

## Chapter 13

# Life-Cycle Concepts, Product Stewardship and Green Engineering

by

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### 13.1 INTRODUCTION TO PRODUCT LIFE CYCLE CONCEPTS

Products, services, and processes all have a life cycle. For products, the life cycle begins when raw materials are extracted or harvested. Raw materials then go through a number of manufacturing steps until the product is delivered to a customer. The product is used, then disposed of or recycled. These product life cycle stages are illustrated in Figure 13.1, along the horizontal axis. As shown in the Figure, energy is consumed and wastes and emissions are generated in all of these life cycle stages .

Processes also have a life cycle. The life cycle begins with planning, research and development. The products and processes are then designed and constructed. A process will have an active lifetime, then will be decommissioned and, if necessary, remediation and restoration may occur. Figure 13.1, along its vertical axis, illustrates the main elements of this process life cycle. Again, energy consumption, wastes and emissions are associated with each step in the life cycle.

Traditionally, product designers have been concerned primarily with product life cycles up to and including the manufacturing step. Chemical process designers have been primarily concerned with process life cycles up to and including the manufacturing step. That focus is changing. Increasingly, chemical product designers must consider how their products will be recycled. They must consider how their customers will use their products and what environmental hazards might arise. Process designers must avoid contamination of the sites at which their processes are located. Simply stated, engineers must become stewards for their products and processes throughout their life cycles. These increased responsibilities for products and processes throughout their life cycles have been recognized by a number of professional organizations. Box 13.1 describes a Code of Product Stewardship developed by the Chemical Manufacturers' Association.

Effective product and process stewardship requires designs that optimize performance throughout the entire life cycle. The goal of this chapter is to provide an introduction to tools available for assessing the environmental performance of products and processes throughout their life cycle. The primary focus will be on product life cycles, but similar concepts and tools could be applied to process life cycles. Section 13.2 presents quantitative tools used in product life cycle assessments (LCAs). Section 13.3 presents more qualitative tools. Section 13.4 describes a number of applications for these tools and Section 13.5 summarizes the main points of the chapter.

### **Box 13.1 The Chemical Manufacturers' Association Product Stewardship Code**

The purpose of the Product Stewardship Code of Management Practices is to make health, safety and environmental protection an integral part of designing, manufacturing, marketing, distributing, using, recycling and disposing of our products. The Code provides guidance as well as a means to measure continuous improvement in the practice of product stewardship.

The scope of the Code covers all stages of a product's life. Successful implementation is a shared responsibility. Everyone involved with the product has responsibilities to address society's interest in a healthy environment and in products that can be used safely. All employers are responsible for providing a safe workplace, and all who use and handle products must follow safe and environmentally sound practices.

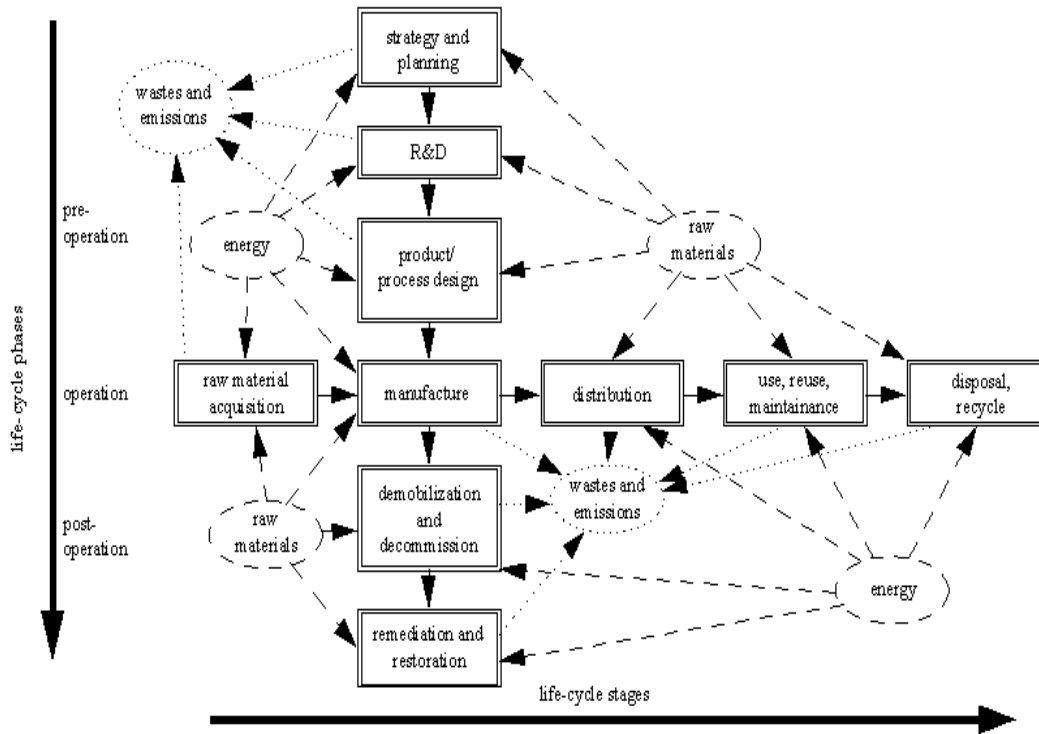
The Code recognizes that each company must exercise independent judgment and discretion to successfully apply the Code to its products, customers and business.

