Life-Cycle Assessment as a Sustainability Management Tool: Strengths, Weaknesses, and Other Considerations

This article highlights the dynamic nature of life-cycle assessment (LCA). With product LCA data being brought increasingly into the public eye, the validity and timeliness of these data may be called into question.

Estimating greenhouse gas (GHG) emissions is an important component of the LCA. This article explores some of the challenges and areas of concern associated with this particular component of LCA. It also offers a brief discussion of opportunities for improvement.

Improving quantification of GHG emissions

Background: Sustainability and LCA

There is a growing need for comprehensive understanding of the total environmental impact of goods and services provided to consumers. Scientific documentation regarding the role of humans in climate change, as well as lessons learned from industrial pollution and its negative impacts on the environment, have led to a greater awareness of the need for sustainability. Consumers are increasingly demanding that the products they utilize be produced in an environmentally friendly manner that limits negative impacts on earth's resources (Swarr, 2009).

Comprehensive environmental impact reviews have traditionally involved life-cycle assessments. LCA is a technique used to assess the environmental aspects and potential impacts associated with a product, process, or service. Typically, LCAs are based on a combination of averaged data values collected from specific processes involved in the production of the product, along with material data pulled from industry-wide surveys that have grown in size over time, making them representative of an industry average.

The specific process and material data are compiled into life-cycle inventories (LCIs). The

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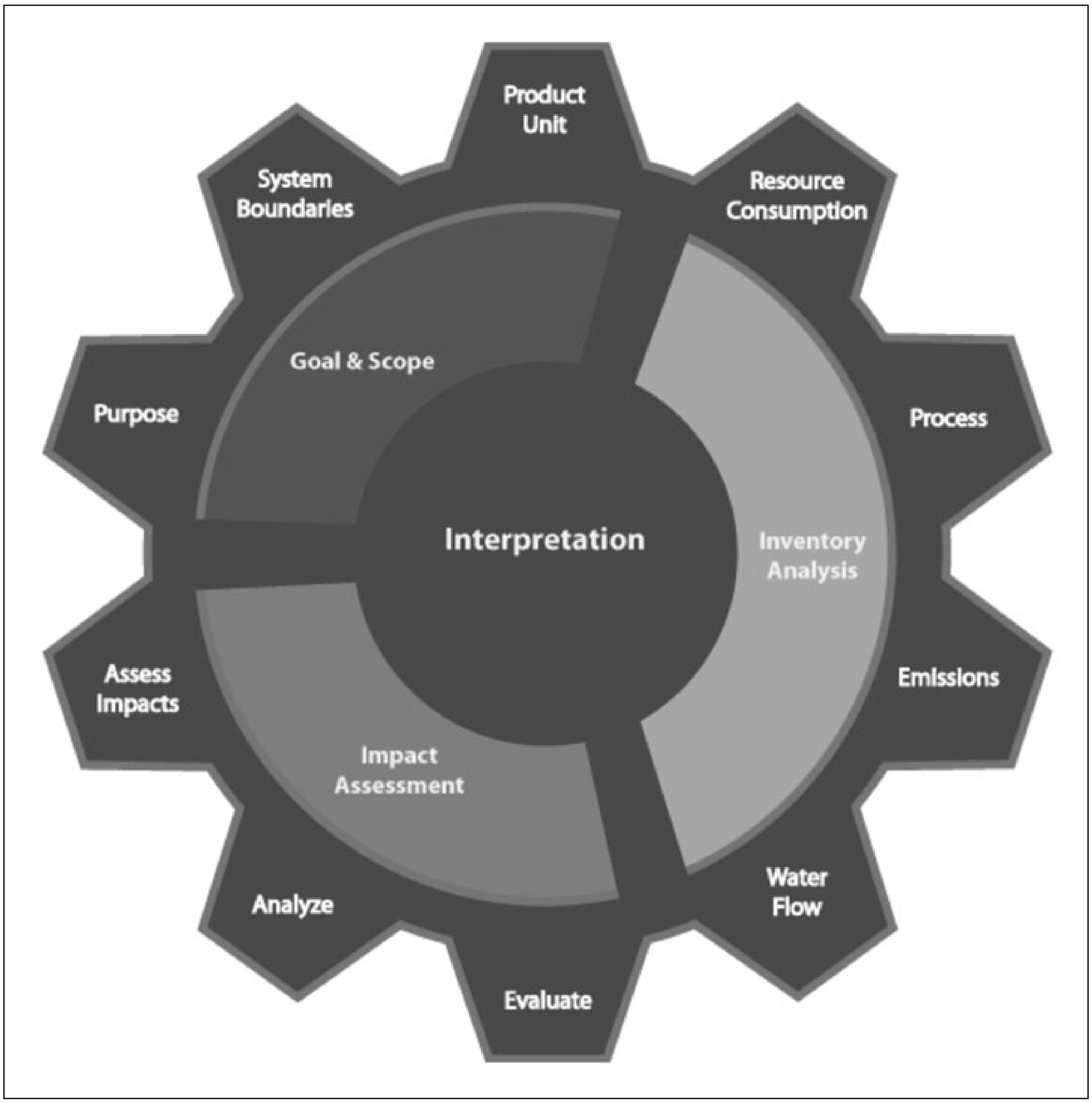
LCI comprises the quantitative portion of the LCA and includes the processes and outputs that go into the manufacture of the product. However, there are still important weaknesses and limitations associated with the use of industry survey data (Curran, Mann, & Norris, 2005). These weaknesses are explored later in this article.

