CHAPTER 6

LIFE-CYCLE ASSESSMENT

6.1 OVERVIEW OF LIFE-CYCLE ASSESSMENT

The environmental impacts associated with the manufacture of a product are not limited to the emissions from the manufacturing line. Let us take a simple example the manufacturing of a common construction nail. The nail factory probably purchases iron wire of the appropriate size, extrudes it, cuts it to length, sharpens or hammers the point, hammers on the end, and packages the resulting nail for shipping. A coating may or may not be applied before packaging. A cursory examination would indicate that the only wastes from the process are the metal filings resulting from cutting and forming nails. A more detailed analysis, however, finds that lubricants are used during the machining stages and water is used for equipment cooling. Electricity is needed to run the equipment and to provide heat and lighting for the factory. Significant environmental impacts result from production of this electricity. There are also wastes associated with the coating and packaging of the nails. A more broadly based impact study may focus on the iron used in the manufacturing"process. Resources were destroyed, energy used, and air pollution created in mining and producing the iron for use in the nails. Additional energy was consumed and pollution produced in transporting the iron to the nail factory and again in transporting the finished nails to retailers and eventually to consumers. Finally, when the useful life of the building in which the nail was used is over, the nail must be disposed of in a landfill as solid waste. Thus the pollutive impact of a product depends on the scale of the process evaluated. The only way to fully understand the magnitude of these impacts is to use "life-cycle assessment."

A life-cycle assessment (LCA) is an evaluation of the environmental effects associated with any given activity from the initial gathering of raw material from the earth until the point at which all residuals are returned to the earth (Vigon et al., 1993). This evaluation includes all sidestream releases to the air, water, and soil from the production of the raw materials (including energy), the use of the product, and its final disposal, as well as from the processing of the product itself. Life-cycle assessments are used to identify and measure both "direct" (e.g., emissions and energy use during manufacturing processes) and "indirect" (e.g., energy use and impacts caused by raw material extraction, product distribution, consumer use, and disposal) (Nash and Stoughton, 1994). A simple depiction of this can be seen in Figure 6.1. The systematic approach of LCA provides a true measure of the impact of a particular product or process. Unlike an environmental audit of an industrial process, which focuses on one particular facility and usually only on the activities that occur on the site, LCA looks at the linked interactions of the firm with the actions of its suppliers and customers. The result is a total cradle-to-grave analysis of the environmental impact of a product.

Life-cycle assessment has been defined as an attitude through which manufacturers accept responsibility for the pollution caused by their products from design to disposal. This is a major change from the traditional philosophy that the responsibility begins with the raw material acquisition and ends with the sale of the finished products (Bhat, 1996).

All of the impacts of a product or process at all of its life stages are examined in LCAs. Thus they can be used to evaluate trade-offs between two possible options. For example, if only energy use impacts are considered when balancing the use of fluorescent versus incandescent light bulbs, the fluorescent bulbs will win hands-down because they use much less energy. However, fluorescent bulbs contain toxic mercury and would lose the comparison if toxic waste generation was the controlling factor. The LCA process can be used to ensure that all environmental impacts are accounted for and to help in the decision-making process to determine which product to use.

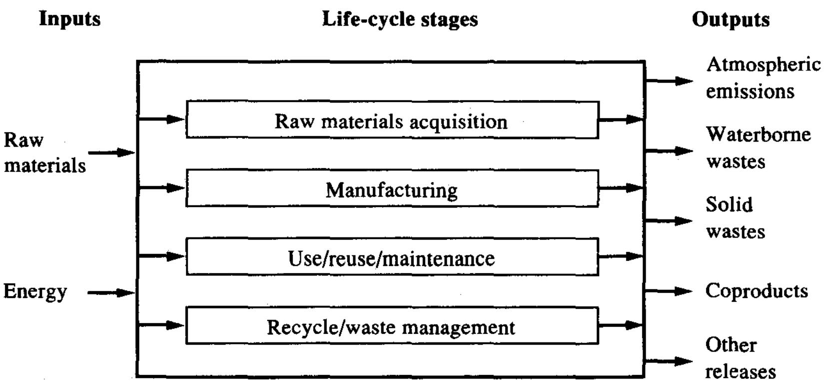

FIGURE 6.1
Life-cycle assessment stages and boundaries. (Source: Vigon et al., 1993)

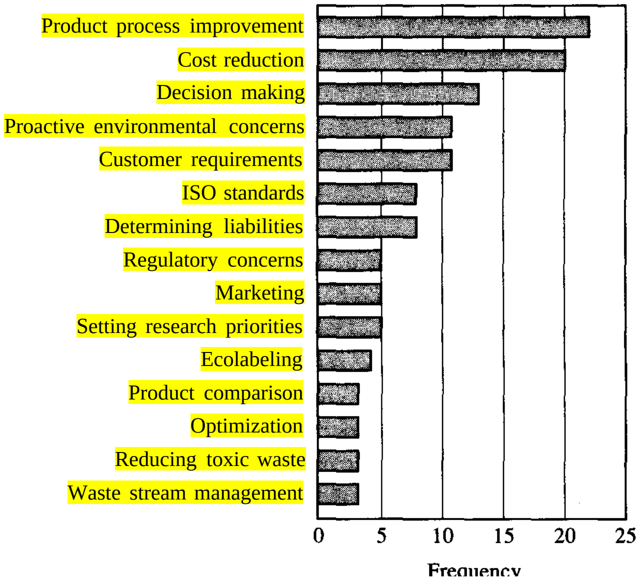

FIGURE 6.2
Motivations for implementing LCA. (Adapted from Foust and Gish, 1996)

Life-cycle assessments can be used for a number of purposes. A recent survey (Breville et al., 1994) showed the motivations for conducting LCAs as presented in Figure 6.2. Life-cycle assessments performed for product and/or process improvement and/or cost reduction will remain the primary drivers; LCAs performed for cost reduction reasons will likely increase in the future, as waste disposal costs continue to increase. The second tier of motivators--decisionmaking, proactive environmental positioning, and customer requirements-will continue as important drivers, with the last probably increasing. The other lower-tier drivers will vary slightly in significance but will probably remain as lower-tier drivers (Foust and Gish, 1996).

6.2 HISTORY OF LIFE-CYCLE ASSESSMENT DEVELOPMENT

The first work that can be considered to be a life-cycle assessment probably was done in the 1960s to 1970s in the field of energy systems. The U.S. Department of Energy commissioned several studies on "net energy analysis," focusing on calculating energy requirements, with some analysis of resulting environmental impacts of the use of energy. The oil shortages of the 1970s and the resulting energy crisis led to more intensive industrial energy analyses. Later in that decade, studies that focused on environmental issues were conducted by the research groups Arthur D. Little (Vigon et al., 1993) and Midwest Research Institutes (Curran, 1996a). Global modeling studies published in *The Limits to Growth* (Meadows, Randers, and Behrens, 1972) resulted in predictions of the effects of the world's growing population on the demand for finite materials and energy resources. In 1969, the Coca-Cola Company developed the current methods of life-cycle analysis to compare the environmental consequences of materials use and environmental releases for several different beverage containers.

Progress in the development of LCA techniques was slow, though, until the "green movement" in Europe in the mid-1980s brought renewed attention to the merits of recycling. Suddenly, pollution releases from industrial operations and both their environmental and economic impacts became important. This led to a rapidly increasing use of the LCA process by industry. These studies are now being used by industry to make management and production decisions and by environmental watchdog groups as a way of comparing the environmental performance of various competing products. Most LCAs have focused on product packaging (beverage containers, fast-food containers, and shipping containers) and have supported efforts to reduce the amount of packaging in the waste stream or to reduce the environmental emissions of producing the packaging. A few studies have looked at actual consumer products, such as diapers and detergents, while others have compared alternative industrial processes for the manufacture of the same product. Many LCAs from a wide spectrum of industry are currently available to the public. Extensive lists of sources for these can be found in Curran (1996b) and Bhat (1996). Several will be discussed more fully later.

One outcome of these studies is the finding that the indirect impacts, particularly those occurring after consumer use, often dwarf direct impacts. The American Fiber Manufacturers Association, for example, conducted an LCA of a polyester blouse and found that far more resources were used by consumers in washing and drying the blouse than were used in its manufacture. More environmental improvement would be realized by changing the fiber properties so that it could be washed in cold water, thus saving energy costs for the consumer, than by altering manufacturing processes (Nash and Stoughton, 1994).

Another finding from these studies is that recycling or switching to less toxic materials is not always advantageous. In many cases, more energy and resources are expended in recycling a product than is consumed to make the new product with virgin materials.

6.3 LIFE-CYCLE ASSESSMENT AND THE REGULATORY PROCESS

In Europe, use of life-cycle assessments is expanding rapidly, particularly as the basis for packaging recovery and recycling targets. In the United States, no current regulations or planned regulations mandate the use of LCAs by industry; however, many of the environmental laws and regulations described in Chapter 4 can be better met through use of LCA techniques. A variety of government actions address the use of LCAs in a nonregulatory sense (Foust and Gish, 1996). Executive Order 12873, signed on October 20, 1993, addresses federal acquisition, recycling, and waste prevention. The order calls for the use of LCA in federal purchases in order to safeguard natural resources through use of recycled products and through waste prevention. It defines as *environmentally preferable* prodiIcts or services that have a lesser or reduced effect on human health and the environment when compared with competing products or services that serve the same purpose. Executive Order 12902, signed in 1994, is a directive dealing with energy efficiency and water conservation at federal facilities. This order directs federal facilities to reduce energy consumption by 30 percent within nine years, with 1985 as the baseline; to increase energy efficiency by 20 percent in nine

Je&"s, with 1990 as the baseline; and to institute cost-effective water conservation whenever possible. All new federal facilities are to be designed and erected as showcase facilities, highlighting energy and water efficiency. Life-cycle approaches are to be used in all of these endeavors.

Congress has debated legislation that would encourage use of life-cycle methodologies, but to date no legislation of this type has been enacted. In Europe, though, LCA has already been mandated for use in areas such as ecolabeling. United States industries are beginning to use LCA on a voluntary basis in a limited way because of the usefulness of the results. Most large organizations have an LCA program in place or plan to implement one in the near future. Life-cycle assessment is a labor-intensive, data-intensive, complex process; wider use of its techniques probably awaits development of simplified procedures. It is the consensus of most experts that LCA will evenwally become an integral part of environmental legislation (Foust and Gish, 1996).

Use of life-cycle assessments will undoubtedly expand rapidly in the near future because of ISO 14000, the Environmental Management Standards, now being implemented throughout the world. In 1993, ISO established TC-207 to develop environmental management tools and systems that would be applicable worldwide. Among the tools under development are environmental management systems, auditing, environmental performance evaluation, life-cycle assessment, and environmentally friendly labeling (Cascio, Woodside, and Mitchell, 1996; Fava and Consoli, 1996). Soon, ISO 14000 certification will be a requirement for doing business in the international marketplace, and LCAs will be an essential part of this certification.

6.4 LIFE-CYCLE ASSESSMENT METHODOLOGY

Life-cycle assessment uSeS a systems approach to identify the environmental consequences of various industrial alternatives. Ideally, it should take a holistic approach, considering choices of materials (premanufacturing), manufacturing processes (including use/reuse and maintenance), recycling, waste management, and product use; it should also evaluate energy use, resource consumption, and environmental releases in a cradle-to-grave scope.

This is usually beyond the ability of most companies, except for very limited projects. The data required may be voluminous and may not even be available, the analytical techniques required are still in the development stages, and the personnel costs to conduct the assessment may be excessive. Pollution prevention options selected may have far-reaching impacts on other industries that may not be easy to assess. For example, in a major study of the petrochemical industry, Rudd et al. (1981) found that simply changing the process route (and consequently the raw materials) used in the production of a particular type of plastic can have a significant impact on the entire petrochemical industry because of the overlapping uses for primary feedstocks. Figure 6.3 shows that many materials can be created using a variety of precursor materials. For example, ethylbenzene can be made from benzene, ethylene, or ethanol. Increasing the demand for one material, and thus lowering the demand for another, can affect the prices for those feedstocks across many other industries, the amounts of them produced, and the environmental impacts of their production. For example, an increase in

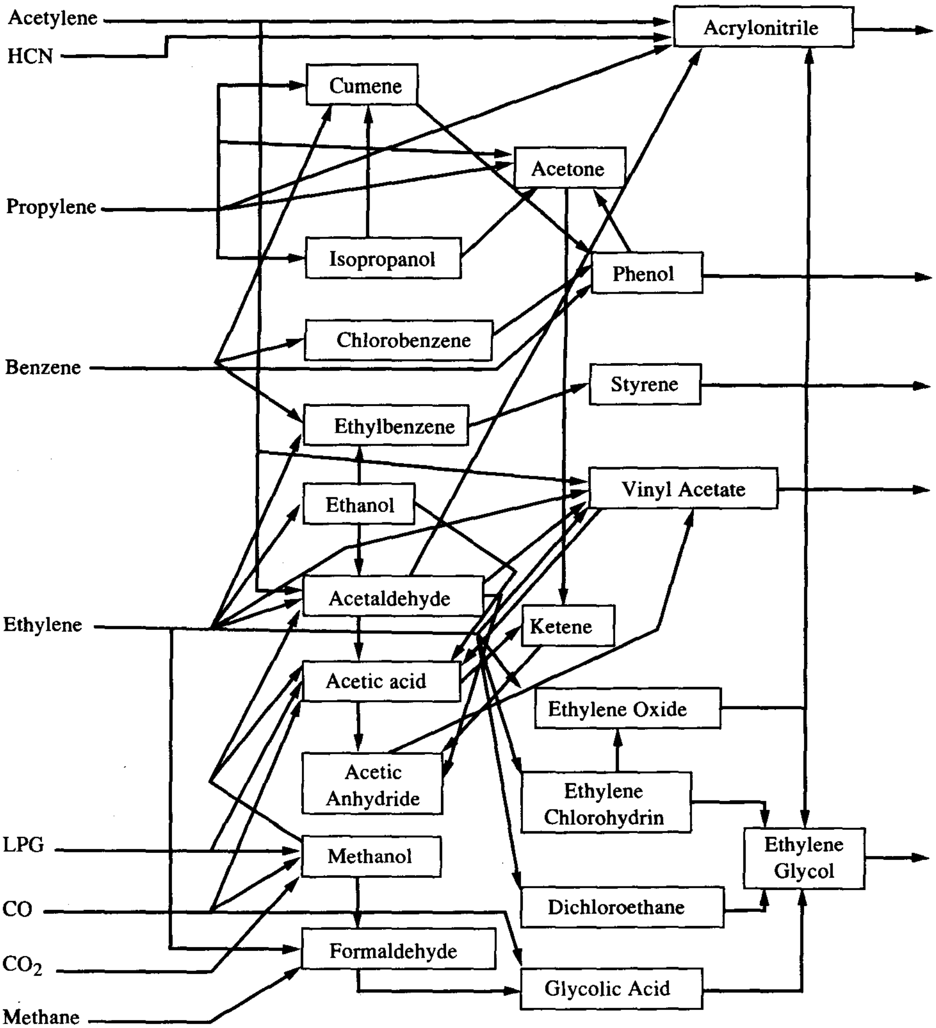

FIGURE 6.3
Part of the industrial system that converts primary feedstocks into end chemicals. (Source: Rudd et al., 1981)

the production of styrene would mean that the production of ethylbenzene would have to increase. Ethylbenzene production requires ethylene, ethanol, or benzene. Increasing the demands on these feedstocks will mean either that more of these will need to be produced or that the amounts of these used to produce cumene, isopropanol, acetaldehyde, chlorobenzene, and so on, would be reduced. This would be a market decision, with the cost of these feedstocks probably increasing, thus increasing the costs of all other associated chemicals. Ultimately, a wide range of chemicals unrelated to styrene will be affected. However, this does not mean that LCA is an unworkable methodology; rather, it means that realistic limits must be set on the objectives to be achieved.

