reuse, recycling, or disposal).

The LCA process is illustrated by Figure 3 below.

The center column identifies the basic life-cycle stages and activities evaluated in an LCA; the specifics of the stages, of course, will differ depending on the product or process being evaluated. Each of these life-cycle stages requires resources, which are listed in the first column – energy is consumed (electricity to run equipment, fuel for transportation, etc.) and materials are used (raw materials, packaging, water, etc.). These resources are referred to as “inputs.” Similarly, each of the life-cycle stages produces one or more types of waste (chemical or particulate emissions to air or water, solid waste, etc.). These emissions are referred to as “outputs.” “Co-products” (useful materials that are not the primary intended product but are produced along with the

intended product) are also identified in the figure as “outputs.” For example, an LCA on gasoline would consider diesel and other fuel products also produced from refining crude oil to produce gasoline to be co-products of the refining process. Material can also be reused or recycled back into the life cycle at various points.

Life-Cycle Assessments identify and quantify the relevant inputs and outputs in a systematic manner (referred to as the “life-cycle inventory” or LCI), and evaluate the data to assess the potential environmental impacts across the full life cycle. Interpreting these results helps decision-makers make a more informed decision by allowing them to:

- Evaluate the environmental consequences associated with a given product.
- Analyze the environmental trade-offs associated with one or more specific products/processes.
- Quantify environmental releases to air, water, and land in relation to each life -cycle stage and/or major contributing process.
- Compare the potential environmental impacts between two or more products/processes.
- Identify potential impacts to one or more specific environmental areas of concern.

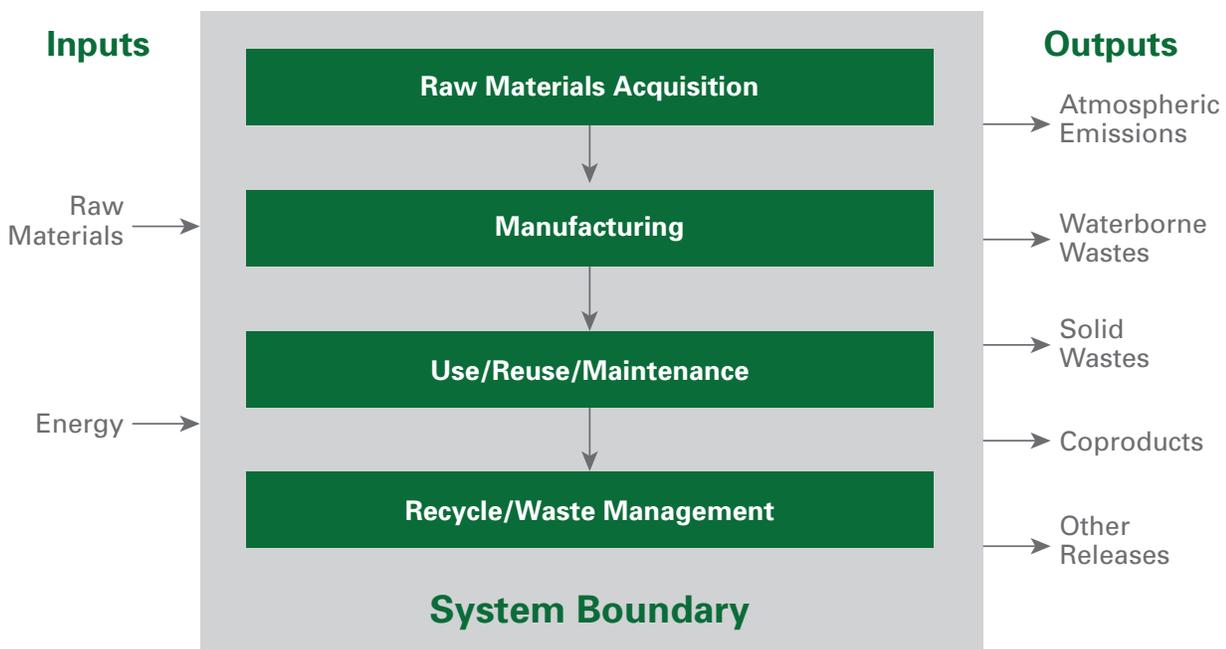


FIGURE 3: The LCA Process

EPA, *Life Cycle Assessment: Principles and Practice (2006)*

By evaluating impacts in various stages of the product life cycle, LCA can provide a comprehensive view of the environmental aspects of the product or process and a more accurate picture of the true environmental trade-offs in product and process selection. Because full LCAs require a significant commitment of resources and significant amounts of data, they are generally recommended for an organization's highest priorities. Simpler screening LCAs or LCAs that focus on particular aspects of a life cycle (e.g., water use in product manufacturing or agriculture) are commonly used where a full-scale LCA is not needed to address the question at hand.

The approach to life-cycle assessment described above is referred to as "process-based," meaning that it identifies and aggregates the inputs to and outputs from individual processes across the full life cycle. Most LCAs are process-based. (An alternative approach, called "input-output LCA" is discussed later.)

Process LCA is a systematic, phased approach, standardized through the International Standard Organization's ISO Standards 14040 and 14044. In general, the ISO methodology consists of four components: goal definition and scoping, inventory analysis, impact assessment, and interpretation.