General LCA Overview

LCA is a prescribed method for determining the environmental impacts generated throughout the life cycle of a product. Impacts on the environment are wide-ranging. They can include "climate change, stratospheric ozone depletion, tropospheric ozone (smog) creation, eutrophication, acidification, toxicological stress on human health and ecosystems, the depletion of resources, water use, land use, and noise" (Rebitzer et al., 2004).

LCA consists of four main elements (De Smet, White, & Owens, 1996), as diagramed in **Exhibit 1**:

Exhibit 1. LCA Elements



- Goals and scope definition
- Life-cycle inventory analysis
- Life-cycle impact assessment
- Life-cycle interpretation

These steps are outlined in International Organization for Standardization (ISO) standard ISO 14040 (which is part of the ISO 14000 series on environmental management). ISO 14040 provides an internationally accepted framework for conducting LCA (International Organization for Standardization, 2006).

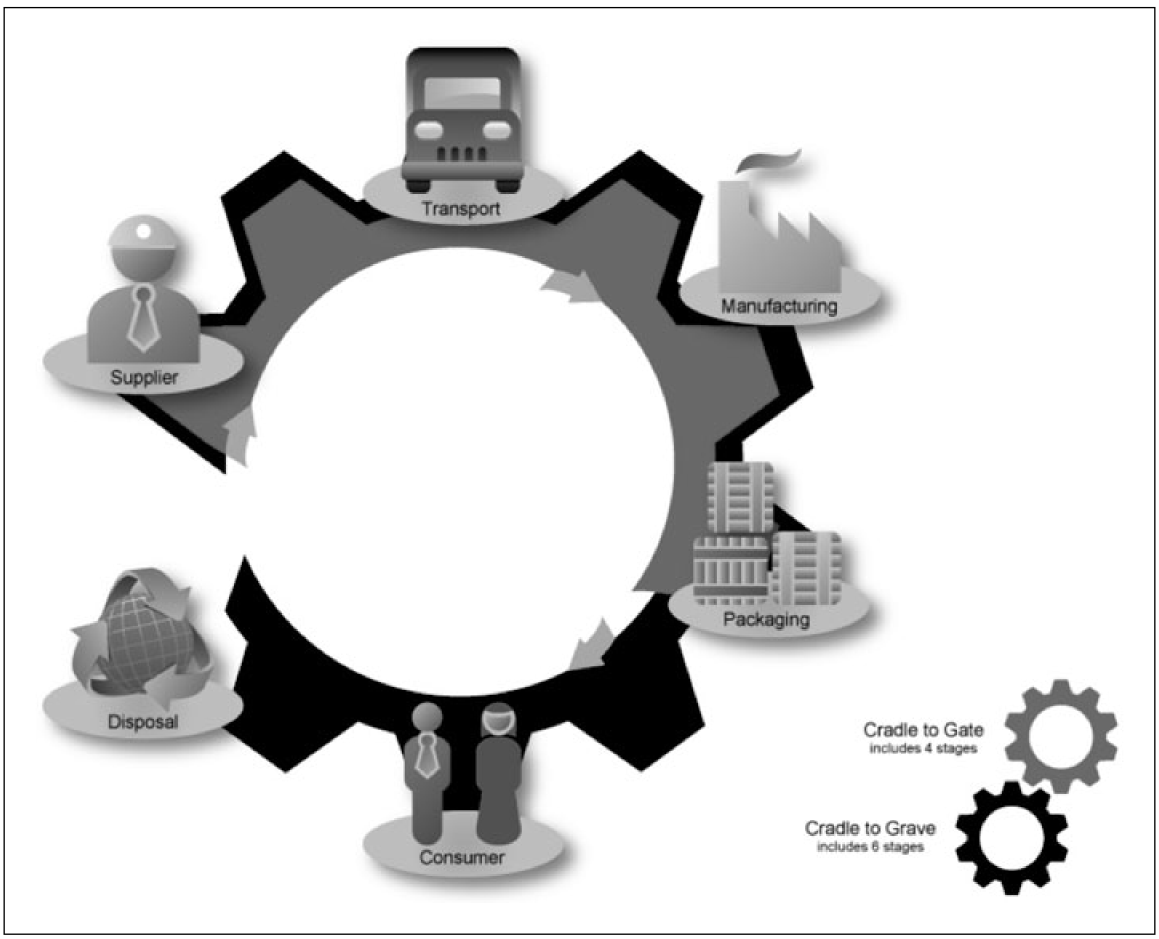
Focusing on Cradle-to-Gate

A complete product LCA can encompass a range of factors, including human or aquatic toxicity, water consumed, waste generated, loss of wildlife habitat, and energy usage. Conducting a full LCA is clearly a complex and time-consuming task, and not viable for many resource-constrained manufacturers. We would suggest that only by breaking the LCA down into manageable pieces and analyzing each part for improvements in efficiency can it be brought into the reach of a larger cohort of manufacturing companies.