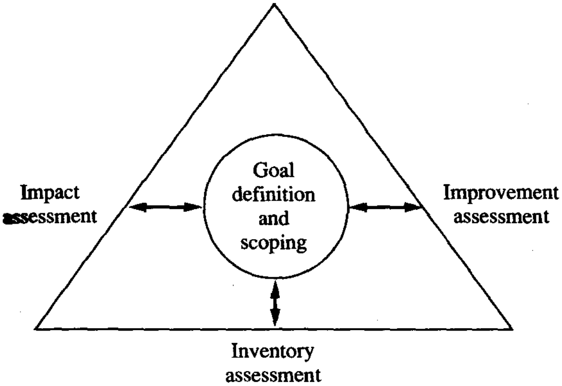

FIGURE 6.4
Components of a life-cycle assessment.

The principal components of life-cycle assessment have been established, and the procedures refined, by the Society of Environmental Toxicology and Chemistry (SETAC). In the early 1990s, SETAC established an LCA Advisory Group whose mission was to advance the science, practice, and application of LCAs to reduce resource consumption and environmental burdens associated with products, packaging, processes, and activities. The SETAC effort has resulted in a "Code of Practice" for life-cycle assessments (Consoli et al., 1993) and a framework for conducting life-cycle assessments (Fava et al., 1994). SETAC continues to lead the way in espousing the virtues of this method of environmental systems analysis.

To express the cradle-to-grave inputs and outputs (Fava et al., 1993), life-cycle assessments usually use three interdependent stages, or subsystems: life-cycle inventory assessment, impact assessment, and improvement assessment (see Figure 6.4). A fourth component, usually considered to be encompassed within the other three, is goal definition and scoping. These can be used independently or combined to achieve proper pollution prevention decisions. A complete LCA would include all of these, but because of the cost and complexity involved in some phases, not all are always done. We will discuss each of these phases individually, and then show how they can be combined for best decision making. However, of the three phases, only the inventory phase has been fully developed; the other phases will be primarily described in generalities. More complete descriptions of the process can be found in Boguski, Hunt, Chlokis, and Franklin (1996) and van den Berg, Huppes, and Dutilh (1996).

6.4.1 Goal Definition and Scoping Stage

This stage, as described by SETAC, defines the purpose of the study, the expected product of the study, the boundary conditions, and the assumptions. This is an essential fIrst step in any LCA. In most cases, an LCA is undertaken to answer specifIc questions management has concerning a particular process or product. It may be used to compare products or to relate a product to a standard, to improve the environmental soundness of a product, or to simply provide more information on the product. The nature of those questions serves as the basis for the goals and scope of the study (Boguski et al., 1996).

This phase establishes what will· or will not be included. Because of cost considerations, not all aspects of the LCA may be done. The extent of the LCA should be established at this stage, rather than later, although periodic reevaluation and modification of the goals and scope are often worthwhile.

The purpose of an LCA is usually to compare several options for making a product, modifying a process, changing packaging, and the like. Before an LCA can be properly undertaken, the company or organization conducting the LCA must have an understanding of the available options that are to be compared. It is incumbent upon the group undertaking the LCA to fully think out what options are available that should be compared, or it may overlook some that are worthwhile. Great thought should go into this phase, as it will set the framework for the LCA analysis.

Proper forethought can reduce the amount of work involved and make the LCA more valuable. If the main intent of the study is to compare the environmentalconsequences of changing the machinery used to make a product, and the product itself or its packaging is not going to change, then the scope of the project can belimited to an inventory analysis and impact assessment of the production stage alone; a full LCA for the product is not needed because the product and the packaging will be the same with either manufacturing option. However, if the question concerns whether to change the product itself (e.g., changing from steel to plastic for the product case), then a more complete assessment may be needed.

The scope of the LCA selected determines the life-cycle stages that need to be considered when setting the boundaries of the study. Among these stages are the following (Vigon et al., 1993):

- Raw materials and energy acquisition.
- Manufacturing, including intermediate materials manufacturing, materials transportation to the fabrication site, product fabrication, filling/packaging/distribution of the product, and transportation to the retail site.
- Use/reuse/maintenance by the consumer during the product's useful life.
- Recycle/waste management after use.

In all cases, all energy requirements to transport, produce, and use the product, and all environmental wastes from transporting, producing, and using the product must be considered, as must the post-consumer disposal of the product. Each step in the process should be evaluated, including production steps for ancillary inputs or outputs such as process chemicals, energy production and use, and packaging.

Life-cycle assessment systems are always complex, involving many steps and requiring a large amount of data. Even simple products may require hundreds of steps, when all input materials' processing steps are included, as well as all possible uses, reuse, and disposal options for the product. This level of detail may not always be needed, as when two alternative manufacturing processes are being compared. The product will be the same, so evaluation of postsales use of the product will be unnecessary. Thus many LCAs examine only subsets of the overall LCA. The more focused the scope of the analysis can be made, the more likely that meaningful results can be obtained. This must be done with caution, though, to ensure that important steps are not overlooked.

Because of the complexity of full LCAs, recent attempts have been made to reduce the workload burden by "streamlining" the process in a prescribed fashion, eliminating some of the LCA phases (such as raw materials acquisition or postconsumer product disposal). Depending on the purpose of the LCA, this may be perfectly acceptable. Streamlining is described more fully later in this chapter.

When the boundary conditions have been determined, a system flow diagram can be developed to better defme the system. The process flow chart provides a qualitative graphical representation of all relevant processes involved in the system studied. It is composed of a sequence of processes (represented by boxes) connected by materials flows (represented by arrows).

6.4.2 Inventory Analysis

Inventory assessment is a systematic, objective, stepwise procedure for quantifying energy and raw materials requirements, atmospheric emissions, waterborne emissions, solid wastes, and other releases for the entire life cycle of a product, package, process, material, or activity (Curran, 1996b; Vigon, 1995; Vigon et al., 1993). Each applicable stage in the life cycle of a product or process is evaluated for each individual contaminant, energy requirement, resource requirement, and so on, and the results summed to determine the overall impact.

There are five basic step in an inventory analysis: (l) define the scope and boundaries; (2) gather data; (3) create a computer model; (4) analyze and report the study results; and (5) interpret the results and draw conclusions (Boguski et al., 1996).

Defining the scope and boundaries is an extension of the initial scoping process described earlier. Here the objective is to focus on those areas defined as being important for the inventory analysis. Resource constraints may be a factor here. Obtaining necessary data may be difficult, the cost may be prohibitive, or information, particularly concerning proprietary data from other companies (e.g., composition of ingredients purchased or their life-cycle assessment), may not be available. However, the accuracy and validity of the analysis should not be compromised by performing a faulty assessment. It may be better to forgo the analysis than to produce one that is in error but is still used for decision making.

Life-cycle inventories are data-intensive exercises and require a systematic approach to be meaningful and doable at reasonable cost. The scoping phase of the inventory analysis should set the framework for the data gathering phase, defIDing which process steps are of importance and to be analyzed and determining what data will be needed. Normally, it is best to organize gathering of the necessary information in an inventory checklist format (Vigon et al., 1993). Eight general decision areas should be addressed in the checklist:

- Purpose of the inventory.
- System boundaries.
- Geographic scope.
- Types of data used.
- Data collection and synthesis procedures.

- Data quality measures.
- Computational model construction.
- Presentation of the results.

An example of an inventory checklist can be seen in Figures 6.5 and 6.6. Figure 6.5 is the checklist for the project's scope and procedures definition; Figure 6.6 is used to quantitatively describe the accumulated data.

LIFE-CYCLE INVENTORY CHECKLIST PART I—SCOPE AND PROCEDURES
INVENTORY OF: ______

Purpose of Inventory: *(check all that apply)*

Private Sector Use
Internal Evaluation and Decision Making
☐ Comparison of Materials, Products or Activities
☐ Resource Use and Release Comparison with Other Manufacturer's Data
☐ Personnel Training for Product and Process Design
☐ Baseline Information for Full LCA
External Evaluation and Decision Making
☐ Provide Information on Resource Use and Releases
☐ Substantiate Statements of Reductions in Resource Use and Releases

Public Sector Use
Evaluation and Policy-making
☐ Support Information for Policy and Regulatory Evaluation
☐ Information Gap Identification
☐ Help Evaluate Statements of Reductions in Resource Uses and Releases
Public Education
☐ Develop Support Materials for Public Education
☐ Assist in Curriculum Design

Systems Analyzed
List the product/process systems analyzed in this inventory: ______

Key Assumptions: (list and describe)
______

Define the Boundaries
For each system analyzed, define the boundaries by life-cycle stage, geographic scope, primary processes, and ancillary inputs included in the system boundaries

Postconsumer Solid Waste Management Options: Mark and describe the options analyzed for each system.
☐ Landfill ______
☐ Combustion ______
☐ Composting ______
☐ Open-loop Recycling ______
☐ Closed-loop Recycling ______
☐ Other ______

Basis for Comparison
☐ This is not a comparative study.
☐ This is a comparative study.
State basis for comparison between systems; (Example: 1000 units, 1000 uses) ______
If products or processes are not normally used on a one-to-one basis, state how equivalent function was established. ______

Computational Model Construction
☐ System calculations are made using computer spreadsheets that relate each system component to the total system.
☐ System calculations are made using another technique. Describe: ______
Describe how inputs to and outputs from postconsumer solid waste management are handled. ______

Quality Assurance: (state specific activities and initials of reviewer)
Review performance on:
☐ Data Gathering Techniques ______
☐ Coproduction Allocation ______
☐ Input Data ______
☐ Model Calculations and Formulas ______
☐ Results and Reporting ______

Peer Review: (state specific activities and initials of reviewer)
Review performed on:
☐ Scope and Boundary ______
☐ Data Gathering Techniques ______
☐ Coproduct Allocation ______
☐ Input Data ______
☐ Model Calculations and Formulas ______
☐ Results and Reporting ______

Results Presentation
☐ Methodology is fully described.
☐ Individual pollutants are reported.
☐ Emissions are reported as aggregated totals only.
Explain why: ______
☐ Report is sufficiently detailed for its defined purpose.
☐ Report may need more detail for additional use beyond defined purpose.
☐ Sensitivity analyses are included in the report.
List: ______
☐ Sensitivity analyses have been performed but are not included in the report. List: ______

FIGURE 6.5
Life-Cycle Inventory Checklist—Scope and Procedures. (Source: Vigon et al., 1993)

LIFE-CYCLE INVENTORY CHECKLIST PART II—MODULE WORKSHEET				
Inventory of: ______ Preparer: ______				
Life-Cycle Stage Description: ______				
Date: ______ Quality Assurance Approval: ______				
MODULE DESCRIPTION: ______				
	Data Value(a)	Type(b)	Data(c) Age/Scope	Quality Measures(d)
MODULE INPUTS				
Materials				
Process				
Other(e)				
Energy				
Process				
Precombustion				
Water Usage				
Process				
Fuel-related				
MODULE OUTPUTS				
Product				
Coproducts(f)				
Air Emissions				
Process				
Fuel-related				
Water Effluents				
Process				
Fuel-related				
Solid Waste				
Process				
Fuel-related				
Capital Repl.				
Transportation				
Personnel				

(a) Include units.

(b) Indicate whether data are actual measurements, engineering estimates, or theoretical or published values and whether the numbers are from a specific manufacturer or facility, or whether they represent industry-average values. List a specific source if pertinent, e.g., "obtained from Atlanta facility wastewater permit monitoring data."

(c) Indicate whether emissions are all available, regulated only, or selected. Designate data as to geographic specificity, e.g., North America, and indicate the period covered, e.g., average of monthly for 1991.

(d) List measures of data quality available for the data item, e.g., accuracy, precision, representativeness, consistency-checked, other, or none.

(e) Include nontraditional inputs, e.g., land use, when appropriate and necessary.

(f) If coproduct allocation method was applied, indicate basis in quality measures column, e.g., weight.

FIGURE 6.6
Life-Cycle Inventory Checklist-Module Worksheet. (Source: Vigon et al., 1993)

The data gathering step should ,be done using the system flow diagram for the process being studied and the checklist or worksheets. For all but the simplest projects, it is usually desirable to divide the system into a series of subsystems (an individual step or process that is part of the defined production system). For each subsystem, the analyst should determine all inflows (materials and energy) and all outputs (products, coproducts, and environmental emissions). Emissions should be quantified by type of pollutant. Transportation of materials from one process location to another should also be included.

Obtaining useful and accurate data is often difficult. Data on generic processes may be available from the literature and may be suitable for the study under way. **It is** essential, though, that the data used be derived from a comparable process. Manufacturing efficiencies often vary widely from business to business, and from one production operation to another within the same company. Numerous sources of data are available, including internal company reports; accounting or engineering reports; machine specifications; publicly available government documents and databases, such as census studies by the U.S. Department of Commerce and the U.S. Department of Energy or the Toxic Release Inventory (TRI) database published annually by the U.S. Environmental Protection Agency; technical books, such as the *Kirk-Othmer Encyclopedia of Chemical Technology* (Kroschwitz and Howe-Grant, 1991); and conference proceedings. A particularly vexing problem is getting data on proprietary products or processes supplied by others. For confidentiality reasons, most companies are reluctant to supply necessary information on these subsystems. Unless some type of confidentiality agreement can be reached, it may be necessary to estimate the required data; this could compromise the credibility of the final overall assessment. Obtaining data on the end-user phase of the life cycle can also be difficult. Market surveys and government reports may be helpful.

The assessment will only be as good as the data used. Care must be taken to ensure that all quantities used are accurate. If possible, materials balances should be performed on key materials to ensure that all material is accounted for. Inputs to a process should equal what is in the output plus what is waste, unless some of the material is created or destroyed during processing.