In the first component, the goal and scope of the LCA is defined, including the purpose of the study, the questions it is designed to answer, a careful description of the product, process, or activity to be studied, and the analytical approach. As part of this component of the LCA, it is important to establish the context in which the assessment is to be made, identify the scope and boundaries of the LCA, its data needs and assumptions, and the environmental effects to be assessed.

- The term "boundary" refers to which processes are included ("in-boundary") or excluded ("out of boundary") in an LCA. It is important to include all processes and factors that may influence the question under assessment. But as a practical matter, analysts conducting an LCA have to make choices about the scope of their assessments. For example, in the DEQ drinking water study referred to earlier, a decision was made not to evaluate the impact of any components that contribute to a very small percentage of the mass

of any system. Using this criterion, the impacts of producing and using automatic dishwasher detergent was not evaluated for the reusable bottle scenarios; this material and its related impacts were initially defined as "out of boundary." During review of the draft report, the study authors went back and reevaluated this boundary decision and realized that, in fact, dishwasher detergent can have a significant bearing on one type of environmental impact: eutrophication. (Historically, automatic dishwashing detergent sold in Oregon had high levels of phosphorous; this is no longer the case.) Thus, the study's boundaries were adjusted to include the dishwasher detergent as part of the study. It is important to be transparent about all boundary decisions and explain why choices are made.

- Some LCAs may only cover part of a product or process's life cycle. For example, some LCAs involving food products cover the food life cycle up to delivery of food "to the table" but not the processes beyond; LCAs focusing on commercial products sometimes cover stages ending once the product is shipped from the final manufacturer's "gate," with subsequent life-cycle stages (transport to the retailer, retail storage, customer shipment, use, and end-of-life management) excluded. These studies, however, might miss important effects – in the earlier food example, food wastage at the consumer stage would not be captured. In all cases the scope and boundaries of the LCA should be designed to best address the question that the LCA is intended to inform, and should be clearly explained.
- Some studies focus only on a single environmental impact, e.g., GHG emissions, while some look at a broader range of impacts (e.g. toxics, carcinogens, water use, GHG emissions, etc.). Limiting the scope of an LCA to a single impact runs the risk of missing important effects; for this reason, international protocols and EPA guidance specify that full LCAs should cover a full range of environmental impacts. However, studies looking at a single or a few attributes can provide important insight into specific questions, and may be appropriate when limitations are acknowledged and explained.

■ Choices in study design and scope can lead to significant differences in results, sometimes in ways that are hard to predict. Even apparently simple choices – for example, what “functional unit” to use in comparing products - can affect results. If we wished to compare paper and plastic grocery bags, the most obvious approach might be to base the comparison on bags of similar carrying capacity. But is one type of bag more likely to be double-bagged than the other? And what about including reusable bags in the evaluation? It should be obvious that answers to these questions will change the study results in important ways.

Indeed, perhaps the single most important step in an LCA is to clearly define the question to be addressed and the scope and study design of LCA best suited to provide information relevant to the question. Resource considerations (time, data, computing power, money, etc.), of course, need to be considered in scoping LCAs.

In the second LCA component, the necessary data (the life-cycle inventory) is identified and quantified for the questions being evaluated, such as energy, water and materials usage, and environmental releases (e.g., air emissions, solid waste, or waste-water discharges). For example, with respect to greenhouse gas emissions, the study would include information regarding the types and amounts of energy used for power generation, transportation, and processing, and the CO₂ emissions associated with each, as well as information on the generation of any other greenhouse gases. For air or water emissions, the study would seek to identify chemical inputs and emissions through the life cycle and their potential toxicity. Other factors such as particulate emissions, ozone effects, eutrophication effects, etc., would also be considered in a full LCA.

In processes where there are multiple outputs and co-products (such as our refining example, with its various fuel types), the data must be distributed across each of the outputs, for example apportioning facility emissions across the gasoline, diesel, and other fuels produced in the refinery example (allocation).

■ For example, consider an LCA of milk production at a dairy farm. The dairy farm typically will produce some meat as a side product, and so the inputs and outputs

of the dairy farm will contribute to meat as well as milk production. The researcher conducting the LCA has to decide how to account for this fact – for example, by including the meat production within the overall scope of the study, by entirely ignoring the meat production – e.g., if it’s a very minor side activity – or by “allocating” some portion of the inputs and outputs to the milk and some to the meat. ISO protocols provide options for allocation. In any case, the LCA should describe how co-products are handled.

Study results can be very different depending on how co-products are addressed and how emissions are allocated among them. It’s critical to choose an approach that does not hide important effects and to carefully explain what allocation approaches are taken and why.

The lack of complete data is often the most difficult part of a comprehensive LCA. Many LCAs have focused on energy consumption and greenhouse gas emissions; therefore, energy use data is frequently the most robust life-cycle inventory data available. Even for energy, however, and more so for many other areas, much of the data needed is proprietary or simply hasn’t been developed. Summary information is sometimes available, but because raw data isn’t always available, it can be difficult to confirm the accuracy of summary data. When direct data is missing, investigators may have to rely on plausible estimates or reasonable assumptions – e.g., in its drinking water study, Oregon DEQ made judgments about how homeowners would wash water containers. These assumptions were clearly articulated and explained, and several different patterns of consumer behavior were evaluated, to better understand the relative importance (or lack thereof) of variability in consumer behavior. Often, uncertainty about data or assumptions can be reduced by sensitivity analyses – for example, by conducting the analysis under a range of different assumptions, to determine whether they could affect the final result.