This discussion focuses on the cradle-to-gate portion of the total product life cycle (see **Exhibit 2**). Cradle-to-gate includes all the processes up to (but not including) the product-use phase (identified as "consumer" in the exhibit). It encompasses Scope 1, 2, and 3 emissions,[1] including a product's supply-chain emissions.

Product LCAs are typically approached from a cradle-to-grave perspective, which includes the

Exhibit 2. Cradle-to-Gate and Cradle-to-Grave Components of Life-Cycle Assessment



product-use phase. However, this phase is one of the more difficult to evaluate because it can be hard to predict how the consumer will use and ultimately dispose of the product.

For this reason, performing LCAs only on cradle-to-gate emissions may result in more reliable and representative results. Cradle-to-gate LCAs also provide information on which manufacturers can act effectively. Manufacturers can directly control their own actions—and to a lesser extent may exert influence over the suppliers with which they do business—resulting in less carbon emitted (Matthews, Hendrickson, & Weber, 2008).

At the company level, the first step in lowering GHG emissions is to gather comprehensive information about the organization's carbon footprint.

Climate Change and LCA

Carbon Footprinting

It is likely that, sometime in the not-so-distant future, reducing GHG emissions will be required of a larger cohort of business enterprises. At the company level, the first step in lowering GHG emissions is to gather comprehensive information about the organization's carbon footprint. Having this knowledge will allow the organization to pursue the most cost-effective carbon-mitigation strategies.