The data obtained will probably not be consistent in terms of units used to express them. Energy consumption may be in terms of kilowatts per month or year, water use in terms of thousands of cubic feet per year, raw materials in tons per year, air or water emissions in parts per million concentration and an average discharge volume per year, and so on. Before the LCA can be performed, the data must be reduced to a consistent format. This is often done based on the product's output level. All o(the data are normalized to amount consumed, produced, or discharged per pound or ton of product produced. Because available plant data are often a composite of all production at the facility, the data need to be adjusted so that only that portion of the material associated with the process, material, or product being studied is considered. The objective should be to model, as closely as possible, what is actually occurring in the life cycle of the product, process, or activity (Boguski et al., 1996).

Once the data are put into a consistent form, the actual assessment can begin. Often extensive, complex computations are required to properly combine the normalized data with present and projected materials flows. If multiple subsystems are involved, they must all be integrated to provide an overall picture of the environmental impacts of the system being studied. Some of the input data are factual and accurate, whereas other data may be assumptions or based on estimates. Sensitivity analyses may be required to determine the impact of these assumptions on the results. Most LCAs are now done using computer modeling, either with a spreadsheet or with more sophisticated computer software. The resulting analysis should give the total energy and resource use and the environmental emissions resulting from the system being studied. Computer models are described in more detail later in this chapter.

Care should go into the preparation of the LCA report because the overwhelming amount of material that is usually gathered may easily confuse the reader unless essential information is separated from the chaff. The presentation should thoroughly describe the methodology employed in the analysis and explicitly define the system analyzed and the boundaries that were set (Vigon, 1995). Both tabular and graphical presentation of results are used, with enough text to make the results meaningful. Interpretation and drawing of conclusions should be done in such a way as to answer the questions set out in the original scoping of the project. Normally, the conclusions should address ways to reduce resource and energy use and minimize environmental emissions. The value of trade-offs (e.g., fossil fuels versus nonfossil fuels, or greater airborne emissions versus greater waterborne emissions) should be left to the impact assessment stage of the LCA (Boguski et al., 1996).

6.4.3 Impact Analysis

Procedures for the inventory analysis described previously have become relatively well established over the past few years. It is essentially a data gathering, accounting, and interpretation process that can be based on generally accepted quantitative procedures. The same cannot be said for the impact analysis stage. It is still in its infancy, and measures of actual impacts on human health, environmental quality, and resource depletion are still being developed.

Life-cycle impact analysis is a quantitative and/or qualitative examination of potential environmental and human health effects associated with the use of resources and environmental releases (Fava et al., 1993). The inventory assessment stage conducted previous to this analysis produced a large quantity of often complex data. A system is needed to convert these data to a form that can be used to assess the impacts of various possible production scenarios. This is the role of the impact analysis.

The conceptual framework for impact analysis consists of three phases: classification, characterization, and valuation (see Figure 6.7).

CLASSIFICATION. Classification is the assignment of items from the inventory assessment to a small number of impact categories, such as human health, ecological quality, and natural resource depletion. Each item from the life-cycle inventory is assigned to one or more of the categories so that impacts can be aggregated in a meaningful way. Potential production changes may also have an effect on the social environment. For example, changing a process so that it no longer requires a cooling tower may eliminate the resulting water vapor plume from the tower and possibly even the tall, sometimes unsightly, cooling tower. This may have some positive impacts on the environment, but a significant effect may be an improvement in the site's aesthetics, resulting in an increase in values of neighboring property and a general improvement in the quality of life in the area. This would be included in the social welfare category.

For each impact category, a list of stressors is developed. These may include such things as specific contaminants emitted (acids, pesticides, chlorinated hydrocarbons, greenhouse gases, noise, etc.) or human health effects (human carcinogens, irritants,

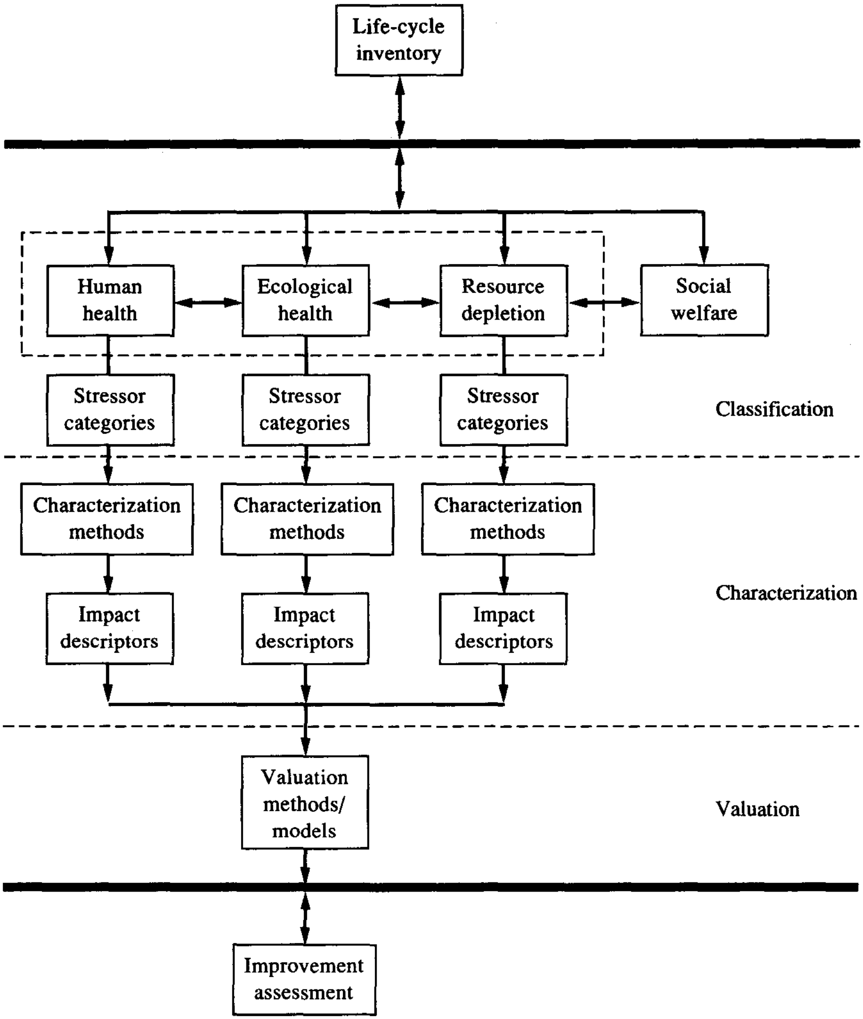

FIGURE 6.7
Conceptual framework for life-cycle impact assessment. (Source: Fava et al., 1993)

odors, behavioral effects). Commonly used environmental issues and stressors are listed in Table 6.1. Thus a material identified in the life-cycle inventory may be assigned to a number of impact groups and to a number of stressor categories within each group. For example, a textile mill may be discharging dyes in its wastewater effluent. These may be included in the ecological health category because of their impacts on fish life and on water quality [i.e., biochemical oxygen demand (BOD) increase]; they may also be included in the human health category because they may be carcinogenic or produce other adverse human health effects. The color imparted to the receiving water may make it aesthetically unpleasant, creating a social impact.

TABLE 6.1
Common environmental issues and stressors

Materials and energy			
1)pe	Character	Resource base	Impacts caused by extraction and use
Renewable Nonrenewable	Virgin Reused/recycled Reusable/recyclable	Location (local vs. other) Scarcity Quality Management/ restoration practices	Materials/energy use Residuals Ecosystems health Human health
Residuals			
Type	Characterization	Environmental fate	
Solid waste Air emissions Waterborne	Constituents, amount, concentration, toxicity Nonhazardous Hazardous Radioactive	Containment Bioaccumulation Degradability Mobility/transport	Treatment/disposal impacts
Ecological health			
Ecosystem stressors	Impact categories		Scale
Physical Chemical Biological	Diversity Sustainability, resilience to stressors	System structure and function Sensitive species	Local Regional Global

Source: "Life Cycle Analysis and Assessment."

CHARACTERIZATION. Characterization is the process of describing the impacts of concern. Usually this is done through the use of models that convert assessment data into impact data. For example, the amount of carcinogenic air pollutants emitted by a factory and reaching a human receptor can be converted into a projected number of new cancers caused by that pollutant loading. The inventory data assigned to each impact category can be analyzed in a variety of ways, from fairly simple to quite complex procedures. Among these, in order of increasing complexity, are:

- Loading.
- Equivalency.
- Inherent chemical properties.
- Generic exposure and effects.
- Site-specific exposure and effects.

Detailed descriptions of each of these procedures can be found elsewhere (Fava et al., 1993; Vigon, 1996).

The *loading technique* sums the data on each input category (i.e., energy usage, BOD contribution, SO_2 emissions) and compares the totals among various options. This is a simple technique that assumes there is a direct relationship between mass loading and environmental or health impact. However, this may not be the case. Moreover, this technique can only be used to compare one process against another based on the one item involved. One process may reduce the amount of particulate emissions into the atmosphere by switching from coal to petroleum as a source of energy and appear to be better based solely on particulate emissions, but this change may result in increased resource depletion of the less abundant petroleum. Thus loading characterization models may be useful as a fIrst cut for comparing the impact of one item for a given process against that of another option, but they are generally not sufficient alone to make good impact analysis decisions.

The *equivalency model* attempts to compare systems on the basis of equivalent impacts. For example, it is difficult to directly compare the impacts of changing solvents so that 1 kg of trichloroethylene is emitted rather than 1 kg of perchloroethylene because they are different chemicals. However, it may be possible to compare them based on equivalency factors. These could include such comparators as acute toxicity values (LD_{50}, or median lethal dose) or cancer potency indexes. In some cases, they could be compared based on regulatory emissions standards, if these were established based on perceived impacts. In some cases, impact potentials for specifIc impacts have been developed. One example is for global warming chemicals, as described in Section 3.2. Unfortunately, acceptable equivalency factors are not always readily available.

Characterization can also be done based on *inherent chemical properties* associated with the materials emitted. These properties may include toxicity, ignitability, carcinogenicity, and bioaccumulation. This approach is similar to the previously described model, with a different set of conversion factors. Again, sufficient accurate data to make this procedure useful may be lacking. Also, the procedure considers the impacts of the chemicals only in the form and concentration they are in at the time of emission. Some may be biochemically or photochemically degraded to less hazardous materials at a more rapid rate than others and have their impact reduced with time after entry into the environment, but this is not accounted for in the model. The model considers only the inherent properties of the specifIc compound itself.

Generic exposure and effects models are designed to estimate potential impacts based on generic environmental and human health information. These models are very complex and require the input of large amounts of information; however, much of the required data may not be available or may be of questionable validity. The model needs to describe complex interactions among the stressors, the environment, and humans. Simplistic models cannot do this adequately, and data needed for complex models often are lacking. Much research is under way to improve the use of these models, and they may someday be of value to individual industries, but at present there are none that are generally acceptable for routine use.

Site-specific exposure and effect models are used to determine the actual impacts resulting from process changes based on site-specific fate, transport, and impact information. These are usually more accurate than the generic models because they are based on site-specific information, but they again require large amounts of reliable data.

A method commonly used in Europe to compare environmental impacts from several options is based on the *critical dilution volume.* Developed by the Swiss Federal Ministry for the Environment, the system characterizes each emission in terms of the volume of air or water required to dilute it to the legal limit set for that emission. For example, if the life-cycle environmental loading from a product is 5 kg of chromium and the water quality standard for chromium is 0.05 mg/L, the critical volume, or volume of water that can safely carry that loading, is equal to 5 kg divided by 0.05 mg/L, or 100 million liters of water. Overall results are expressed as a total volume, that is, the sum of the individual dilution volumes. The procedure is simple, but it assumes that good emission standards are available, and it does not consider fate of the contaminant or exposure assessment (Postlethwaite and de Oude, 1996). It is a very conservative approach in that it also assumes that all loadings are cumulative, which often is not the case.

The life-cycle impact assessment characterization process is still in its development stage and there are still gaps in information needed to make good assessments. As more companies undertake impact assessments, the procedures will become more refined and more standardized. This process is needed, as it is the only way to quantifiably correctly decide on the best pollution prevention options to undertake.

VALUATION. The final step in the life-cycle analysis is to assign relative values or weights to different impacts so that the evaluator can compare the importance of the various impacts. For example, if an industry is comparing two possible pollution prevention projects, one that will result in a reduction of 100 kg/day of toluene emitted to the sewer and the other that will decrease air emissions of TCE by 100 kg, how do the evaluators decide which will have the most beneficial environmental impact? They must do a valuation based on the overall environmental impacts of each option. Because the impacts are very different, a weighting system is needed. This step is the least developed of the three phases of an environmental assessment. The major shortcoming is that assigning weights is higWy subjective, depending on the values of the assessor and the perceived relative importance of the particular item. One evaluator may consider energy consumption to be the most critical issue, another might favor biodiversity, a third might weight global climate protection more heavily, and so on. Decision making is based on emotional as well as rational valuations. There is no formal scientifically based procedure for doing this at the present time, and there probably shouldn't be. It would eliminate the freedom of people to express their own preferences and apply them in their own evaluation assessment. It does mean, though, that there can be more than one impact assessment outcome.

That said, the valuation step in life-cycle impact assessment can be described as follows:

> Valuation can be understood as the act of using "objective" information and considering it with "subjective" value-based environmental goals with some kind of methodology in order to derive a judgment. (Giegrich and Schmitz, 1996)

Judgment of an issue depends on facts and issues connected with one's values, emotions, previous judgments, and experience. The final impact assessment is a reduction of complex inventory data to impact-related figures and a final judgment of the environmental impacts of these figures.

Various methods have been suggested to conduct the valuation. Among these are the use of ecological scarcity factors, environmental loading factors, human health factors, and environmental acceptability factors. Several of these approaches are described in detail elsewhere (Graedel and Allenby, 1995). Following is a brief discussion of a few of the more widely accepted procedures.

Ecopoint method. This approach was developed in Switzerland in 1984 and later refined. It is a further development of the critical volumes approach described earlier, and it is based on regulatory limits. The fundamental concept is *ecological shortage,* defined as the resilience of an environmental resource to the current pollution level. It measures the relationship between total pollution involved from the process being studied and the maximum permissible pollution. The results are calculated in terms of single dimensionless numbers called *ecopoints.* This consists of the product of the pollution load and an ecological factor for that pollutant based on its· contribution to ecological shortage. An overall assessment is obtained by totaling the ecopoints from all of the individual emissions to give a single number, or *ecoscore.*

Environmental effects. This approach is being developed in several European countries. The Dutch are developing a comprehensive system to characterize environmental effects of a variety of chemical substances using environmental indexes (equivalency factors) for various emissions and categories. This requires much research and reams of data, because a suitable indicator must be found for each environmental impact category that can be used when evaluating a pollution load to assess potential impact. For example, the environmental impact of ozone depletion in the stratosphere due to an emitted chemical can be related to the ozone depletion potential of Freon (Giegrich and Schmitz, 1996). The Germans are taking this one step further by incorporating valuation into the equivalency factors. It is likely that ISO will use this system as its preferred valuation approach.