In the third LCA component (the life-cycle impact assessment), the inventory data is used to assess the energy, water, and material used, as well as the identified environmental releases. LCAs quantify environmental

emissions, although it is more typically risk assessments that quantify actual environmental or human health effects. LCAs may assess hundreds or thousands of different chemical and other releases, but most readers can't easily differentiate between, for example, the cancer-causing potential of benzene vs. dioxin or the greenhouse gas impact of methane vs. nitrous oxide. So impact assessment takes the results of inventories and converts the results to a smaller number of more easily-understood impact categories, such as "global warming potential" (where all gases are expressed in terms of carbon dioxide equivalents) and "carcinogenic potential."

Finally, the interpretation phase of the LCA provides the findings of the analysis in light of its goal and scope. Typically, this phase identifies significant issues, defines limitations, and summarizes results.

Whoever the audience of an LCA may be, the study's design, conduct, and results need to be effectively communicated. Clearly communicating the scope of an LCA (the question to be addressed, the scope boundaries) and the analysis (the data used, key assumptions, weaknesses, and strengths of the data and assumptions) is critical to ensure that the output of the LCA can be properly understood by parties using the LCA outputs for decision making. Decision makers and interested readers more generally need to understand the sensitivities and the limitations of the study. For this reason, the ISO standards for LCAs set requirements for communicating the study's results, which include a detailed explanation of the purposes, scope, limitations, etc., of the study. The study's results, data, methods, assumptions, and limitations need to be transparent, and they have to be presented in enough detail for readers to understand the complexities and trade-offs of the study. Transparency is particularly important when the results of the LCA will be used outside the organization performing the assessment, such as a public agency using LCA to make a public policy decision or a private company using LCA to make a product claim. While not all LCAs need to rigorously follow the ISO standards, these standards provide an invaluable reference for key considerations in scoping and communicating LCAs.

The ISO standards also require external peer review of all LCAs supporting a "comparative assertion" disclosed

to the public, an effort most relevant when there is a need for broad public understanding and buy-in on actions or claims relying in part on LCAs. A comparative assertion might, for example, be a claim that one product or process is superior to another because it was associated with lower environmental impacts. The peer review requirement has the effect of strengthening and providing greater credibility to LCAs conducted under ISO standards. While a particular decision may not justify the level of effort required for a formal peer review - such as a private entity using LCA to consider which supplier to buy their raw materials from - it can improve the rigor, transparency, and credibility of LCAs used for highly public purposes.

Input-Output Life-Cycle Assessments

"Input-Output LCAs" or IO is an alternative to full Life-Cycle Assessment. Unlike process LCAs, which look at particular process through its life cycle, Input-Output LCAs take a more economy-wide view, estimating life-cycle emissions resulting from the production of economic outputs (e.g., automobiles, household foods, etc.). Input-output LCAs are based on traditional economic input-output analyses, which estimate the amount of economic activity (across multiple industries, via supply chains) it takes to produce a unit of economic output. Using industry-specific data, input-output LCAs go beyond this economic analysis to estimate life-cycle emissions associated with the amount of economic activity required to make the product being evaluated. This approach allows studies to estimate the emissions associated with different inputs of a product or activity. Input-output LCAs are often used for evaluating the impacts of large sectors or systems. For example, the Carnegie-Mellon LCA discussed earlier, which showed that emissions from production of US household food far outweighed those from transportation, was an input-output analysis. Input-output analyses have the advantage of being quick and easy (compared to process LCAs), and they can be particularly useful at the level of the whole economy.

Focused LCAs and "Back-of-the-Napkin" Evaluations

A full process LCA can be costly (running to hundreds of thousands of dollars) and time-consuming; the expense

“Back-of-the-Napkin” Review of Coffee Packaging Options

In 2012, EPA conducted a quick analysis of options for coffee packaging to better understand the relative values, from a GHG perspective, of different packaging options: steel cans with a plastic lid, plastic canisters, and flexible plastic pouches. The study, which was largely based on readily available data, required minimal effort. It concluded that, while the steel cans and plastic containers had advantages on the “disposal” end of the life-cycle (e.g., were both recyclable), the use of a non-recyclable flexible plastic pouch created 1/4 to 1/10 the CO₂ emissions and produced 1/4 and 1/8 the solid waste as steel cans and plastic containers. The benefits were due to the facts that the flexible packaging was many times lighter per unit of coffee shipped than the cans and canisters (resulting in less material production), that use of flexible packaging allowed much more efficient packing of the coffee during shipment and on store shelves, and that the flexible bags could be produced at the shipment site rather than remotely (meaning less shipment of empty containers).

The data sources for this study were widely available industry LCAs on flexible packaging and coffee packaging systems, and US LCI Database, <http://www.nrel.gov/lci/>

of the LCA is directly related to the level of detail undertaken. The cost and time-intensity of an LCA make it particularly important for those conducting the analysis to clearly identify its purpose and potential scope – a company’s strategic decision encompassing millions of dollars may warrant an expansive, exhaustive LCA. For example, an investment decision on implementing a new industrial process or developing a new product may easily justify the cost of a full LCA. For many situations, however, a full LCA conducted according to ISO standards is likely to be impractical or unnecessary.

As a general matter, it is useful to incorporate life-cycle thinking into materials-management decision-making at all levels. In some cases, this may be as simple as giving thought to potential environmental ramifications of the most relevant steps in the value chain as choices are made.