#### *Relationship to Guiding Principles*

Implementation of the Code promotes achievement of several of the Responsible Care Guiding Principles:

- ◆ To make health, safety and environmental considerations a priority in our planning for all existing and new products and processes;
- ◆ To develop and produce chemicals that can be manufactured, transported, used and disposed of safely;
- ◆ To extend knowledge by conducting or supporting research on the health, safety and environmental effects of our products, processes and waste materials;
- ◆ To counsel customers on the safe use, transportation and disposal of chemical products;
- ◆ To report promptly to officials, employees, customers and the public, information on chemical-related health or environmental hazards and to recommend protective measures;
- ◆ To promote the principles and practices of Responsible Care by sharing experiences and offering assistance to others who produce, handle, use, transport or dispose of chemicals.

Figure 13.1 Product life cycles include raw material extraction, material processing, use and disposal steps, and are illustrated along the horizontal axis. Process life cycles include planning, research, design, operation and decommissioning steps and are shown along the vertical axis. In both product and process life cycles, energy and materials are used at each stage of the life cycle and emissions and wastes are created.



## 13.2 LIFE-CYCLE ASSESSMENT

Life-cycle studies range from highly detailed and quantitative assessments that characterize, and sometimes assess the environmental impacts of energy use, raw material use, wastes and emissions over all life stages, to assessments that qualitatively identify and prioritize the types of impacts that might occur over a life cycle. As shown in this chapter, different levels of detail and effort are appropriate for the different uses to which life-cycle information is put. In this section, the steps involved in conducting detailed, highly quantitative life-cycle assessments are described.

### 13.2.1 Definitions and Methodology

There is some variability in life cycle assessment terminology, but the most widely accepted terminology has been codified by international groups convened by the Society for Environmental Toxicology and Chemistry (SETAC) (see, for example, Consoli, et al., 1993). Familiarity with the terminology of life-cycle assessment makes communication of results easier and will aid in understanding the concepts presented later in this chapter. To begin, a **life-cycle assessment (LCA)** is the most complete and detailed form of a life-cycle study. A life-cycle assessment consists of four major steps.

*Step 1:* The first step in an LCA is to determine the scope and boundaries of the assessment. In this step, the reasons for conducting the LCA are identified; the product, process, or service to be studied is defined; a functional unit for that product is chosen; and choices regarding system boundaries, including temporal and spatial boundaries, are made. But what is a functional unit, and what do we mean by system boundaries? Let's look first at the system boundaries.

The **system boundaries** are simply the limits placed on data collection for the study. The importance of system boundaries can be illustrated by a simple example. Consider the problem of choosing between incandescent light bulbs and fluorescent lamps in lighting a room. During the 1990's the U.S. EPA began its Green Lights program, which promoted replacing incandescent bulbs with fluorescent lamps. The motivation was the energy savings provided by fluorescent bulbs. Like any product, however, a fluorescent bulb is not completely environmentally benign, and a concern arose during the Green Lights program about the use of mercury in fluorescent bulbs. Fluorescent bulbs provide light by causing mercury, in glass tubes, to fluoresce. When the bulbs reach the end of their useful life, the mercury in the tubes might be released to the environment. This environmental concern (mercury release during product disposal) is far less significant for incandescent bulbs. Or is it? What if we changed our system boundary? Instead of just looking at product disposal, as shown in the first part of Figure 13.2, what if the entire product life cycle were considered, as shown in the second half of Figure 13.2? In a comparison of the incandescent and fluorescent lighting systems, if the system boundary is selected to include electric power generation as well as disposal, the analysis changes. Mercury is a trace contaminant in coal, and when coal is burned to generate electricity, some mercury is released to the atmosphere. Since an incandescent bulb requires more energy to operate, the use of an incandescent bulb results in the release of more mercury to the atmosphere than the use of a fluorescent bulb. Over the lifetime of the bulbs, more mercury can be released to the environment due to energy use than due to disposal of fluorescent bulbs. Thus, the simple issue of determining which bulb, over its life cycle, results in the release of more mercury

depends strongly on how the boundaries of the system is chosen.