Environmental Priority Strategies. The EPS (Environmental Priority Strategies in Product Design) has been developed in Sweden to assess a wide variety of product types. For each basic material used to produce a product, an *environmental load index* (ELI) is determined. This index assigns values to emissions and resource consumption based on five criteria: biodiversity, human health, ecological health, resources, and aesthetics. Different components of the index account for the environmental impact of a product during three stages of its life-cycle: product manufacture, use, and disposal. These indexes are multiplied by the material's loadings to give environmental load units (ELUs) per kilogram (ELU/kg) of material used. These are then summed to quantify the total environmental load (Graedel and Allenby, 1995; Postlethwaite and de Oude, 1996). Thus, based on the amount of each material required, the environmental indexes are used to calculate the environmental load values at each stage of the product life cycle. Environmental load units derived for different options can be compared to determine the best option. The key to this valuation procedure is developing appropriate ELls. These can be highly subjective.

A complete life-cycle impact assessment will be invaluable to industries desiring to make proper, informed decisions on environmentally compatible process or product modifications. Studies of this nature have been performed and many more are under way. However, the field is still in its infancy, and there is much room for improvement to the procedures used or for the development of entirely new procedures. The next few years should see a major step forward in refinement of these processes.

6.4.4 Improvement Analysis

The objective of the improvement analysis stage of the life-cycle assessment is to identify opportunities to reduce energy use, raw materials consumption, or environmental emissions throughout the entire life cycle of the product, process, or activity. The analysis relies on the output of the previous two stages. The inventory analysis may identify opportunities to reduce waste emissions, energy consumption, or materials use. The impact analysis identifies those areas that are contributing the greatest environmental impacts and that should be considered for modification. The improvement analysis should use this information to develop strategies for optimizing the improvement of the product or process.

Conducting the improvement analysis is much more difficult than the foregoing description implies. To be effective, there must be ways of adequately equating impacts from various options that may be quite different from one another. The effort that goes into a good LCA that will lead to an effective assessment analysis can be significant. The cost of conducting a comprehensive life-cycle assessment is often enormous; repeating the LCA for each of several options, some of which may be innovative and have little existing data, greatly compounds the cost and the effort required. With this in mind, it can still be stated that an improvement analysis is desirable, even if it must be conducted on a limited basis.

6.5 STREAMLINING LIFE-CYCLE ASSESSMENTS

Because of the complexity and cost of conducting a comprehensive life-cycle assessment, and the extensive time it takes, many firms are reluctant to undertake one. A full-scale life-cycle assessment can cost from $10,000 to several hundred thousand dollars for each product studied (Todd, 1996). This has led researchers to begin developing streamlined procedures for LCAs to produce useful results at lower cost and with less required input. This is often done by truncating the LCA at either or both ends from the actual production steps. Raw material acquisition, fmal product disposal, or both may be ignored in the streamlined LCA (Curran, 1996a). This must be done very carefully to prevent reaching erroneous conclusions. In other cases, the streamlined LCA is designed to focus on a few critical environmental impacts, such as ozone depletion or acute health hazards, rather than at the "total" life-cycle impacts (Office of Technology Assessment, 1992).

Streamlining refers to various approaches used to reduce the cost and effort required for LCA studies. It is a modified approach to conducting LCAs and should not be confused with screening to determine where additional study is needed.

Assessors using a streamlined LCA approach must select with care the information they will omit from their studies. There is a minimum criterion that should be required of all assessments to ensure validity of the results. One set of minimum standards is as follows (Todd, 1996):

- The study should include some form of inventory; it may also include impact assessment and improvement assessment.
- The study should describe clearly the boundaries defmed for the study and the methods used to streamline accepted LCA methodology.
- The study should yield results that are consistent with those produced by a full-scale LCA of the product.

Several approaches have been suggest for streamlining LCAs, including narrowing the boundaries of the study, particularly during the inventory stage; targeting the study on issues of greatest interest; and using more readily available data, including qualitative data (Todd, 1996; U.S. EPA, 1997). Approaches that are currently used are listed in Table 6.2. Each of these approaches has advantages as well as drawbacks. Eliminating particular life-cycle stages may eliminate from consideration important environmental consequences of raw materials extraction or production or ultimate product disposal or reuse. Focusing on one pollutant or one specific environmental impact can also lead to exclusion of other potentially important environmental impacts. Care should be taken to ensure that the results obtained are still accurate and meaningful.

The type of streamlining approach taken should relate to the goals of the study and the intended use of the results. The results then must be evaluated within the context of the study limitations and should not be used to imply something broader than intended (Todd, 1996).

Recently, it has been suggested that the streamlining process be incorporated into the goals and scoping phase of an LCA, rather than considering LCAs and streamlined

TABLE 6.2
Approaches to streamlining LCA methods

Limiting or eliminating life-cycle stages (usually upstream or downstream stages from the main manufacturing stage)
Focusing on specific environmental impacts or issues
Eliminating specific inventory parameters
Limiting or eliminating impact assessment
Using qualitative as well as quantitative data
Using surrogate process data
Establishing criteria to be used as "show stoppers" or "knockouts"
Limiting the constituents studied to those meeting a threshold quantity (e.g., ignore raw materials comprising less than 20% by weight of the life cycle inventory (LCI) total mass)
Combining streamlining approaches

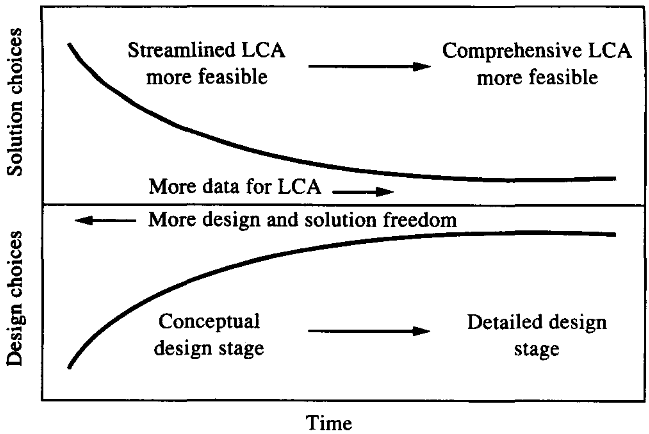

FIGURE 6.8
Design choices and LCA solutions as a function of the design stage. (Adapted from Keoleian, 1994)

LCAs as two separate procedures. Streamlining approaches can be used at the goals and scoping stage to set realistic objectives for the assessment. Streamlining can thus be viewed as "What can be eliminated from a full-scale LCA design and still meet the study goals?" or "What elements of a full-scale LCA must be included to meet the study goals?" (SETAC, 1997).

Streamlined LCAs are often used as a precursor to full life-cycle assessment in order to show where potentially environmentally significant improvements in product design can be made. It is also useful at the conceptual stage of design where limited data may be available. The complete set of life-cycle environmental effects associated with a product system can be evaluated only after the design has been specified in detail. But at this time the opportunities for design change become drastically limited (Keoleian, 1996). Figure 6.8 shows that as the design moves from the conceptual to the detailed stage, both the number of design choices and the number of solutions to environmental problems posed by the design become smaller (Keoleian, 1994). To be useful, comprehensive LCAs require an enormous amount of data that may be available only as the design becomes more detailed, but the opportunities to use the LCA to influence product design are reduced as the design proceeds. Streamlined LCAs may be necessary at these early stages of design.

6.6 POLLUTION PREVENTION FACTORS

The complete life-cycle assessment process is usually very expensive and time-consuming because of the voluminous amount of data required to do a creditable job, and the results may not be totally accurate because of a lack of quality data or the overuse of assumed data. Companies are continually "reinventing the wheel" in their data gathering because there is little sharing of information among various competing companies. In an attempt to overcome this, the U.S. Environmental Protection Agency and Battelle (Tolle et aI., 1994) have begun development of a new LCA approach called *P2 factors.*

P2 factors are intended to be an indicator of the general degree of environmental improvement over an entire life cycle that has occurred or might occur as a result of implementing a particular P2 activity (Curran, 1995). A P2 factor is defmed as a numerical or semiquantitative ratio between alternative source reduction activities which indicates the magnitude of the resulting environmental effects. It is in the form of a ratio, where the denominator is the summed score for criteria before application of a P2 activity, and the numerator is the summed score of the same criteria after implementation of the P2 criteria. Thus it can be used to compare only two alternative P2 options by one company; it cannot be used to compare products or processes between competing companies. It is not a "full LCA" but rather a simplified LCA methodology involving a mix of life-cycle inventory and impact assessment scoring criteria that can be used to screen candidate P2 activities. It usually is used to study only a few of the life-cycle stages, those that are expected to be affected by implementation of the P2 activity.

The methodology developed for calculating P2 factors includes a matrix of scoring criteria that can be used by different industries. The P2 factors are developed by first identifying which criteria are likely to change as a result of implementing a P2 activity. This is accomplished with the help of the stressor/impact chains, as proposed by SETAC and discussed earlier. Stressor/impact chains can be developed by considering the energy, water, and raw material inputs to each life-cycle stage, as well as the air, water, and solid waste emission impacts. Table 6.3 lists the criteria that may be selected to develop P2 factors for any industry (Tolle et al., 1994). The life-cycle stages where these criteria may be relevant are indicated by an X. The resulting P2 factors can be used to calculate both an industry average for an entire industry and a site-specific value for an individual company, in order to determine which P2 activities result in the greatest environmental improvement.

Briefly, the P2 factor methodology is as follows (Curran, 1995). Criteria related to environmental impacts that are likely to occur before and those likely to occur after implementation of the P2 activity are selected and scored according to their degrees of impact. The P2 factor is a ratio of the two scores. The environmental impacts are scored individually using a five-number scale (1, 3, 5, 7, and 9) to indicate descending levels of environmental impact likely to be generated by the activity, with 1 indicating the most and 9 indicating the least environmental impact.

To demonstrate the use of this framework for developing P2 factors, the EPA selected the lithographic printing industry for the first case study. Two P2 activities were selected for this case study: (1) solvent substitution for blanket or press wash; and (2) use of waterless versus conventional printing.

The solvent substitution option will be investigated further here. The main reason for possibly instituting this P2 option is to reduce the quantity of volatile organic compounds released to the air. Figure 6.9 shows the stressor/impact chains developed for the solvent substitution P2 options. Based on these, scoring criteria were selected for each of three life-cycle stages: (1) habitat alteration and resource renewability for the raw materials acquisition stage; (2) energy use, airborne emissions, and waterborne

TABLE 6.3
Potential scoring criteria for determining P2 factors

Scoring criteria	RMA	MAN	UIR/M	RIWM
Habitat alteration	X			
Industrial accidents	X	X		
Resource renewability	X			
Energy use	X	X	X	X
Net water consumption	X	X	X	X
Preconsumer waste recycle percentage		X		
Airborne emissions	X	X	X	X
Waterborne emissions	X	X	X	X
Solid waste generation rate		X		
Recycle content		X		
Source reduction potential		X		
Product reuse		X		
Photochemical oxidant creation potential	X	X	X	X
Ozone depletion potential	X		X	X
Global warming potential	X	X	X	X
Surrogate for energy/emissions to transport materials to recycler		X	X	
Recyclability potential (postconsumer)				X
Product disassembly potential				X
Waste-to-energy value				X
Material persistence				X
Toxic material mobility after disposal				X
Toxic content		X		X
Inhalation toxicity		X		X
Landfill leachate (aquatic) toxicity				X
Incineration ash residue				X

Key: X = relevant life-cycle stage; RMA = raw material acquisition; MAN = manufacturing; UIR/M = use/reuse/maintenance; R/WM = recycle/waste management.

effluents for the materials manufacturing (petroleum refining) step of the manufacturing stage; and (3) photochemical oxidant creation potential, ozone depletion potential, global warming potential, and inhalation toxicity for the product fabrication (printing) step of the manufacturing stage. Table 6.4 presents the evaluation criteria for the materials manufacturing portion of the manufacturing life-cycle stage. Similar criteria are developed for the raw material acquisition stage and the product fabrication (printing) stage [see Tolle et al. (1994) for these].

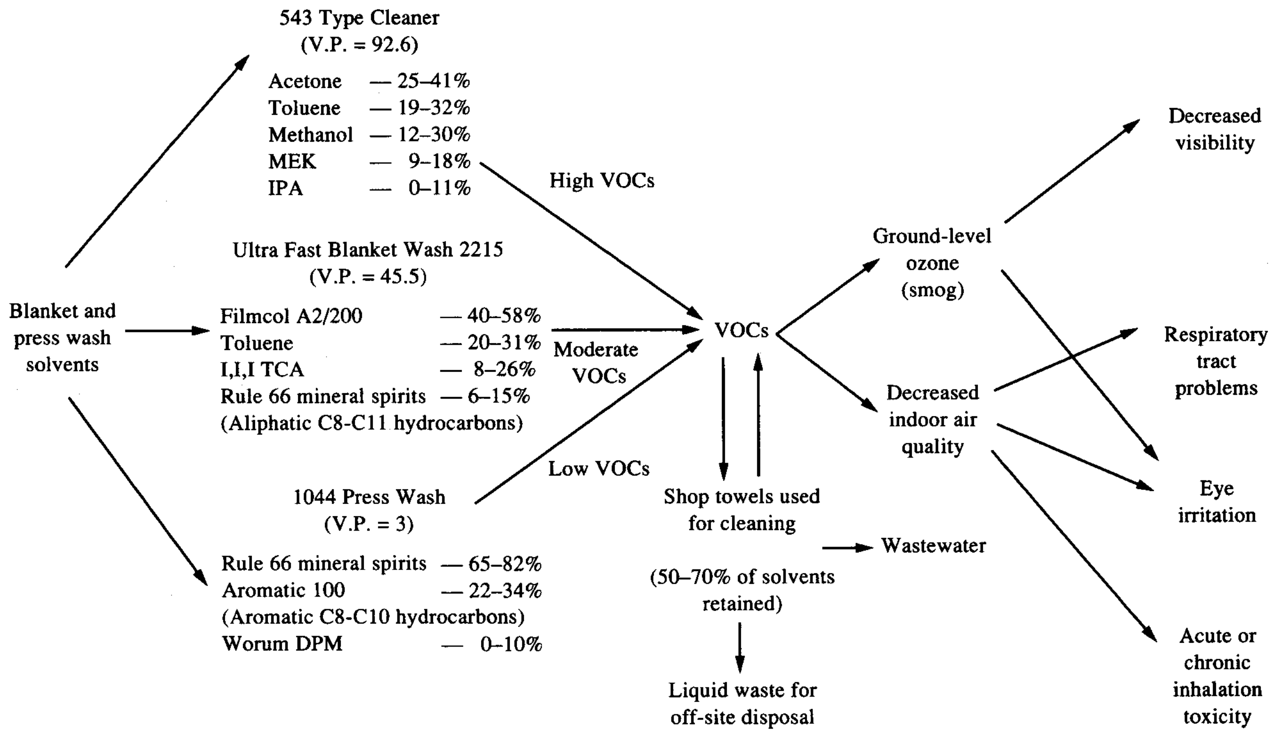

FIGURE 6.9
Stressor/impact diagram for solvent substitution in blanket or press wash in the lithographic printing industry. (Source: Tolle et al., 1994)

TABLE 6.4
Evaluation criteria and scoring ranges for calculation of P2 factors for the material manufacturing life-cycle stage for lithographic printers

Energy Use	
Score	Criteria ranges for energy used per unit output
9	<5,000 Btu/lb
7	5,000-10,000 Btu/lb
5	10,000-20,000 Btu/lb
3	20,000-30,000 Btu/lb
1	>30,000 Btu/lb

Toxic/bazardous airborne emissions	
Score	Criteria ranges based on airborne pollutant regulatory limits
9	Airborne pollutant emissions consistently > 50% below limits
7	Airborne pollutant emissions consistently> 25-50% below limits
5	Airborne pollutant emissions consistently> 10-24% below limits
3	Airborne pollutant emissions typically at the limits
1	Airborne pollutant emissions often exceed one or more limits

Waterborne effluents	
Score	Criteria ranges based on waterborne pollutant regulatory limits
9	Water pollutant emissions consistently > 50% below limits
7	Water pollutant emissions consistently> 25-50% below limits
5	Water pollutant emissions consistently> 10-24% below limits
3	Water pollutant emissions typically at the limits
1	Water pollutant emissions often exceed one or more of the limits

Source: Tolle et aI., 1994.