More formal LCAs may also be streamlined. For example, sometimes analyses can be conducted through existing LCA-based tools (such as EPA’s Waste Reduction Model – found at www.epa.gov/warm - (which can be used to calculate GHG benefits of different waste management practices). In many cases, a company or other interested parties may easily compare one or more existing products by assembling readily available existing data. Oregon’s DEQ, for example, has found streamlined approaches based on existing data to be a valuable complement to its more extensive LCA analyses. Also see the text box above, which describes a “back-of-the-napkin” EPA review of packaging options for shipping

coffee. The study, which used readily available data, shows the advantages, from a solid waste and GHG perspective, of flexible plastic pouches over steel cans and conventional plastic containers.

Streamlined LCA approaches like these typically require some expertise in life-cycle assessment and familiarity with available data bases, but – assuming that level of expertise – they can be quickly completed with minimal effort. Screening level LCAs can also be useful to identify those elements that should be evaluated more deeply in a more formal LCA to help streamline the process. The scoping of an LCA should be driven by a clear articulation of the question being addressed.

As noted above, streamlined LCAs may also generally follow the ISO protocols, but limit their analysis to only a few effects or define one or more life-cycle stages out of the study’s scope. For example, many analyses are limited to GHG emissions because of current attention to climate change. Regardless, one advantage of starting with a cheaper, faster approach is that it can be used to focus or inform more costly LCA studies if the cheaper, faster approach did not produce results that were sufficiently detailed or conclusive. In any case, it is important for the authors of the study to communicate its scope, purpose, and results, with an emphasis on transparency, and a clear explanation of what choices were made in conducting the study (e.g., why particular effects were chosen for assessment and why others were not included), and what the limitations might be.



3. Communication of LCA Results

16

ONE OF THE CHALLENGES OF AN LCA, ESPECIALLY A FULL LCA, IS EFFECTIVELY COMMUNICATING ITS RESULTS. FULL LCA REPORTS ARE LENGTHY, HIGHLY TECHNICAL DOCUMENTS, LARGELY UNINTELLIGIBLE TO ANYONE NOT WELL VERSED IN ENVIRONMENTAL SCIENCE AND LCA PROCEDURES. THEY ARE INTENDED FOR HIGHLY SPECIALIZED AUDIENCES, AND EVEN THE SUMMARY SECTIONS AND CONCLUSIONS OF MOST LCAS ARE HEAVY READING FOR NON-SPECIALISTS. THIS MAY NOT BE A PROBLEM IF THE LCA IS PURELY FOR PROFESSIONAL PEERS, BUT IF IT IS BEING USED TO SUPPORT A PRODUCT CLAIM OR IT DEALS WITH AN ISSUE OF PUBLIC IMPORTANCE, THE AUTHORS OF THE STUDY ARE DOING THEMSELVES AND THE PUBLIC A DISSERVICE IF THE STUDY IS NOT WELL COMMUNICATED.

In some cases, an LCA is developed to meet an environmental certification program like LEED building certification, a Green Seal label, or an Environmental Product Declaration. In these cases, the certification or the label itself may partially serve as the “communication.” But as a general principle, where a company, a government agency, or another organization is making environmental claims or drawing environmental conclusions based on an LCA, they are well advised to provide a more accessible summary report, with focused and readily comprehensible charts and graphics, and with accessible explanations of the study’s scope, limitations, etc. Whether the study is designed to meet full ISO standards or not, its data and conclusions need to be transparent if the authors expect it to be given any credence. Most private companies

are now well aware that the public is sensitive to “greenwashing” and wants to understand the basis for claims coming from business. Therefore, transparency and external review are all the more important where the LCA will be used to support a public claim. In some cases, a company or government agency may work in collaboration with independent academics, who publish technical results jointly or separately in an academic journal. Product manufacturers and retailers - in developing life-cycle-based metrics to green their supply chains - often now team up with NGOs and academics. These kinds of partnerships can give a study more credibility. Of course, a company conducting an LCA for purely internal purposes, e.g., to evaluate different manufacturing processes or sourcing options for a raw material or a product, may choose not to make

the study public. In such a case, public transparency (e.g., reflected in an accessible summary report complete with graphics) or external peer review may not be needed, though clarity and transparency are still required for proper use of the LCA within the company.

LCA reports are frequently obscure, but there are exceptions. The state of Oregon's Department of Environmental Quality has produced several LCAs addressing one aspect or another of materials management, some of which have been discussed earlier in this report. Together with a final peer-reviewed report, DEQ typically publishes brief summaries of their LCAs, identifying the scope, limitations, and findings of the study, and highlighting notable results and broader policy conclusions. These documents are an invaluable complement to the lengthier reports. Any organizations conducting lengthy and complex LCAs should consider similar approaches. Citations to several of DEQ's summaries are provided in the end notes.¹³

Good communications will help the audience of an LCA to understand its results and its limitations. This is particularly important when the results of an LCA are presented to the general public, local community organizations, or others who may not be well versed in the details of life-cycle analysis. In weighing the analysis, readers should particularly take note of limitations on the scope of the assessment and its

boundaries and whether these limitations are clearly explained and justified. For example, if a study is limited to GHG emissions, it can't be used to draw any conclusions about, for example, water use or ozone depletion; this limitation needs to be recognized. Peer review can also be important, and the extent to which comments are addressed can be very instructive to the reader. If underlying data and assumptions are not transparent, readers can legitimately raise questions. Finally, LCAs of course are not the whole answer; even at their most complete, for example, they do not address social, community, and economic impacts, which also need to be weighed. They can provide valuable information on environmental emissions, but they generally do not attempt to evaluate potential health risks associated with those emissions; they also tend to be more conceptual and broad rather than location-specific in their evaluations. At the same time, they have proved themselves our most useful tool for better understanding the full environmental impacts of different products or economic activities.