Some companies now voluntarily estimate their carbon footprints. Many of these organizations have environmentally aware customers, making market pressure a motivating factor. Some are also driven by increasing concerns about climate change and anticipation of upcoming regulations.

Documenting carbon emissions for products and services is gaining momentum but is still in its infancy. The Intergovernmental Panel on Climate Change (IPCC) inventories do not identify where emissions originate (Hertwich & Peters, 2009). However, in order to efficiently lower GHG emissions, it is imperative to know emissions sources. LCA can enable this task, but manufacturers and suppliers must monitor and track their own carbon footprints.

Drafting effective climate change legislation and regulations also requires accurate GHG emission data (Liska & Perrin, 2009). In the United States, the Climate Action Registry provides industry-wide data to help with the estimation of carbon footprinting.

Standardized Methods for Calculating GHG Emissions

Standardized methods are available for calculating a product's GHG emissions. One such method is provided in PAS 2050, which was developed in 2007 by the British Standards Institution, sponsored by Carbon Trust and the United Kingdom's Department for Environment, Food, and Rural Affairs (DEFRA) (British Standards Institution, 2007). PAS 2050 provides guidance for measuring the "embodied GHG emissions" of goods and services.

Another set of guidelines can be found in the GHG Protocol Initiative's *Corporate Accounting and Reporting Standard* (GHG Protocol Initiative, 2004). The GHG Protocol, which is sponsored jointly by the World Resources Institute and the World Business Council for Sustainable Development, is the most widely used international greenhouse gas accounting tool (Global Reporting Initiative, 2004). The corporate standard focuses on Scope 1 and 2 emissions. Scope 3 emissions are being addressed in a new GHG Protocol that was available in draft form as of this writing (GHG Protocol Initiative, 2010).

Supply-Chain Emissions

When estimating a product's carbon footprint, it is beneficial to consider all factors that contribute to the manufacture of the product. Current methods used by large carbon registries consider direct energy expended in manufacturing and transportation (Scope 1 and 2 emissions) but generally neglect to consider GHGs emitted by suppliers (Scope 3 emissions).

A study by Matthews et al. (2008) reviewed carbon footprints for 491 economic sectors in the US economy. On average, traditional footprinting methods captured only 26 percent of total GHG emissions, with most omissions originating from inaccurate Scope 3 inventories. For the majority of economic sectors (including those that manufacture goods), traditional methods would document less than 25 percent of Scope 3 emissions. The study found that it was easiest to track GHGs in the case of large emitters that provide commodities, such as electricity generators and cement manufacturers; for these sectors, traditional footprinting methods captured 80 percent of GHG emissions.

Clearly, conducting an accurate LCA for goods and services requires capturing supply-chain emissions. Otherwise, the carbon footprint may be a severe underestimation.

GHG Emissions: Better Information Needed

Given today's increasing demands for information on GHG emissions and the growing number of proposals for legislation to control these emissions, we clearly need a methodology for addressing GHGs within the LCA framework. But information is rarely gathered on GHG emissions, so it is difficult to estimate a product's carbon footprint. Methods for quantifying carbon LCA results rely on data accumulated from large databases that allocate average energy expenditures for a given product or process.

Monitoring the amount of electricity necessary for the manufacture of a product is important since it gives a general idea of the product's environmental footprint. However, different utility infrastructures, fuels, and emission-control technologies result in widely varying carbon dioxide equivalent (CO_2e) emissions.[2] It is therefore necessary to know as much as possible about the energy source in order to obtain the most accurate assessment.

Challenges in Compiling Data

Database Issues

Traditional databases for LCA often are large government-based and publicly funded projects that produce aggregated regional default values. The data are collected by the statistical agencies of national governments (such as Sweden's Sustainable Product Information Network for the Environment, or SPINE, and Switzerland's EcoInvent) and by industrial associations, such as PlasticsEurope, the association of European plastics manufacturers (Rebitzer et al., 2004).