Table 6.5 presents data from three companies that made solvent changes in their printing processes, which were used to calculate P2 factors. When more than one solvent was mixed, scores were calculated for each solvent individually, and then the scores were combined based on the weight percentages used. Company A made two changes in blanket and press wash over a five-year period. The company started with 543 Type Cleaner in 1988, changed to Ultra Fast Blanket Wash 2215 in 1990, and made another switch to 1044 Press Wash in 1993. The first change resulted in a P2 factor of 0.82, indicating a greater environmental impact from the second solvent used. Switching from this solvent to the 1044 Press Wash resulted in a P2 factor of 1.18, indicating a significant improvement in environmental impacts over the use of Ultra Fast Blanket Wash 2215. However, when compared with the original solvent used (543 Type Cleaner), the P2 factor was only 0.97. Thus, from an environmental standpoint, the company may have been better off staying with the original solvent system. Company B initially used 555 Typewash and 70 Press Wash, but switched to 1066 Press Wash.

TABLE 6.5
P2 factors modified scores for solvents used in lithographic printing

Solvent	Energy use	Air-borne emissions	Water-borne emissions	Photo-chemical oxidant creation potential	Inhalation toxicity	Ozone-depleting potential	Global warming potential	Individual solvent mixture score	Average concurrent solvent mixture score	Inter-mediate P2 factor	Overall P2 factor
Company A											
534 Type Cleaner	4.0	6.5	6.5	4.5	7.7	9.0	7.0	45.1		0.82	
Ultra Fast Blanket Wash	3.0	5.6	5.9	4.6	5.5	6.5	6.0	37.0			0.97
1044 Press Wash	2.9	6.4	5.1	4.4	7.0	9.0	9.0	43.8		1.18	
Company B											
555 Typewash	2.9	4.9	5.5	4.5	5.4	9.0	6.5	38.7	43.7		
70 Press Wash	3.0	7.0	5.0	5.0	7.0	9.0	9.0	44.9			0.97
1066 Press Wash	2.8	5.7	5.0	4.0	7.0	9.0	9.0	42.5	42.5		
Company C											
VT3-A	2.7	5.9	5.9	1.9	7.7	9.0	7.0	40.0	39.4		
Power Kleen XF Plus	2.8	5.8	5.1	2.0	4.8	9.0	8.9	38.6			1.05
IP Wash	3.0	6.0	5.0	2.4	7.0	9.0	9.0	41.4	41.4		
										Average P2 ratio = 1.00	

Source: Tolle et al., 1994.

The resulting P2 factor was 0.97, indicating a slight increase in environmental stress due to the solvent switch. Company C was initially using VT3-A and Power Kleen XF Plus and switched to IP Wash. The P2 factor was 1.05, indicating a small improvement in environmental impacts by changing the solvent used. These differences may not be significant, though, because the differences found may be within the margin of error of the data available. The average P2 factor for the three companies (four solvent changes) was 1.00, indicating very little overall environmental improvement was achieved, on average, by solvent substitutions.

The second P2 activity evaluated in this study involved switching an offset press used in printing from conventional dampening system printing, using either 2-butoxy ethanol or ethylene glycol in the fountain solution, to a waterless printing system. Waterless printing received a score of 9 for all of the criteria associated with fountain solution solvents, since no fountain solution is required for waterless printing, whereas scores for the fountain solution in the conventional process averaged 6.3. The overall P2 factor for switching from conventional to waterless offset printing was 1.25, indicating decreases in the overall impacts from this P2 activity.

6.7 APPLICATIONS OF LIFE-CYCLE ASSESSMENT

The LCA concept can be used in a number of ways to achieve pollution prevention. Among these are corporate strategic planning, product development, process selection and/or modifications, market claims and advertising (Vigon, 1995), evaluation by government agencies to ensure compliance with pollution prevention requirements, and evaluation and comparison of products by consumers or environmental groups. Thus LCAs may be used by a company as part of its production and sales strategies or by outside groups to evaluate products. A few of these are discussed further here.

6.7.1 Corporate Strategic Planning

Manufacturing organizations are driven by product sales and the resultant net profits. However, many companies in recent years have realized the importance of considering the environmental impacts of their manufacturing processes and products. Consumers, in increasing numbers, are demanding environmental accountability from producers and often are making purchasing decisions based on the "greenness" of a company. By conducting and implementing LCAs and publicizing the results, companies can show that they are concerned about the environment. Since these are *life-cycle* analyses, the management can use the results to make decisions that impact on other industries as well, such as their suppliers, transporters, and potential users of their by-products. By making a corporate decision to improve the product's LCA by requiring suppliers to adhere to strict pollution prevention practices, for example, the producer can affect a much greater sphere than its own operation.

In Chapter 1, the Chemical Manufacturers Association (CMA) Responsible Care Program was described. This program was designed to promote the practice of product stewardship, that is, making safety, health, and environmental protection an integral part of design, manufacture, distribution, product use, recycling, and disposal (Fava and Consoli, 1996).

Many companies are now making pollution prevention a fundamental part of their operating strategy and are using life-cycle assessments to monitor progress in that direction. The LCA results become an intrinsic part of the corporate decision-making process. In some cases, this has meant altering the company's way of deciding what products to produce or processes to modify. Typically, decisions of this nature are made based primarily on financial considerations (Le., rate of return, benefit-cost ratio, pay-back period). As will be discussed in the next chapter, these procedures usually do not account well for the benefits of pollution prevention projects. If life-cycle analyses are to be used successfully, accommodations must be made for such factors as reduced long-term liability, extended project implementation times, and improved public image, none of which are usually included in corporate decision making based on financial return.

Scott Paper Company is one example of a company that is incorporating life-cycle considerations as one of the decision criteria for its pulp material and supplier selection for the tissue paper it produces. The company developed a clear set of world-wide positions on environmental management and committed the company to pursue an LCA cradle-to-grave approach, rather than continuing to act on individual issues. Within this program, Scott established a supplier assessment protocol, building environmental criteria into pulp purchasing decisions for its European operations. Suppliers were evaluated using a common set of environmental criteria. Suppliers that did not meet the criteria were given an opportunity to change their practices so that they could comply. Those that could not or would not meet the criteria (about 10 percent of the suppliers) were dropped as suppliers. Thus Scott was able to impact a much larger part of the industrial waste stream than that from its own facilities (Fava and Consoli, 1996).

6.7.2 Product Development

Production of waste materials during manufacturing is a direct sign of an inefficient manufacturing process. Avoidable wastes produced during the use of a product, wastes generated by the disposal of the product after its use, and excessive energy use required to operate the product are also signs of needless inefficiency. These can often be eliminated, or at least reduced, through proper use of life-cycle assessment and implementation of the results. There are many examples of this being successfully accomplished.

Among companies that are incorporating LCA into their decision-making procedures are Motorola, a large electronics company. Motorola is working to integrate environmental considerations into all of its product designs in order to meet customers' environmental demands. The company has found that it can have the biggest pollution prevention impact by focusing on the concept development stage of product design. In an effort to make up for the lack of detailed data available at this stage for making environmental assessments, Motorola has developed a matrix-based streamlined life-cycle assessment procedure for the concept development design stage. The company is beginning to use full-scale life-cycle assessments for the manufacturing stage (Hoffman, 1997).

The most common use of life-cycle assessment is to identify critical areas in which the environmental performance of a product can be improved (Allen, 1996). As discussed earlier, a study of the life-cycle of a woman's polyester blouse indicated that 86 percent of the energy consumed during the life-cycle of the blouse is associated with bot water cleaning and machine drying (see Figure 6.10). It was found that the energy demand associated with cleaning could be reduced by 90 percent if the garment fabric could be redesigned so that it could be washed in cold water and air-dried. Thus, from a life-cycle viewpoint, product improvement should be directed toward development of fabrics, dyes, and detergents that are compatible with cold water washing. Accomplishing this would be a boon to the environment. Any financial benefits from doing this, though, accrue to the consumer and not the garment maker, unless the blouse maker can increase sales by aggressive advertising of the benefits of the new fabric. Thus a beneficial product improvement based on life-cycle assessment mayor may not be implemented, depending on whether it benefits the producer.

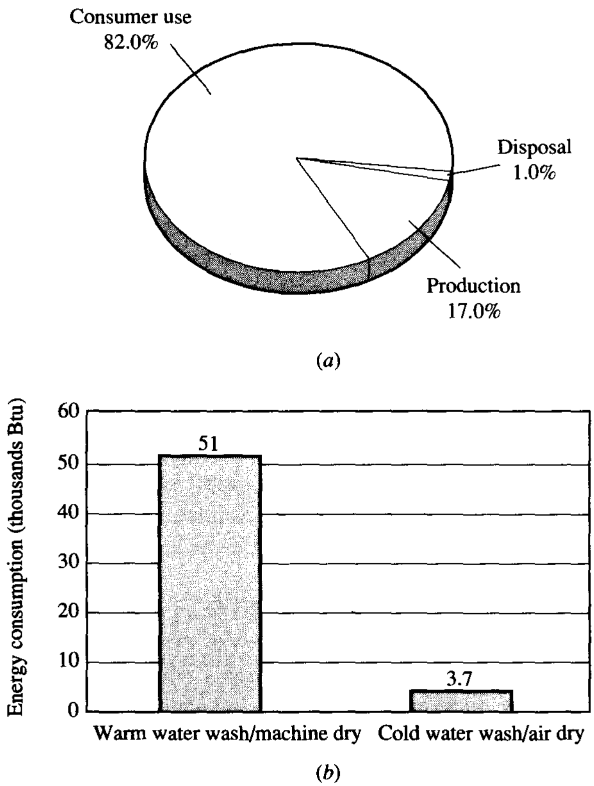

FIGURE 6.10
A life-cycle inventory for a woman's polyester blouse. (*a*) Distribution of life-cycle energy requirements. (*b*) Energy consumption comparisons for one load of home laundry. (Adapted from Franklin Associates, Ltd., 1993)

6.7.3 Process Selection and Modification

Life-cycle assessment has frequently been used to select between several alternative processes to achieve the greatest potential waste prevention or reduction. This can be done as part of an overall LCA for a product or as a focused study to evaluate improved manufacturing processes. An LCA restricted to process modifications may be streamlined because the final product should be the same and should have the same environmental impacts, regardless of the manufacturing process. The study can then be limited to such items as changes in feedstocks, different energy requirements, possibly altered production efficiencies, different by-products, and waste effluents.

IBM is constantly evaluating the environmental burdens associated with the materials used in its information technology equipment (Besnainou and Coulon, 1996; Brinkley et aI., 1995). In one study, IBM wanted to know the impacts associated with increasing the amount of recycled polyvinyl chloride (PVC) used in making covers for personal computer monitors. IBM compared a closed-loop recycling option, in which used or surplus monitor equipment was collected at an IBM site and shipped to a qualified recycler who reclaimed the PVC and sent it back to IBM for use as a feedstock in new monitor housings, with two disposal options: (1) landfilling as scrap, and (2) incineration with heat recovery. IBM was mainly interested in studying the recovery/disposal options, so it limited the scope of the LCA to these components, while including all life-cycle phases of that component and material. Since the PVC used in manufacturing the monitor housings was essentially the same whether it came from virgin or recycled materials, the manufacturing process was not studied. The assessment was limited to the three disposal options (see Figure 6.11). Table 6.6 summarizes the life-cycle inventory of materials, energy requirements, air emissions, water effluents, and solid wastes generated by each option. With few exceptions, the recycling option presents the best inventory profile. When coupled with an economic analysis, the ability to recover and use recycled PVC rather than using virgin PVC clearly made this the best option.

The Tennessee Valley Authority (TVA), the major producer of power in the southeastern United States, produces significant quantities of waste materials. In 1993, the TVA began a program to reduce the generation of solid waste by 30 percent by the year 1997. Using an LCA procedure developed by the Electric Power Research Institute (EPRI), the TVA was able to cost-effectively reduce overall solid waste production by 19 percent within two years. In addition to the environmental benefits that resulted from this reduction, the TVA has realized an annual life-cycle cost saving of $41,000 and a one-time saving of $70,000 (West, 1997).