4. Conclusions

ENVIRONMENTAL DECISION MAKERS IN ANY ORGANIZATION, AND ANYONE INTERESTED IN MATERIALS MANAGEMENT ISSUES, NEED TO ADOPT A LIFE-CYCLE PERSPECTIVE IF THEY WISH TO GAIN A CLEAR UNDERSTANDING OF THE ENVIRONMENTAL IMPLICATIONS OF EVERY-DAY CHOICES. IF WE FOCUS ON ONE ATTRIBUTE OR ONE LIFE-CYCLE STAGE, WE MAY MISS THE BIG PICTURE. IF WE LOOK AT THE ENTIRE LIFE CYCLE, WE CAN MAKE BETTER CHOICES AND REDUCE ENVIRONMENTAL IMPACTS.

Over the last decade or two, life-cycle thinking, and more specifically LCAs, have made remarkable progress. Thousands of LCAs have been conducted, peer reviewed, and published. Publicly available life-cycle data inventories are improving. Life-cycle thinking plays an increasing role in product stewardship and supply-chain management by manufacturers and retailers, and voluntary standards like green buildings and environmental product declarations are increasingly common. A thriving professional and academic research community has emerged.

Yet, to a large extent, the results of this work have not made it to the general public or to the working level in industry; Federal, State, tribal, and local governments; non-governmental organizations (NGOs); and citizen groups. We often see a lack of life-cycle thinking in product development and product claims, in governmental environmental programs, in local community recycling and waste programs, in the public's life-style or product choices – to give just a few examples. We still see too much focus on single stages in a material's life cycle, individual attributes, or single environmental effects, and on received environmental wisdom rather than careful analysis; and we see too little appreciation of how traditional approaches can lead to unintended consequences and missed opportunities.

This guidance attempts to provide a simple description of the LCA process and to provide examples of cases of where life-cycle thinking – sometimes reflected in a full LCA, sometimes in a more streamlined study – can help lead to solutions that weren't obvious and help identify unintended consequences. As noted in the initial report of the Sustainable Materials Management Coalition, LCA can help practitioners make more refined decisions about how to manage discarded materials than they could by adopting a simplistic "materials hierarchy" set of rigid definitions.

The guidance also seeks to provide some simple tools to help practitioners scope LCAs. Industry, government, NGOs, and other interested parties can integrate life-cycle thinking more effectively into their environmental decision-making, and life-cycle practitioners need to make a more concerted effort to communicate the importance of a life-cycle perspective. Life-cycle thinking is an important input to the decision-making process; organizational decision-makers must consider this tool along with other factors in making the ultimate decision.

5. End Notes

- 1 See James Fava, Life Cycle Knowledge Informs Green Products,” in Mary Ann Curran ed., *Life Cycle Assessment Handbook: A Guide for Environmental Sustainability Products*, John Wiley & Sons, 2012, pp. 585-596; Robert G. Hunt and William E. Franklin, “LCA - How It Came About - Personal Reflections on the Origin and Development of LCA in the USA,” *International Journal of Life Cycle Assessment* 1(1) 4-7, 1966.
- 2 From Erwan Saouter and Gert van Hoof, A Database for the Life-Cycle Assessment of Procter&Gamble Laundry Detergents, *International Journal of Life-Cycle Assessment* 7 (2002), 103-114, p. 111.
- 3 Christopher L. Weber and H. Scott Matthews, “Food-Miles and the Relative Climate Impacts of Food Choices in the United States,” *Environ. Sci. Technol.* 2008, 42, 3508-3513, pp. 3508, 3512.
- 4 Kumar Venkat, “The Climate Change and Economic Impacts of Food Waste in the United States, *International Journal of Food System Dynamics* 2 (4), 2011, 431-446, p. 444.
- 5 Oregon Department of Environmental Quality, “Life Cycle Assessment of Drinking Water Systems: Bottle Water, Tap Water, and Home/Office Delivery Water,” Revised Final Peer-Reviewed LCA Report, October 22, 2009, <http://www.deq.state.or.us/lq/sw/wasteprevention/drinkingwater.htm>.
- 6 Oregon Department of Environmental Quality (DEQ), “Life Cycle Inventory of Packaging Options for Shipment of Retail Mail-Order Soft Goods,” Final Peer-Reviewed Report, April 2004, <http://www.deq.state.or.us/lq/pubs/docs/sw/packaging/LifeCycleInventory.pdf>
- 7 USEPA, <http://www.epa.gov/reg3wcmd/solidwasterecyclingfacts.htm>
- 8 David Allaway, “Climate Change and Materials Management: Introduction – West Coast Forum on Climate Change, Waste Prevention, Recovery & Disposal, June 2008, slides 23-24, ftp://ftp.epa.gov/reg10ftp/westcoastclimate/webinar_intro_to_ccmm_6-26-2008/101_presentations_part1.pdf.
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- 10 David Allaway, personal communication.
- 11 Oregon DEQ, “A Life Cycle Approach to Prioritizing Methods of Preventing Waste from the Residential Construction Center in the State of Oregon,” Phase 2 Report, Version 1.4, September 29, 2010, <http://www.deq.state.or.us/lq/pubs/docs/sw/ResidentialBldgLCA.pdf>. See pp. xv, 141, 153.
- 12 Mary Ann Curran, ed., *Life Cycle Assessment Handbook*, provides a helpful summary of current LCA challenges and developments.
- 13 Oregon DEQ, “Life Cycle Inventory: Packaging Options for Shipping Soft Goods in E-Commerce and Catalog Sales,” 2005, <http://www.deq.state.or.us/lq/pubs/docs/sw/packaging/lifecycleinventoryshort.pdf>; Oregon DEQ, “Comparing Prevention, Recycling, and Disposal: A Supplement to DEQ’s ‘Life Cycle Assessment of Drinking Water Delivery Systems,” 2009, <http://www.deq.state.or.us/lq/pubs/docs/sw/LifeCycleAssessmentDrinkingWaterSupplement.pdf>; Oregon DEQ, “A Life Cycle Approach to Prioritizing Methods of Preventing Waste from the Residential Construction Sector in the State of Oregon,” Phase 2 Report, Version 1.4 - Executive Summary, September 29, 2010, <http://www.deq.state.or.us/lq/pubs/docs/sw/ResidentialBldgLCAExecSummary.pdf>.