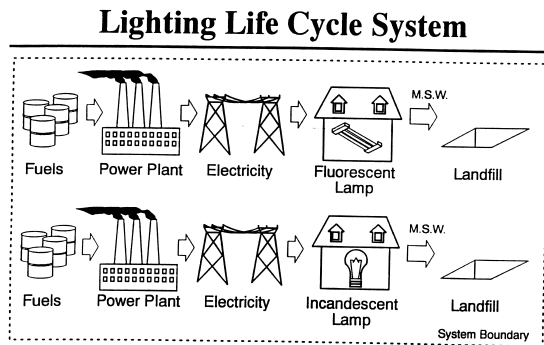
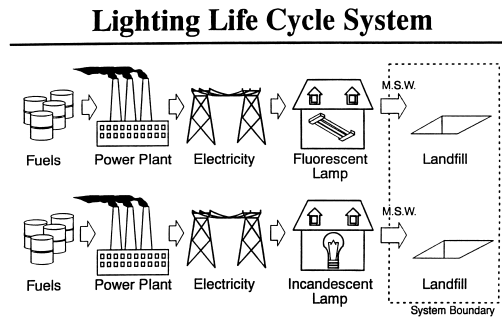


Figure 13.2 The importance of system boundaries in life cycle assessment is illustrated by the case of lighting systems. As noted in the text, fluorescent bulbs contain mercury and if these bulbs are sent directly to municipal solid waste landfills, mercury might be released into the environment. Use of incandescent bulbs would result in a smaller amount of mercury in the municipal solid waste stream. Thus, an analysis focusing on just municipal solid waste disposal would conclude that fluorescent bulbs release more mercury to the environment than incandescent bulbs. If a larger system is considered, however, the conclusion changes. Mercury is a trace contaminant in coal, and when coal is burned to generate electricity, some mercury is released to the atmosphere. Since an incandescent bulb requires more energy to operate, the use of an incandescent bulb can result in the release of more mercury to the atmosphere than the use of a fluorescent bulb. Over the lifetime of the bulbs, more mercury can be released to the environment due to energy use than due to disposal of fluorescent bulbs.

As this simple example illustrates, the choice of system boundaries can influence the outcome of a life

cycle assessment. A narrowly defined system requires less data collection and analysis, but may ignore critical features of a system. On the other hand, in a practical sense it is impossible to quantify all impacts for a process or product system. Returning to our simple example, should we assess the impacts of mining the metals, and making the glass used in the bulbs we are analyzing? In general, we would not need to consider these issues if the impacts are negligible, compared to the impacts associated with operations over the life of the equipment. On the other hand, for specific issues, such as mercury release, some of these ancillary processes could be important contributors. What is included in the system and what is left out is generally based on engineering judgement and a desire to capture any parts of the system that may account for 1% or more of the energy use, raw material use, wastes or emissions.

Another critical part of defining the scope of a life cycle assessment is to specify the **functional unit**. The choice of functional unit is especially important when life-cycle assessments are conducted to compare products. This is because functional units are necessary for determining equivalence between the choices. For example, if paper and plastic grocery sacks are to be compared in an LCA, it would not be appropriate to compare one paper sack to one plastic sack. Instead the products should be compared based on the volume of groceries they can carry. Because fewer groceries are generally placed in plastic sacks than in paper sacks, some LCAs have assumed a functional equivalence of two plastic grocery sacks to one paper sack. Differing product lifetimes must also be evaluated carefully when using life-cycle studies to compare products. For example, a cloth grocery sack may be able to hold only as many groceries as a plastic sack, but will have a much longer use lifetime that must be accounted for in performing the LCA. As shown in the problems (see Problem 13.1) at the end of this chapter, the choice of functional unit is not always straightforward and can have a profound impact on the results of a study.

*Step 2* The second step in a life-cycle assessment is to inventory the outputs that occur, such as products, byproducts, wastes and emissions, and the inputs, such as raw materials and energy, that are used during the life-cycle. This step, shown conceptually in Figure 13.3, is called a **life-cycle inventory**, and is often the most time consuming and data intensive portion of a life cycle assessment. Examples of life cycle inventories and more detail concerning the structure of a life cycle inventory are provided in the next section.