In another study of the way that LCAs can be used to analyze and design manufacturing processes, the process used to produce nitric acid was evaluated (Kniel, Delmarco, and Petrie, 1996). Assessment of the nitric acid process was ideal for this because of the process's simplicity (few materials and energy flows with well-known technologies, one principal waste and product stream; see Figure 6.12) and because necessary data were readily available. This is not often the case. The manufacturing process consists of oxidizing ammonia gas to NO_x with air under high pressure (3.25

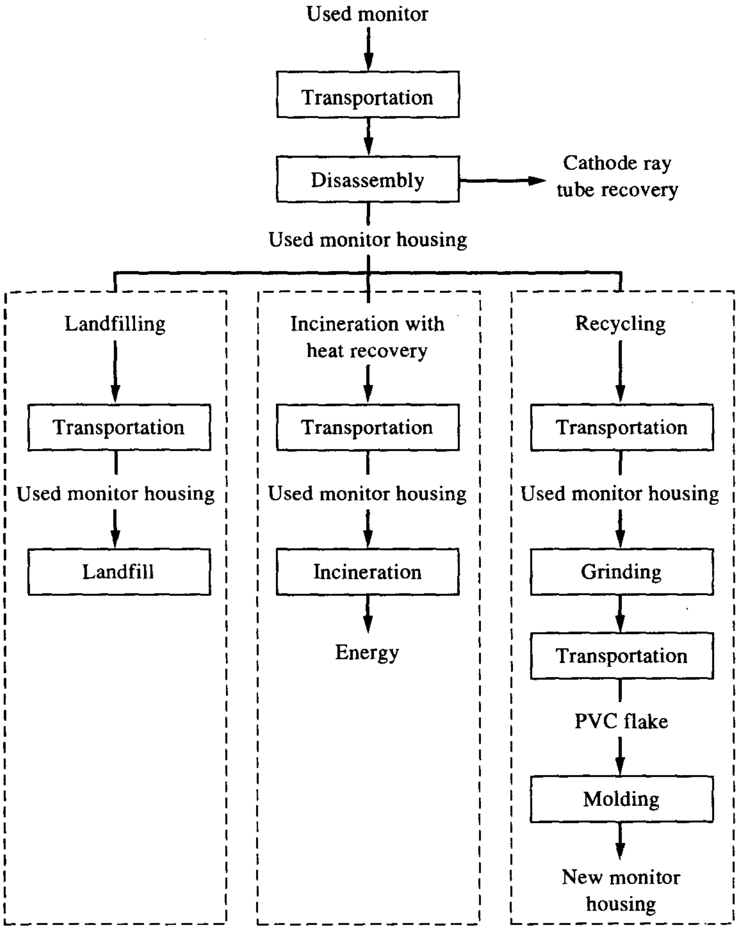

FIGURE 6.11
Functional analysis of the three PVC monitor housing disposal options by IBM. (Adapted from Besnainou and Coulon, 1996)

bar) and then absorbing the NO_x in water in the presence of a catalyst (platinum-rhodium) to form nitric acid ($HN0_3$). Among the proposed changes that were evaluated were a common end-of-pipe solution; adding a selective catalytic reduction (SCR) unit to the tail gas stream to reduce NO_x levels; and one following waste minimization principles, increasing the pressure in the absorption system to increase the efficiency of NO_x absorption. The nitric acid process modification LCAs and results of economic models for a number of design alternatives aimed at waste reduction were linked and compared to maximize economic returns and minimize environmental impact. The

TABLE 6.6
Life-cycle inventory analysis results for the three disposal options

	Unit	Landtilling	Incineration	Recycling
Raw materials				
Crude oil	kg	0.036	0.025	-1.07
Coal	kg	0.0002	-0.67	-0.44
Natural gas	kg	0.0001	0.004	-1.28
Limestone	kg		1.50	-0.004
NaCI	kg			-1.5
Water	L	0.007	-0.008	-4.2
Air emissions				
Particulate matter	g	0.15	33	-8.3
CO_2	g	115.	2400	-4000
CO	g	0.41	1.07	-5.3
SO_x	g	0.16	-13.0	-27
NO_X	g	1.17	-4.17	-33
NH_3	g	0.0007	0.0143	0.0011
$C1_2$	g			-0.004
HCl	g		300	-0.48
Hydrocarbons	g	0.31	-13.70	-42.6
Other organics	g	0.00	-0.02	-1.60
Water emuents				
Biochemical oxygen demand (BOD_5)	g	0.0002	0.0002	-0.18
Chemical oxygen demand (COD)	g	0.0006	0.0007	-2.46
Chlorides	g			-89.4
Dissolved solids	g	0.42	0.48	-2.6
Suspended solids	g	0.0002	-0.004	-5.3
Oil	g	0.005	0.007	-0.10
Sulfates	g			-9.6
Nitrates	g		-0.0004	0.00004
Nitrogen-TKN	g			-0.01
Sodium ions	g			-5.1
Metals	g			-0.45
Solid wastes				
Hazardous chemicals	g			-0.003
Landfilled PVC	g	2.2	0	0.02
Slags and ash	g		1.7	-0.10
Other	g	0.00005	-0.44	-0.14
Energy				
Total primary energy	MJ	42		-103
Electricity	kWh	0.0012	-2.1	-2.3

Source: Besnainou and Conlon, 1996.

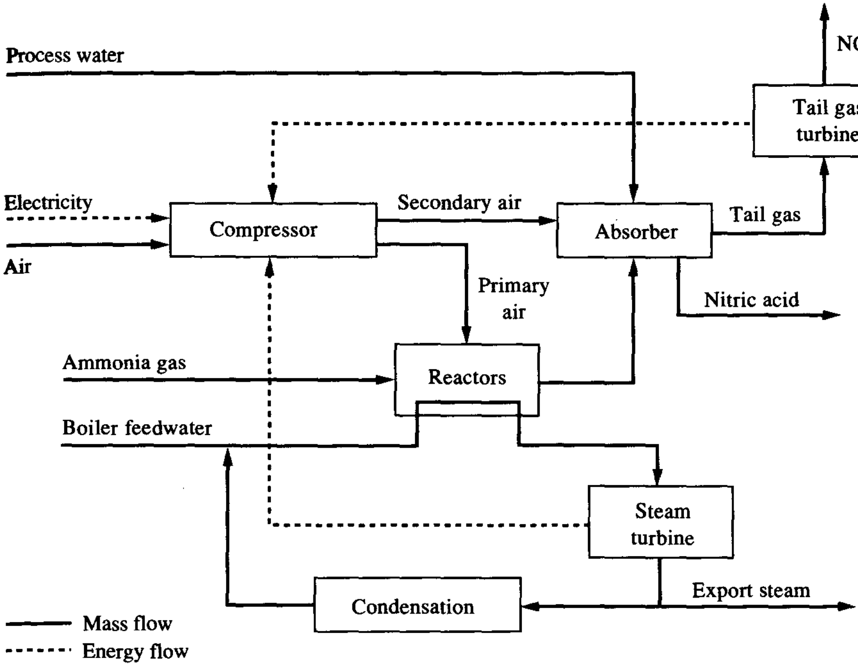

FIGURE 6.12
Process schematic for a nitric acid plant. (Adapted from Kniel, Delmarco, and Petrie, 1996)

comparative study showed that the waste minimization option was clearly superior from an environmental point of view; it also had the highest economic rate of return, because the SCR unit is only a treatment system and provides no additional revenue, whereas the high-pressure modification increases efficiency of absorption and therefore increases production rates.

6.7.4 Marketing Claims and Advertising

Many companies are beginning to see the value of using LCAs to support their claims to product consumers that the company is a good steward of the environment and that its products are environmentally friendly. Typically, though, little information concerning the scope of the LCA or the information derived is provided. Manufacturers generally advertise their products as environmentally friendly based on a single criterion such as recycling potential or the amount of waste generated during one or two stages of the product's life (Bhat, 1996). For example, a manufacturer may label its product as "nontoxic," "biodegradable," "CFC-free," or "phosphate-free," without any other indications as to its "greenness" or the meaning of the terms used. Thus many of these claims must be viewed skeptically. Taking limited data out of context, without all the information from a full life-cycle assessment, can easily lead to misinformation and misleading claims.

6.7.5 Ecolabeling

Industries are not alone in finding a use for life-cycle assessments; both governments and environmental watchdog groups have discovered that LCAs can be used to compare products on an equal basis or to ensure that the products meet minimum environmental standards. These results are used by some governments to ensure regulatory compliance; they can also be used in making product purchase and acquisition decisions by governments, industry, and the general public.

The United States has been slow in adopting LCA techniques as a part of public policy decision making. Progress is being made, though. In 1993, President Bill Clinton signed the Executive Order on Federal Acquisition, Recycling and Waste Prevention, which requires the Environmental Protection Agency to issue guidance that recommends the purchase of "environmentally preferable products and services," based on life-cycle assessment.

In Europe, on the other hand, life-cycle assessment concepts have become a basis for much of the environmental public policy. Several Nordic countries, including Denmark, Norway, and Sweden, are using LCAs of waste management options to determine the best strategies to undertake. A task force in Europe is developing guidelines for *environmental product profiles*, a qualitative description of the environmental impacts of a product for use by commercial and institutional buyers. Under this system, environmental information would be collected for each stage of a product's life cycle. This information will be shared with any user of that product so that the user can add the information from these previous life-cycle stages to its own life-cycle assessment. Thus cumulative impacts can be determined without each manufacturer having to begin the LCA from scratch. Based on an LCA of beverage packaging, Denmark banned the use of nomefillable bottles and cans and requires the use of refillable bottles. It also has greatly increased the fees for solid waste disposal as an incentive to recycle more waste materials. One of the most far-reaching actions is that taken by Germany, which has passed a law making manufacturers responsible for collecting and recycling various kinds of packaging and requiring manufacturers to take back and recycle many products from consumers after the product's useful life.

Probably the most visible application of LCAs in the public sector is the growing use of environmental labeling. Until recently, environmental labeling claims in the United States have been largely umegulated, sometimes resulting in misleading claims by manufacturers and confusion among consumers. Regulation of ecolabeling is still in its infancy in the United States, but progress is being made. Several states have passed regulations that govern the use of specific terms such as "recyclable" or "biodegradable." The Federal Trade Commission is issuing guidelines on the use of environmental labeling claims on product packaging and advertising. To be effective, evaluation of "greenness" should be performed by a third party, independent of the manufacturers or marketers of the product. A private organization, Green Seal, is using life-cycle assessment to evaluate the environmental impact of various categories of consumer products and to award environmental seals of approval to those products judged to be environmentally preferable (similar to the Underwriters' Laboratories' approval) (Marron, 1995). The expectation is that products receiving the env.ironmental seal of approval will receive a larger share of the market, forcing companies making competing products to change their practices so that they can also receive approval. Recent surveys have shown that four out of five consumers are more likely to purchase a product with a Green Seal label when choosing between products of equal quality and price; the surveys also showed that the Green Seal would have more impact on their purchase decisions than government guidelines.

Ecolabeling in the United States is relatively new, but it is a well-accepted practice in many European countries, Canada, and Japan. Among the G-7 countries, there are six official Eco-Logo Certification programs: Environmental Choice (Canada), Green Seal (United States), Eco Mark (Japan), Ecolabel (European Union, used by the United Kingdom and Italy), NF Environment (France), and Blue Angel (Germany). Each program is somewhat different, but they have some common elements.

ECO-LABELING IN OTHER COUNTRIES. Germany's Blue Angel Program, begun in 1978, is generally regarded as the model for all other ecolabeling programs. The program awards its Blue Angel label to consumer products that are clearly more beneficial to the environment than others in the same product category, as long as the product's primary function and safety are not significantly impaired (Marron, 1995). The assessment program is voluntary, and businesses that are certified pay a fee. The decision-making process for establishing criteria for environmental labeling is a joint effort of German governmental agencies and nongovernmental organizations. The criteria for awarding the Blue Angel includes the efficient use of fossil fuels, alternative products with less of an impact on the climate, reduction of greenhouse gas emission, and conservation of resources. The evaluation procedure consists of using a checklist or matrix to identify important parts of the product's life cycle and the most significant environmental attributes of the product class, supplementing this with the use of expert panels. If there is insufficient information to develop screening criteria, a streamlined LCA will be done using available information with caution (Shen, 1995). Once approved, Blue Angel-labeled products are reviewed every two or three years to reflect state-of-the-art developments in ecological technology and product design. Seventy-one product groups have been identified, with more than four thousand products approved for the Blue Angel seal. The program has been credited with increasing Germany's use of recycled paper and low-VOC paints, lacquers, and varnishes.

In a similar fashion, the Netherlands began awarding the Dutch Ecolabel in 1993 based on a qualitative matrix of environmental criteria. Label criteria are developed by a Board of Experts for product groups based on life-cycle assessments. At present, all consumers see is the label, indicating that the product has passed the "greenness" test, but no background information on the product is provided. In the future, the Dutch plan to expand the labeling program to include simplified descriptions of the product's impact on energy, waste, resources, emissions, and nuisance value (Allen and Rosselot, 1997).

The European Union (EU) is now coordinating the actions of member countries in implementing ecolabeling through its Community Eco Label Award Scheme (Postlethwaite and de Oude, 1996). Member states were requested to develop criteria for a number of product categories, such as shoes and laundry detergents, based on specific ecological criteria. The goal is that roughly 20 percent of the products currently on the market will comply with the initial criteria. There is a period of criteria validity of usually three years, after which the criteria will be reviewed and the standards possibly raised. This will encourage a progressive increase in environmental performance of consumer goods. The intent is to make the standards uniform over all of Europe. Once a set of criteria is approved, it can be used throughout all member countries, avoiding costly and redundant applications. Eventually, all member states will be required to implement the new regulations without any modifications into their national legislation.

The Canadian government began administering its Environmental Choice Program in 1998. The Canadian Standards Association, an independent testing and standards-setting organization, verifies products against guidelines set by the government and licenses companies on behalf of the Environmental Choice Program. The criteria are set such that only 10 percent to 20 percent of the products within a given category can qualify. The program is designed to address long-term environmental issues, including energy efficiency, hazardous by-products, enhanced use of recycled materials, and a design that allows for easier recycling. The criteria are based on a product's full life-cycle assessment. Currently, Canada has more than 1400 approved products.

The ISO 14000 program is also addressing the issue of environmental labeling by developing an international labeling standard. When completed, it will provide a consistent approach and uniform rigor to testing. Currently, labeling programs among various countries are often inconsistent. Major international companies have found that these programs are often confusing and may be based on idiosyncratic, nonscientific objectives. Environmental labeling has the potential to create serious international trade issues through its power to discriminate against products from countries using different environmental criteria. Compliance with multiple labeling requirements is complicated, costly, and administratively burdensome (Cascio, Woodside, and Mitchell, 1996). As a result, many corporations that do business in several countries are reluctant to use such labels. A uniform labeling standard should lead to greater respectability for ecolabeling and a greater rate of participation.

ECOLABELING **IN THE** UNITED STATES. Green Seal is an independent, nonprofit environmental labeling organization dedicated to protecting America's environment by promoting the manufacture and sale of environmentally preferable consumer products. It awards a "Green Seal of Approval" (see Figure 6.13) to products that cause less harm to the environment than other similar products during the product's manufacture, use, and ultimate disposal. Green Seal standards also consider packaging and product performance. Standards are set on a category-by-category basis, using an "environmental impact evaluation" procedure, based on life-cycle analysis. Categories are generally chosen according to the significance of the associated environmental impacts and the range of products available within the category.