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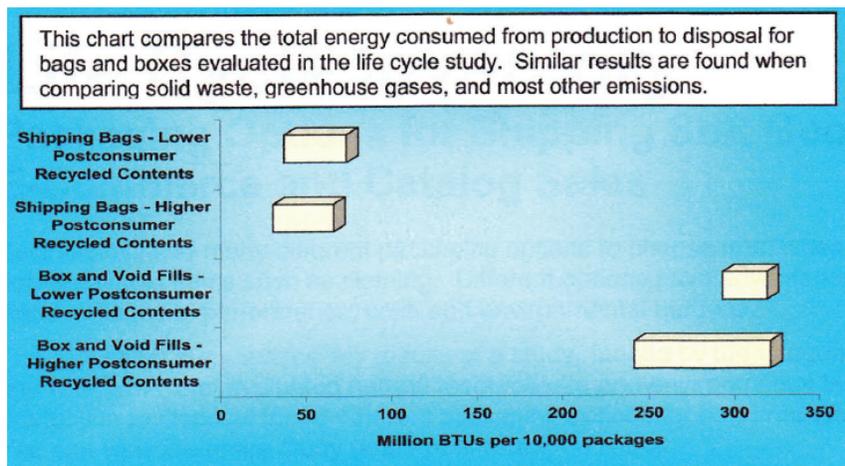
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- ISO 14044: 2006, Environmental Management – Life Cycle Assessment – Requirements and Guidelines, http://www.iso.org/iso/catalogue_detail?csnumber=38498
- US EPA, National Risk Management Research Laboratory's Life Cycle Assessment website, <http://www.epa.gov/nrmrl/std/lca/lca.html>
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7.

APPENDIX 1 – Examples of Life-Cycle Assessments

Oregon Department of Environmental Quality Shipping-Container Study

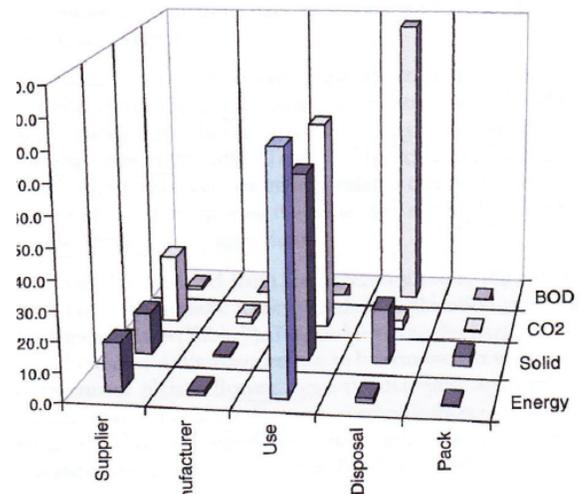
- In 2004, Oregon’s Department of Environmental Quality commissioned a Life-Cycle Inventory Assessment evaluating packaging options for non-breakable items shipped by mail. DEQ undertook this study because of the increased use of e-commerce by consumers buying products like books, clothing, etc. The purpose of the study was to identify best practices for businesses and others using packaging for non-breakable items, based on a consideration of multiple environmental criteria.
- In conducting the study, DEQ looked at twenty-six different packaging options for non-breakable items shipped by mail. The options included (1) a highly recyclable corrugated box with different types of fillers, and (2) a variety of paper and plastic shipping bags. In both cases, the shipping materials were evaluated for both lower and higher levels of post-consumer content. The inventory covered a full range of pollutants and the full life-cycle of the packaging material.
- The study reached several noteworthy conclusions:
 - Regardless of what materials were used for the shipping package or the filler, shipping bags consistently were associated with lower environmental burdens than boxes.
 - The worst performing shipping bag led to $\frac{1}{3}$ less energy consumed than the best performing box.
 - Padded bags with little to no recycled content and few convenient recycling options had significantly lower energy requirements than the best performing boxes.
 - Bags performed better because they required much less material and were more compact when shipped.
- Impacts associated with upstream activities were typically greater than downstream impacts, usually by significant amounts. For example, even if corrugated boxes and newsprint fill are landfilled (leading to maximum downstream emissions), upstream activities -- resource extraction, manufacturing, and transportation – account for 92% of the total greenhouse gas emissions; only 8% of the net total greenhouse gas emissions occur at the landfill.
- The study confirmed the importance of source reduction: Recycling and post-consumer content were far less important factors than reducing the total amount of material in packaging.
- The chart below shows that, for the packaging materials studied, bags consumed far less energy than boxes, regardless of the materials involved and regardless of their postconsumer recycled content. As noted, similar results are found for solid waste, greenhouse gases, and most other emissions. Within each category, materials with postconsumer content show benefits, but overall the advantage of bags is striking.