Because these databases have been criticized for being inaccurate, researchers have tried to address the accuracy issue (Lenzen, 2000; Reap, Roman, Duncan, & Bras, 2008a, 2008b; Rebitzer et al., 2004). EcoInvent offers data on individual technological processes. The Society of Environmental Toxicology and Chemistry (SETAC) is also collecting data on individual processes (electricity, transportation, raw materials) in an attempt to individualize LCA.

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The large aggregated databases have also been criticized because their data often are not current. For example, the National Renewable Energy Laboratory (NREL) database currently in use was published in 1997 (National Renewable Energy Laboratory, 1997). The NREL database is currently under revision.

European organizations have led the way in terms of compiling LCI databases. PlasticsEurope was one of the first organizations to gather data on energy usage for plastics manufacturing, beginning in the early 1990s (Rebitzer et al., 2004). As a result, much of the default data originates from Europe.

This can create difficulties in the case of products manufactured in other parts of the world, especially developing countries with older utility infrastructures (Lloyd & Ries, 2007). Even in the United States, using a European database for compiling LCIs could be problematic since different supply chains and energy structures exist for manufactured products.

Most LCA practitioners use software packages that compile one of the major aggregated industry default databases (Rebitzer et al., 2004). Their results would be much more accurate if they could use tailored LCA software systems specific to a manufacturer's suppliers. Only a few companies perform such analyses currently. But as manufacturers and suppliers become more aware of the need to collect their individual data, more accurate and individualized LCAs will become possible.

While there is potential for error in all phases of LCA, the inventory phase is where errors are more likely to occur because the data used for the LCA are gathered and manipulated during this phase.

Potential for Error

While there is potential for error in all phases of LCA, the inventory phase is where errors are more likely to occur because the data used for the LCA are gathered and manipulated during this phase (Reap et al., 2008a). LCA conclusions are based on these data. For example, one of the most challenging steps of the inventory phase is determining how to allocate environmental burdens when there are multiple processes that produce several products at the same facility (Reap et al., 2008a).

Other errors may originate in the broader product system. Product system LCIs include data on energy supply, transportation, chemical and materials manufacturing, and waste disposal. Some of the processes involved are global in nature—such as oil extraction, much of which takes place in the Middle East. Other processes are local, such as energy expenditure for manufacturing and transportation (Rebitzer et al., 2004). Overseas production and transport can be difficult to quantify (or may be overlooked completely) because many developing countries have less stringent environmental regulations (Matthews et al., 2008).

Data-Collection Complexity

The manner in which data are collected can make it challenging to conduct LCAs for individual products. In fact, data collection is usually the most time-consuming and complicated part of the LCA. When data are collected, they may be gathered on an organizational level, not on a functional level. In other words, energy totals for a particular facility may be available, but not for individual equipment or products. As a result, it can be difficult to separate individual processes out for inclusion in the LCI, which makes it difficult to perform LCA for a particular product (Curran et al., 2005; Rebitzer et al., 2004).

Another difficulty with preparing LCAs is that data may not have been collected for certain processes or systems that contribute to the footprint of a product, or the data may not be readily accessible (Reap et al., 2008a). Waste-disposal data typically are not collected and are omitted from the traditional LCA, but waste contributes a significant amount of CO_2 and methane to the atmosphere (Christensen, Gentil, Boldrin, Larsen, Weidema, & Hauschild, 2009; Gentil, Christensen, & Aoustin, 2009).

GHG Emissions: Other Considerations

Calculating Carbon Emissions When Multiple Supply-Chain Entities Are Involved

In order to conduct LCAs properly, it is necessary for suppliers to begin monitoring, tracking, and reporting their carbon emissions. This transparency will enable the preparation of complete LCAs for individual products.

There are problems to be avoided, however. One potential error involves the possibility of overestimating a product's emissions. For any product, multiple entities within the supply chain can potentially claim the carbon emissions associated with the manufacture of the materials necessary for that product, resulting in double counting (Matthews et al., 2008).