All Green Seal standards are first issued in proposed form for public comment; they may be revised based on information provided before being published in fmal form. Manufacturers submit products to Green Seal that they would like to have certified. Underwriters' Laboratories, Inc. (UL), is Green Seal's primary testing and factory

FIGURE 6.13
The Green Seal label logo.

inspection contractor. UL evaluates products to determine whether they meet Green Seal's environmental standards. UL is also responsible for conducting follow-up inspections at the manufacturer's facility to monitor continued compliance. To date, Green Seal has .awarded its seal of approval to over 250 products. It certifies products in more than 50 categories including paints, water-efficient fixtures, bath and facial tissue, re-refmed engine oil, energy-efficient windows, and major household appliances.

6.8 USE OF COMPUTER MODELS IN LIFE-CYCLE ASSESSMENT

Conducting a life-cycle assessment is usually a data-intensive operation. Software packages are beginning to become available to help with the collection and analysis of all the data, primarily from government agencies and university researchers. Some of these include packages to analyze the costs associated with a pollution prevention initiative, as well as the environmental impacts. These programs are designed to provide decisioQ support on process optimization, comparative processes, and environmental needs assessments by looking at purchase, design, installation, start-up, and yearly costs information. They also help the user assess possible effects that the company's processes may have on the environment, such as the generation of hazardous air pollutants (Petty, 1997).

Life-cycle assessment software can be classified into three generic categories: strict LCA tools, product design tools, and engineering tools (Vigon, 1996). Strict LCA tools are intended to supply information to support LCA as a stand-alone activity. Most are intended to be used to collect, organize, and analyze data for life-cycle inventory assessments, but a few are also available for impact assessments; no commercially available software exists as yet for the improvement assessment phase ofLCA. Product design-oriented tools are usually directed at design engineers who may not be expert in LCA. They embed LCA computations in a design package, such as that for packaging design. The LCA portion of the software is intended to provide recommendations on materials and process choices based on LCA considerations. Some engineering analysis tools have also been adapted for use in LCA. One example of this is process simulators. In these models, industrial process inputs and transformation functions are described for each process. The model predicts the form and amounts of products, coproducts, and residuals, based on the operating conditions and process rules. These models can provide indications of potential production efficiencies and environmental burdens from a proposed process, and therefore can be very beneficial in a life-cycle assessment. However, these simulations are very complex and require a great deal of data and knowledge about the physical and chemical operations involved. The results will only be as good as the information provided to the model.

Most commercial LCA software is based on a spreadsheet format, using either Lotus 1-2-3 or Excel, but some are much more complex. Unfortunately, most LCA software packages focus on only one or two life-cycle stages, such as packaging or a specific manufacturing process; very few consider the full life-cycle of a product in the assessment. Also, many packages are process or industry specific.

Europe has again taken the lead in developing LCA tools. In addition to computer models, a number of European LCA databases can be used to obtain industry- or product-focused data that can be used in the models (Postlethwaite and de Oude, 1996; SustainAbility Ltd., 1993).

Comprehensive reviews of life-cycle assessment software are provided by Wood, King, and Cheremisinoff (1997) and Vigon (1996). The Environmental Protection Agency also provides useful information on P2 and LCA software (U.S. EPA, 1995; Vigon et al., 1993).

An example of an existing comprehensive LCA software package is TEAM (Tools for Environmental Analysis and Management), a Windows-based C+ + program developed to assist with life-cycle cost and life-cycle assessment calculations. The software generates life-cycle inventories and cost results, including sensitivity analysis. It covers raw material acquisition, the manufacturing stage, use/reuse/maintenance aspects, transportation, and recycle/waste management stages. Very complex systems can be analyzed, along with fairly simple estimations (Wood, King, and Cheremisinoff, 1997).

In the future, LCAs and process design will be integrally linked with database systems. An excellent example of how this will occur is the Clean Process Advisory System (CPAS) being developed by a coalition of industry, academia, and government. The CPAS is a computer-based pollution prevention process and product design system that will provide environmental design data to design engineers. It is composed of many separate but integrated software applications containing design information for new and existing clean process or product technology, technology modeling tools, and other design guidance. An overview of the CPAS system is seen in Figure 6.14.

6.9 LIFE· CYCLE ASSESSMENT IN WASTE MANAGEMENT OPERATIONS

The application of life-cycle assessments is not restricted to industrial processes. For example, LCA procedures have been used to evaluate waste management practices by municipalities, particularly in the area of solid waste management. Solid waste disposal is reaching the crisis level in some communities (see Chapter 3), due to lack of acceptable, approved landfill space and a general public opposition to incineration. One solution to this problem that has often been espoused is increased use of recycling of solid waste. Many communities, and some states, have set goals for the percentage of their

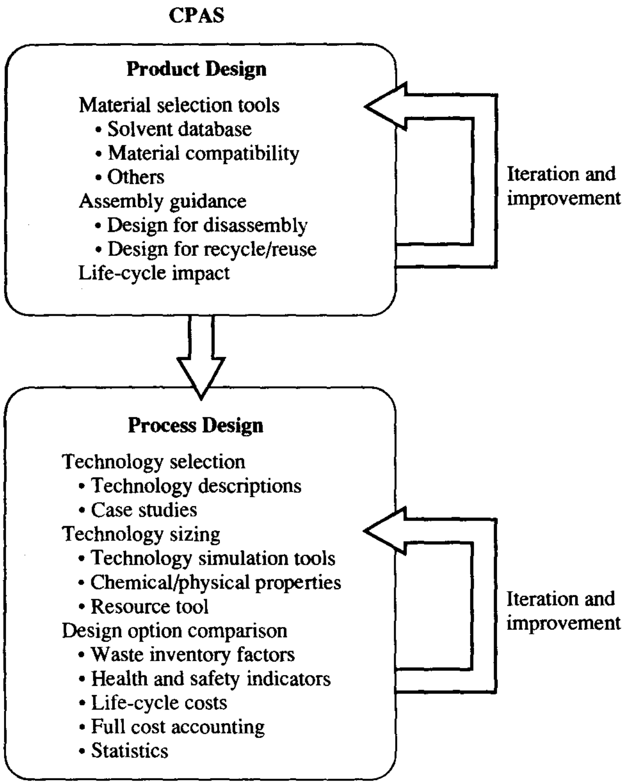

FIGURE 6.14
Overview of the Clean Process Advisory System.

solid waste that must be recycled. In many cases this action is driven by the desire to extend the use of existing landfill space; in other cases the impetus is a desire to conserve resources. In any event, the public perception usually is that recycling will also result in cost savings to the community through sale of the recovered materials. This mayor may not be true, depending largely on the high variability in the market prices for these commodities.

As an example, in 1996 the price of recovered cardboard was $130 per ton; in 1997 the price had dropped to $10 per ton. Old newsprint sold for $120 per ton in 1996, while the going price in 1997 was down to $10-$20 per ton. The same trends could be seen for plastic bottles, where the price went from 30 cents per pound to 3 cents per pound in one year. Many communities found that profitable, environmentally correct community recycling programs were losing great amounts of money. It was cheaper to send the separated materials to the landfill than to sell them to a recycler. Recycled materials are commodities subject to the same economic laws of supply and demand as other materials. When supplies are low, prices will be high; these high prices will result in more material being recycled. If too much material is recovered, glutting the market, prices will plunge and recycling will be reduced. Thus the recycling market is highly volatile and cyclical.

A major difficulty in trying to assess the desirability of a solid waste recycling program is determining the true costs, both economic and environmental, associated with recycling. Often a recycling program is considered independent of the community solid waste management program. From an economic standpoint, a community often requires that the recycling program be profitable on its own; that is, profits from sales of recyclables must at least match the cost of recovering the materials in order to break even. However, hidden costs are often overlooked. Removing materials from the waste stream represents an overall negative cost because the recovered material does not need to be landfilled or incinerated. That cost represents a disposal cost savings to the community of $30-$100 per ton of recovered material. If this cost saving is not allocated to the recycling program, it may appear that the recycling program is losing money, even though there is an overall significant cost saving.

The overall (life-cycle) environmental impacts ofrecycling must also be considered. Removing waste materials from landfills or incinerators and recycling them is generally believed to be beneficial to the environment, but from the life-cycle standpoint this is not always the case. Reclaiming used newsprint greatly reduces the amount of solid wastes going to a landfill. However, during reprocessing, the dyes and fillers found in the newsprint are leached from the paper fibers and sent to wastewater treatment plants, along with chlorine solutions used to bleach the fibers and the fme fibers that are not useful in recycled paper. Thus the solid waste problem has been reduced, but at the expense of increased water pollution. Some of these pollutants removed from the wastewater will be removed as sludge, which may wind up back in the landfill anyway. Another factor that is often overlooked is transportation of recovered materials to the reprocessor. Economic costs for this could be significant and could be the deciding factor in determining whether recycling is economically viable. The environmental impacts (air pollution, fossil fuel consumption) are normally not accounted for. Recycling of low-value renewable materials in one city may be environmentally preferable, but it may not be in a more remote city where there are greater transport impacts ("Life Cycle Analysis," 1995).

To properly assess whether using recycled or virgin materials in a process will result in the least environmental damage, it is essential that a complete LCA be conducted. Life-cycle assessment has begun to be used to evaluate a city or region's future waste management options. The LCA covers the environmental and resource impacts of alternative disposal processes, as well as those other processes that are affected by disposal strategies--different types of collection schemes for recyclables, changed transportation patterns, and so on. This is a very complex analysis, as can be seen in Figure 6.15, a simplified diagram showing some of the different routes that waste might take and some of the environmental impacts incurred along the way.

Life-cycle assessment of waste management operations can be conducted in an analogous way to that for product LCAs. They can consist of the same three components: inventory analysis, impact assessment, and improvement assessment. The only difference is that the functional unit used to define the system is an *input to the system*, rather than an *output from the system.* For solid waste management, this will typically be kilograms of solid waste handled. Waste management LCAs also differ from product LCAs in that waste management LCAs must consider a wider range of materials types (Kirkpatrick, 1996). This complicates the analysis, but the procedures used are the same.

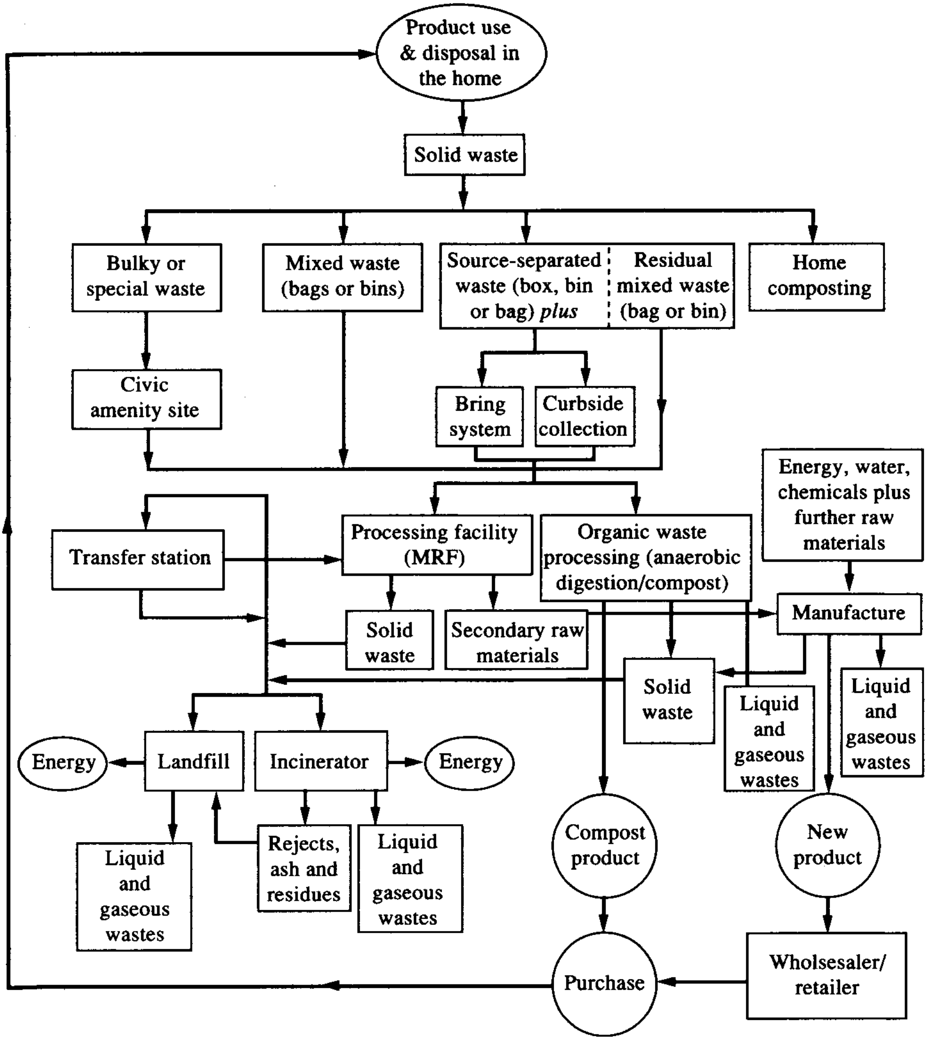

FIGURE 6.15
A simplified flow chart of alternative waste collection and disposal strategies showing the complexity of conducting an LCA. (Adapted from "Life Cycle Analysis," 1995)

The system boundary definition for a waste management LCA can also be complicated. Product LCAs usually consider the life cycle beginning with extraction of the resources from the earth, but where should the solid waste management LCA begin? Often this is defined to be at the point of solid waste pickup. Thus no materials production, manufacturing, transportation, or product use stages prior to disposal are included in the LCA. This means that these LCAs do not include any prior industrial waste minimization or recycling efforts by industry; these activities would be included in the product LCA. The end of the waste management LCA life cycle is typically accepted as occurring when all residues from the system are returned to land. Thus the LCA would include any recycling or energy recovery impacts from the waste management system itself. Once the system boundaries are set, the appropriate data can be gathered for the inventory analysis and impact assessment, analyzed, and used to perform an improvement assessment.

REFERENCES

Allen, D. "Applications of Life-Cycle Assessment." In *Environmental Life-Cycle Assessment,* ed. M. A. Curran. New York: McGraw-Hill, 1996, pp. 5.1-5.18.

Allen, D. T., and Rosselot, K. S. *Pol/ution Prevention for Chemical Processes.* New York: Wiley-Interscience, 1997.

Besnainou, J., and Coulon, R. "Life-Cycle Assessment: A System Analysis." In *Environmental Life-Cycle Assessment,* ed. M. A. Curran. New York: McGraw-Hill, 1996, pp. 12.1-12.28.

Bhat, V. *The Green Corporation: The Next Competitive Advantage.* Westport, CT: Quorum Books, 1996.

Boguski, T. K., Hunt, R. G., Cholakis, J. M., and Franklin, W. E. "LCA Methodology." In *Environmental Life-Cycle Assessment,* ed. M. A. Curran. New York: McGraw-Hill, 1996, pp. 2.1-2.37.

Breville, B., Gloria, T., O'Connell, M., and Saad, T. *Life Cycle Assessment, Trends, Methodologies and Current Implementation.* Department of Civil and Environmental Engineering, Tufts University, Medford, MA, 1994, pp. 145-55.