Oregon Department of Environmental Quality (DEQ), “Life Cycle Inventory of Packaging Options for Shipment of Retail Mail-Order Soft Goods,” April 2004, <http://www.deq.state.or.us/lq/pubs/docs/sw/packaging/LifeCycleInventory.pdf>

Procter & Gamble Laundry Detergent Inventory

- In 2001, scientists working for Procter & Gamble published a life-cycle inventory of the environmental impacts of household laundry detergents.¹The purpose of the study was to identify what aspects of a household laundry detergent's life cycle offered the best opportunities for environmental improvement and to provide a benchmark to track progress.
- The inventory covered extraction and production of raw materials, manufacture of the detergents, packaging, consumer use of the detergents, and disposal of waste-water from laundering.
- The study calculated environmental emissions covering a full range of environmental effects (acidification, aquatic toxicity, eutrophication, GHG, human toxicity, ozone depletion, and photochemical) throughout the detergent's life-cycle.
- The environmental emissions study reflected consumer use data from Belgium.
- The results were striking: the study found that approximately 80% of energy use through detergent's entire life cycle came from their home use, with heating the water for washing in automatic washing machines being the major contributing factor.
 - The use phase was also responsible for 64% of solid waste, over 70% of CO₂ emissions, and 60% of human toxicity, because of solid waste and air emissions from the generation of energy, again primarily to heat the wash water.
 - The study also identified other areas for potential improvements. The disposal phase (i.e., wastewater from home laundering) accounted for 90% of the total biological oxygen demand (BOD) – a measure of organic pollution of water – of the process, and the ingredients-supplier phase accounted for 66% of photochemical smog (from VOCs from process emissions).
- The chart at right, taken from the study, graphically summarizes the total energy consumption, solid waste, CO₂, and BOD distribution between supplier, manufacturer, use, wastewater treatment and packaging from the LCI of 1000 wash cycles in Belgium using a traditional laundry detergent powder.
- Based on this information, P&G concluded that the most promising avenue for improvement (and the only avenue under their direct control) was to reformulate their products so that they could be used in colder water. In response, P&G scientists developed cold-water detergents, introduced in 2005, as a way of reducing their products' environmental footprint. Other manufacturers followed suit.
- Consumers, unfortunately, were skeptical that cold-water detergent would work and did not take to it. Even when the customers bought the product, they often continued to use hot water. By 2011, according to the New York Times, sales of cold-water detergent had stagnated or declined. P&G and other companies came to emphasize the detergent's cleaning performance rather than its environmental benefits.²
- This example shows how LCAs can be used to identify opportunities for environmental gains, but it also illustrates that green claims don't always help. At this point, industry representatives concluded that education, not advertising, was needed to change customer behavior.³



1 From Erwan Saouter and Gert van Hoof, A Database for the Life-Cycle Assessment of Procter&Gamble Laundry Detergents, *International Journal of Life-Cycle Assessment* 7 (2002), 103-114, p. 111.

2 New York Times, "Cold-Water Detergents Get a Cold Shoulder," September 16, 2011, http://www.nytimes.com/2011/09/17/business/cold-water-detergents-get-a-chilly-reception.html?pagewanted=all&_r=0

3 NYT, September 16, 2011

Oregon Department of Environmental Quality Drinking Water Study

- In 2009, the Oregon Department of Environmental Quality (DEQ) commissioned a full Life Cycle Assessment on different options for delivering drinking water to consumers within the state: (1) through the tap, (2) in single-use bottles, and (3) through home/office delivery in reusable containers.⁴
- The purpose of the study was to provide information to help consumers in making environmental choices and to help DEQ and others design more effective programs.
 - It hoped to answer members of the public who asked, “I recycle my bottles... isn’t that enough?”
 - It addressed a range of packaging questions.
 - It hoped to evaluate the presumption that tap water is better (no North American studies had addressed this issue in a transparent manner).
- The assessment looked at the full life cycle of drinking-water delivery systems and a full range of environmental impacts, including impacts on energy, global warming, human health effects, and ecotoxicity.
- The study concluded that delivery of drinking water through the tap was by far the best option in all impact categories. The single-bottle option was worst, primarily because of impacts from the manufacture of the bottles and shipping bottled water to the customers.
- This conclusion confirmed EPA’s traditional hierarchy by showing that prevention (that is, avoided bottle manufacture and avoided shipping) is the preferred strategy.
- Where single-use bottles were used, recycling typically provided benefits - although far smaller than the benefits from eliminating bottles by use of tap water. This answered the question of whether recycling is enough. The answer was no. DEQ concluded that single-minded focus on recycling rates and recycling programs, as important as they are, can divert attention from more critical goals, in this case source reduction.
- The Oregon’s study showed other interesting results.
 - If the bottled water was shipped from the bottler to the consumer for a relatively short distance (for example, less than 50 miles), the impacts of transportation are small.
 - Where the water was transported for longer distances (such as across the country or the globe), the transportation of water became a driving factor, because water is heavy and requires a lot of energy to transport.
 - In these conclusions, the study confirmed the general principle that the impacts of transportation are usually relatively small, although it also showed that transportation impacts can become significant with the long haul of heavy materials, particularly by truck.
- Oregon’s study also confirmed that:
 - Recycling is beneficial where single-use bottles are used.
 - Light-weighting the bottles has a greater benefit than recycling, showing the importance of source reduction.
 - How often consumers wash water containers at home and how they use their dishwashers (full v. low-water) affect the results for home/office delivery systems.