There are also areas of ambiguity about who should claim emissions. In one example offered by Matthews et al. (2008), a book publisher's Scope 1 and 2 emissions comprise only 6 percent of the total carbon emissions for the product. Many of the emissions associated with publishing are generated from final delivery, through package delivery services. These emissions could be claimed by either the publisher or the transportation company (Matthews et al., 2008).

Problems in Calculating GHG Emissions

LCA for greenhouse gas emissions presents particular problems. With the databases currently available, GHG emissions must be extrapolated from existing energy data, and assumptions must be made about the energy source.

A case study by Ross, Evans, and Webber (2003) highlights some issues involved with GHGs. The study examines the LCA of containerboard packaging, with a focus on GHG abatement policy. In addition to the usual inaccuracies involved in gathering data, the study notes some GHG issues that are specific to the type of packaging under review.

Containerboard requires cutting down trees that remove tons of CO_2 from the atmosphere. Even if replacement trees are planted in a sustainable forest, it can be many years before the new trees are as efficient at removing CO_2 as the trees that were cut down, resulting in less carbon being sequestered from the atmosphere. Moreover, disposing of containerboard in landfills leads to large emissions of CO_2 and methane, further adding to the carbon footprint of the packaging material (Ross et al., 2003).

Methods for Improving LCA

Adopting Cradle-to-Gate Assessments

Moving away from cradle-to-grave and toward cradle-to-gate assessments would improve the accuracy of LCA. Focusing on the stages of product life that can be controlled by manufacturers and their suppliers would be a more practical approach than attempting to account for the entire life cycle.

It is difficult to determine what happens to products after manufacture and delivery. There is no way of knowing how long a product will last, or when a consumer will replace it. Of course, consumers should be encouraged to replace products only when necessary and recycle used products rather than landfilling them, but those issues should be treated separately from production.

Focusing on the stages of product life that can be controlled by manufacturers and their suppliers would be a more practical approach than attempting to account for the entire life cycle.

Using Site-Specific Data

Traditional LCAs are site-independent, but they could be greatly improved if site-specific data were used. The potential for improvement was highlighted by a Swedish study that compared modeling results for a hypothetical manufacturing smokestack using two different approaches, one using site-independent emissions data and the other using site-dependent data (Finnveden & Nilsson, 2005).

When modeling differences in emissions between similar geographical areas, the results obtained by the alternate methods varied by no more than a factor of 2. When modeling emissions between significantly different geographical areas, however, the results varied by several orders of magnitude (Finnveden & Nilsson, 2005). This study demonstrated the necessity of using data that are specific to the product manufactured, or at least gathered from sources with similar utility and transportation infrastructures.

Technology now available can enable site-specific LCAs. Energy power monitors and submeters allow energy-consumption data from manufacturing equipment to be continually updated (Measurlogic.com, 2010). A network of continuous monitors and submeters can be placed on manufacturing equipment to interface with software from multiple utilities so that current real-time data can be accessed. This allows an environmental footprint to be continually estimated, thus enabling the minimization of power usage and associated costs.

Rather than monitoring energy usage, another approach is to utilize continuous emissions monitors (CEMs) to monitor stack CO_2 emissions (as well as many other pollutants) to more accurately generate emission data. Monitoring actual emissions will improve LCA accuracy, but the emission monitoring equipment must be continually maintained to ensure that it is working appropriately. If equipment maintenance is overlooked, emissions can be higher than expected. Continual monitoring of emissions results in a more accurate LCA (ejnet.org, 2010).

Standardized methods are needed in order to deliver consistent results when calculating carbon footprints across multiple supply chains.

Of course, site-specific data are not always available. In these cases, a hybrid approach can be used. A hybrid approach takes advantage of existing data on, for example, electricity generation, while collecting specific data on the manufacture or transport of a product (Rebitzer et al., 2004).

Understanding Product Supply Chains

In order to effectively manage carbon dioxide equivalent (CO_2e) emissions, it is of prime importance to understand a product's supply chain. Scope 3 (supply chain) emissions are frequently ignored in computing LCAs. As noted earlier, traditional footprinting methods capture only about a quarter of total GHG emissions (Matthews et al., 2008).

It may initially be difficult to calculate supply-chain carbon emissions because internal data from suppliers are not available. Eventually, as more companies report their carbon emissions, averaged estimates can be replaced with product-specific emissions.

Standardized methods are needed in order to deliver consistent results when calculating carbon footprints across multiple supply chains. PAS 2050 has been the primary protocol for conducting a GHG LCA. To further improve the process, PAS 2050 entered a formal review process at the end of 2009 to ensure that the recommended protocol results in accurate assessments (Sinden, 2009).

PAS 2060 and ISO 14067

In April 2010, the British Standards Institution issued PAS 2060, a specification providing requirements that must be met by companies that wish to claim carbon neutrality. This would encompass quantifying, reducing, and offsetting carbon emissions (British Standards Institution, 2010).

Based on the success of PAS 2050, ISO is also developing a new standard for quantifying the carbon footprint of products, ISO 14067. The standard will incorporate GHG accounting into the general LCA (Huang, Lenzen, Weber, Murray, & Matthews, 2009).

Market and Legislative Pressure

As market and legislative pressure grows, conducting comprehensive LCAs will become more feasible. Consumers are becoming increasingly aware of sustainability efforts being implemented by the manufacturers of the products they consume. They also increasingly make buying decisions based on a product's perceived environmental friendliness (Swarr, 2009).

The European Union already has regulations in place for carbon emissions reporting. The United States, while a bit further behind, will likely see more legislation in the near future in response to increasing pressure from consumers and abroad (European Commission, 2010). California is already leading the way, with carbon regulations becoming effective in 2013 for large energy users, followed by requirements for moderate energy users in 2015 (California Environmental Protection Agency, 2010).

Conclusion

LCA is a tool with an array of applications that can aid in the understanding and management of environmental impacts. Accurate LCAs can target efforts to use resources more efficiently and decrease harmful emissions, including GHGs. Companies must adopt responsible disclosure policies about their supply chains and manufacturing to ensure that data are available.

It will not be an insignificant task to improve quantification of GHG emissions, which continuously vary over the course of production. To facilitate quantifying emissions, technology may be used to enable the compilation of real-time data. This in turn will make LCA a powerful tool for controlling actual emissions.

To aid in implementation, encouraging companies to report their energy outputs and supply chains will go a long way toward improving the data that are needed for accurate LCAs.

The use of standards such as PAS 2050 and the GHG Protocol for Corporate Accounting and Reporting will only strengthen GHG emission estimation efforts within the LCA process and add consistency to these efforts. The upcoming ISO 14067 standard for assessing the carbon footprint of products and the GHG Protocol *Corporate Value Chain (Scope 3) Accounting and Reporting Standard* will also ensure that the information obtained from LCAs will be comparable and comprehensive. In addition, the work being done on PAS 2060, the specification for demonstrating carbon neutrality, will help drive standardized methods for assessing product-related carbon impacts.

Notes

1. Scope 1 includes direct emissions by the company itself (e.g., company vehicles, stack emissions). Scope 2 includes carbon emissions from energy inputs used by the organization (e.g., purchased electricity). Scope 3 for cradle-to-gate includes total supply-chain emissions up to the production gate (Matthews et al., 2008).

2. CO_2e refers to the global warming potential (GWP) of a gas and the amount of GWP that the gas produces compared to CO_2. There are other gases besides CO_2 that contribute to global warming, such as methane, nitrous oxide, hydrofluorocarbons, and perfluorocarbons. These gases contribute to global warming at varying rates. For example, the GWP of methane is 21 times that of CO_2. In order to make comparisons consistent, all gases that contribute to global warming are compared to CO_2. Thus, a unit of methane would have a CO_2e of 21 compared to the same volume of CO_2, which would have a CO_2e of 1.

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