⁴ Oregon Department of Environmental Quality, “Life Cycle Assessment of Drinking Water Systems: Bottle Water, Tap Water, and Home/Office Delivery Water,” October 22, 2009, <http://www.deq.state.or.us/lq/sw/wasteprevention/drinkingwater.htm>.

8.

APPENDIX 2 – Sustainable Materials Management Coalition

The Sustainable Materials Management Coalition (Coalition) was created in Spring 2011. The Coalition is a diverse stakeholder group made up of representatives of business and industry, academic institutions, environmental and community organizations, and State and local government organizations. The U.S. Environmental Protection is not a member, but is a critical Coalition partner, who participates in all Coalition meetings. The Coalition focuses on serving human needs by using and reusing resources most productively and sustainably throughout their life cycles, generally minimizing the amounts of materials involved and all the associated impacts.

The members of the Coalition include the following:

TIM FIELDS

Former Assistant Administrator,
Office of Solid Waste and
Emergency Response, EPA
Senior Vice President, MDB, Inc.
Coalition Chair

MATT HALE

Former Director, Office of Resource
Conservation and Recovery, EPA
Senior Advisor, MDB, Inc.
Coalition Vice Chair

LINDA ADAMS

Former Chair, California
Environmental Protection Agency

DAVID ALLAWAY

State of Oregon
Department of Environmental
Quality

SUE BRIGGUM

Vice President, Federal Public
Affairs
Waste Management

BARRY CALDWELL

Senior Vice President, Public Affairs
and Communications
Waste Management

DAN FIORINO

Director, Center for Environmental
Policy, American University

DENNIS FITZGIBBONS

Former Chief of Staff, Committee
on Energy and Commerce
U.S. House of Representatives

PHYLLIS HARRIS

Senior Vice President and Chief
Compliance Officer
Wal-Mart Stores, Inc.

JARED LANG

Program Manager, Green
Government Initiative
National Association of Counties

TAD MCGALLIARD

Director of Sustainability
International City-County
Management Association

VERNICE MILLER-TRAVIS

Vice Chair, Maryland State
Commission on
Environmental Justice and
Sustainable Communities

TOM MURRAY

Managing Director, Corporate
Partnerships
Environmental Defense Fund

MICHAEL PARR

North American Advocacy Manager
DuPont

TOM SCHNEBERGER

Director of Sustainability
FMC Corporation

CRAIG SLATIN

Professor and Chair, Department
of Community Health and
Sustainability
University of Massachusetts,
Lowell

WILMA SUBRA

President
Louisiana Environmental Action
Network

TAMMY ZBOREL

Director of Sustainability Programs
National League of Cities

The EPA partners include the following:

MATHY STANISLAUS

Assistant Administrator
Office of Solid Waste and
Emergency Response, EPA

BARNES JOHNSON

Director
Office of Resource Conservation
and Recovery, EPA

BETSY SMIDINGER

Acting Deputy Director
Office of Resource Conservation
and Recovery, EPA

CHERYL COLEMAN

Director
Resource Conservation and
Sustainability Division
Office of Resource Conservation
and Recovery, EPA

CHARLOTTE MOONEY

Associate Director
Resource Conservation and
Sustainability Division
Office of Resource Conservation
and Recovery, EPA

SARA HARTWELL

Materials Conservation and
Recycling Branch
Resource Conservation and
Sustainability Division
Office of Resource Conservation
and Recovery, EPA

The Coalition produced an initial report in July 2012 entitled “Sustainable Materials Management: A New Materials Hierarchy, Solutions to Barriers, and Recommendations for a Path Forward.”

http://www.michaeldbaker.com/news_sustainable.html

One recommendation in this report was that a Coalition Subgroup be created to further examine the implications and benefits of life-cycle thinking in environmental decision making. As a result of this effort, a new document was produced entitled “Guidance on Life–Cycle Thinking and Its Role in Environmental Decision Making.” This Guidance is designed to address the needs of stakeholders representing Federal, State, Local, and Tribal government; business and industry; environmental and community organizations; and academic institutions.

This Coalition Subgroup included representatives of the following organizations:

- Waste Management
- State of Oregon
- Maryland State Commission on Environmental Justice and Sustainable Communities
- Environmental Defense Fund
- DuPont, and
- MDB, Inc.

The U.S. Environmental Protection Agency representatives served as partners in this effort.