Brinckley, A., Kirby, J. R., Wadehra, I.L., Besnainou, J., Coulon, R., and Goybet, S. "Life Cycle Inventory of PVC: Disposal Options for a PVC Monitor Housing." In *Proceedings of the 1995 IEEE Tnternational Symposium on Electronics and the Environment.* Orlando, FL: IEEE, 1995, p. 145.

Cascio, J., Woodside, G., and Mitchell, P. *ISO 14000 Guide.* New York: McGraw-Hill, 1996.

Consoli, E, Allen, D., Boustead, I., Fava, J., Franklin, W., Jensen, A., de Oude, N., Parrish, R., Perriman, R., Postlethwaite, D., Quay, B., Seguin, J., and Vigon, B. *Guidelines for Life-Cycle Assessment: A "Code of Practice:'* Pensacola, FL: SETAC, 1993.

Curran, M. A. *Environmental Life-Cycle Assessment.* New York: McGraw-Hill, 1996a.

Curran, M. A. "The History of LCA." In *Environmental Life-Cycle Assessment,* ed. M. A. Curran. New York: McGraw-Hill, 1996b, 1.1-1.9.

Curran, M. A. "Using LCA-Based Approaches to Evaluate Pollution Prevention." *Environmental Progress* 14 (1995): 247-53.

Curran, M. A., and Young, S. "Report from the EPA Conference on Streamlining LCA." *Tnternational Journal on LCA* 1 (1996): 570.

Fava, J. A., and Consoli, F. J. "Application of Life-Cycle Assessment to Business Performance." In *Environmental Life-Cycle Assessment,* ed. M. A. Curran. New York: McGraw-Hill, 1996, pp. 11.1-11.12.

Fava, J. A., Consoli, E, Denison, R., Dickson, K., Mohin, T., and Vigon, B. *Guidelines for Life-Cycle Assessment: A "Code of Practice,"* Pensacola, FL: Society of Environmental Toxicology and Chemistry, Workshop Proceedings, N, 1993.

Fava, 1., Jensen, A., Lindfors, L., Pomper, S., De Smet, B., Warren, J., and Vigon, B, *Life-Cycle Assessment Data Quality: A Conceptual Approach.* Pensacola, FL: SETAC, 1994.

Foust, T. D., and Gish, D. D. "Future Perspective." In *Environmental Life-Cycle Assessment,* ed. M. A. Curran. New York: McGraw-Hill, 1996, pp. 18.1-18.16.

Franklin Associates, Ltd. *Resources and Environmental Profile Analysis of a Manufactured Apparel Product.* Report to the American Fiber Manufacturer's Association, Washington, DC, 1993.

Giegrich, J., and Schmitz, S. "Valuation as a Step in Impact Assessment: Methods and Case Study." In *Environmental Life-Cycle Assessment,* ed. M. A. Curran. New York: McGraw-Hill, 1996, pp. 13.1-13.14.

Graedel, T. E., and Allenby, B. R. *Industrial Ecology.* Englewood Cliffs, NJ: Prentice Hall, 1995.

Hoffman, W. F. "Recent Advances in Design for Environment at Motorola." *Journal of Tndustrial Ecology* 1 (1) (1997): 131--40.

Keoleian, G. "The Application of Life Cycle Assessment to Design." *Journal of Cleaner Production* 1 (1994): 143-49.

Keoleian, G. A. "Life-Cycle Design." In *Environmental Life-Cycle Assessment,* ed. M. A. Curran, New York: McGraw-Hill, 1996, pp. 6.1-6.34.

Kirkpatrick, N. "Application of Life-Cycle Assessment to Solid Waste Management Practices." In *Environmental Life-Cycle Assessment,* ed. M. A. Curran. New York: McGraw-Hill, 1996, pp. 15.1-15.14.

Kniel, G. E., Delmarco, K., and Petrie, J. G. "Life Cycle Assessment Applied to Process Design: Environmental and Economic Analysis and Optimization of a Nitric Acid Plant." *Environmental Progress* 15 (1996): 221-28.

Kroschwitz, 1., and Howe-Grant, M. *Kirk-Othmer Encyclopedia of Chemical Technology,* 4th ed. New York: Wiley-Interscience, 1991.

"Life Cycle Analysis and Assessment." *Warmer Bul/etin* 46 (1995): 1-4.

Marron, 1. "Product Labeling." In *Industrial Pol/ution Prevention Handbook,* ed. H. Freeman. New York: McGraw-Hill, 1995, pp. 313-28.

Meadows, D. H., Meadows, D. L., Randers, J., and Behrens, W. *The Limits to Growth: A Reportfor the Club of Rome's Project on the Predicament of Mankind.* New York: Universe Books, 1972.

Nash, J., and Stoughton, M. D. "Learning to Live with Life Cycle Assessment." *Environmental Science and Technology* 28 (1994): 236-37.

Office of Technology Assessment. *Green Products by Design: Choices for a Cleaner Environment.* (ITA-E-541. Washington, DC: U.S. Government Printing Office, 1992.

Petty, M. "Pollution Prevention in the Information Age." *Environmental Protection* 8 (1997): 34-36.

Postlethwaite, D., and de Oude, N. T. "European Perspective." In *Environmental Life-Cycle Assessment,* ed. M. A. Curran. New York: McGraw-Hill, 1996,9.1-9.13.

Rudd, D. E, Fathi-Afshar, S., Trevino, A. A., and Stadtherr, M. A. *Petrochemical Technology Assessment.* New York: Wiley, 1981.

SETAe. *Streamlining Environmental Life Cycle Assessment.* Preliminary draft report of the SETAC LCA Streamlining Group. Pensacola, FL: SETAC, 1997.

Shen, T. *T.Industrial Pol/ution Prevention.* Berlin: Springer-Verlag, 1995.

SustainAbility Ltd. *The LCA Sourcebook: A European Business Guide to Life-Cycle Assessment.* Prepared for the Society for the Promotion of LCA Development and Business in the Environment. London: SustainAbility Ltd., 1993.

Todd, J. A. "Streamlining." In *Environmental Life-Cycle Assessment,* ed. M. A. Curran. New York: McGraw-Hill, 1996, pp. 4.1-4.17.

Tolle, D. A., Vigon, B. W., Becker, J. R., and Salem, M. A. *Development of a Pol/ution Prevention Factors Methodology Based on Life-Cycle Assessment: Lithographic Printing Case Study.* EPN600/R-94/157. Cincinnati, OH: U.S. EPA, 1994.

U.S. Environmental Protection Agency. *Life-Cycle Assessment: Public Data Sources for the LCA Practitioner.* EPA/530/R-95/009, Washington, DC: U.S. EPA, 1995.

U.S. Environmental Protection Agency. *Streamlining Life-Cycle Assessment II: A Conference and Workshop.* Proceedings, Cincinnati, OH: U.S. EPA, 1997.

Van den Berg, N. W., Huppes, G., and Dutilh, e. E. "Beginning LCA: A Dutch Guide to Environmental Life-Cycle Assessment." In *Environmental Life-Cycle Assessment,* ed. M. A. Curran. New York: McGraw-Hill, 1996, pp. 17.1-17.41.

Vigon, B. "Life-Cycle Assessment." In *Industrial Pol/ution Prevention Handbook.* ed. H. Freeman. New York: McGraw-Hill, 1995,293-312.

Vigon, B. W. "Software Systems and Databases." In *Environmental Life-Cycle Assessment,* ed. M. A. Curran. New York: McGraw-Hill, 1996, pp. 3.1-3.25.

Vigon, B. W., Tolle, D. A., Cornaby, B. W., Latham, H. e., Harrison, e. L., Boguski, T. L., Hunt, R. G., and Sellers, J. D. *Life-Cycle Assessment: Inventory Guidelines and Principles.* EPA/600/R-92/245. Cincinnati, OH: U.S. EPA, 1993.

West, P. *Pol/ution Prevention Actions Reduce Waste Generation at TVA, Innovators with EPRI Technology.* EPRI Report RP3006, Palo Alto, CA, 1997.

Wood, M. E, King, J. A., and Cheremisinoff, N. P. *Pol/ution Prevention Software Systems Handbook.* Westwood, NJ: Noyes Publications, 1997.

PROBLEMS

6.1. Draw a flow chart depicting the full life cycle of a peanut butter and jelly sandwich. Be sure to include the feedstocks of the sandwich.

6.2. For the peanut butter and jelly sandwich described in Problem 6.1, conduct an inventory assessment for the sandwich manufacturing stage. Use the Life-Cycle Inventory Checklists reproduced in Figures 6.5 and 6.6 as the basis for your assessment.

6.3. Your local laundromat consumes large quantities of water and energy and transfers dirt from your clothes to the washwater going to the municipal sewer. What are the environmental issues involved with the use of laundromats and what are the stressors?

6.4. An industrial wastewater, flowing at 500 m^3/day, contains 20 mg/L chromium, 40 mg/L cadmium, and 5 mg/L mercury. The receiving water quality standards are, respectively, 50 JLg/L, 10 JLg/L, and 2 JLg/L. What is the critical dilution volume?

6.5. Evaluate Table 6.3 with respect to the manufacture of a peanut butter and jelly sandwich, as described in Problem 6.1. Fill in the boxes marked X with what you think the impact might be.

6.6. Consider the lithographic example described in the text and in Tables 6.4 and 6.5. The company decides that its most pressing issue is reduction of air pollutants. Which of the P2 activities would be the most beneficial, based on P2 factors?

6.7. Three computer monitor housing disposal options are described in Figure 6.11 and Table 6.6. Which option produces the least water effluents? The most water effluents?

6.8. Table 6.6 shows the life-cycle inventory for computer monitor housings. The recycling option presents the best inventory profile. Why isn't it used more often?

6.9. Visit a supermarket and find 10 items for which the manufacturer makes some environmental claims. List the products and their environmental claims, and evaluate whether they are useful to the consumer and whether they are factual or may be misleading.

6.10. Visit a local store and find items that display a Green Seal logo. What are these items? Where is the logo located and how large is it? Does it appear that having the logo makes the products sell better?

6.11. Solid waste recycling programs are generally considered to be environmentally friendly, but paper recycling by a community that incinerates its waste may not be advisable. Why?

6.12. A company is considering imposing its product design by use of LCA. The company produces liquid fabric conditioners. It is considering a variety of product reformulations and packaging alternatives, as listed in the accompanying table. The energy and waste burdens associated with each of these options are also shown. Evaluate the trade-offs and discuss the advantages and disadvantages of each option. Which option is most environmentally acceptable? Which option do you think would be the most acceptable to the public? Why? (Problem developed using data presented in Allen and Rosselot, 1997.)

Strategies for packaging improvement	Decrease in energy needs, %			Decrease in emissions, %		
	Process	Transport	Feedstock	Solid	Aqueous	Air
1. Incorporate 25% recycled paper	3	0	9	9	(+4)	4
2. Encourage 25% consumer recycling	3	2	11	11	(+4)	5
3. Triple concentrate (3X) product	55	53	56	55	54	55
4. Market product in soft pouch	3	18	67	85	(+ 12)	24
5. Market 3X product in soft pouch	68	73	89	95	63	75
6. Market 3X product in paper carton	53	58	94	91	40	62
7. Encourage 25% composting for strategy 6	53	58	94	92	40	62

CHAPTER 14

TOWARD A SUSTAINABLE SOCIETY

Mahatma Gandhi [when asked if, after independence, India would attain British standards of living]: "It took Britain half the resources of the planet to achieve its prosperity; how many planets will a country like India require?"

14.1 INTRODUCTION

As the municipalities of the world grow and develop, they contribute to the depletion of natural resources and addition of pollution to the air, water, and land. As if an enormous debt were suddenly falling due, the United States and the rest of the world are discovering that unfettered consumption of Earth's natural resources and nonrenewable energy sources in support of economic growth has polluted air, water, and land and is visibly damaging the environment. This damage is exacting the heavy price of global climate deterioration, loss of biodiversity, and dangerous accumulation of hazardous and solid waste.

In the book *Silent Spring*, written in 1965, Rachel Carson said:

For the first time in the history of the world, every human being is now subjected to contact with dangerous chemicals, from the moment of conception until death. In the less than

> two decades of their use, the synthetic pesticides have been so thoroughly distributed throughout the animate and inanimate world that they occur everywhere. Residues of these chemicals linger in soil to which they have been applied a dozen years before. They occur in the mother's milk, and probably in the tissues of the unborn child.

The book painted an accurate picture of environmental conditions at that time. More than three decades later, very little has changed. Indeed, in some places it is now worse. Carson said that nothing but reform can change this, but reforms must be radical in approach to change fundamental aspects of society. We have to change the way we do business to integrate the concept of sustainability of the planet. Only then can we say that business operations are environmentally friendly. But does this mean we cannot have economic growth or development? No, but we must find new ways of development to ensure that it doesn't degrade the environment. The conventional view of competition between economic growth and environmental quality must be changed through public policy, management, and investment practices. To maintain the critical balance between a healthy economy and a healthy environment, economic growth and environmental quality must be treated as complementary objectives. This balanced perspective is essential to "sustain" our communities.

Our understanding of the relationship between people and the landscape is complex and intricate, often blurred, and at times contradictory. Business as usual is no longer an option-for government, the private sector, or individual citizens. Our soils, waters, forests, and minerals are not inexhaustible. Farms, industries, homes, and lifestyles must become more sustainable, in every community on our planet.

Sustainable development is not a new concept. It is the latest expression of a longstanding ethic involving people's relationship with the environment and the current generation's responsibilities to future generations. For a community to be truly sustainable, it must adopt a three-pronged approach that considers economic, environmental, and cultural resources. Communities must consider these needs not only in the short term, but also in the long term. To be sustainable, development must improve economic efficiency, protect and restore ecological systems, and enhance the well-being of all peoples. Ours is a finite global system, and in some cases the limit has been reached beyond which no more resources can be taken out from the system, hence the need for conservation and sustainability.

There is growing evidence that many current global trends in the use of resources or sinks for wastes are not sustainable. This is not unique to the late twentieth century, but the magnitude of the problem has certainly increased during this period. Throughout the history of mankind, man has destroyed or damaged the natural resources. Now this destruction has reached a point where it is seriously affecting the future availability of natural resources and biodiversity in the global environment. Different regions may have different problems and focal points (e.g., one area may have problems with sustainability of renewable resources such as forests, whereas another area may be gripped with problems of waste, pollution, or the greenhouse effect). But all of these problems point to one main problem, and that is unsustainability.

We continually interact with the environment around us. This environment encompasses the entire natural world: air, land, oceans, plants, and animals. We have gained increasing control over the environment, leading to increases in our ability to alter the environment in which we live. But the capacity of the environment to absorb those alterations is limited. Invariably, the "carrying capacity" of every natural resource is either overstretched or exceeded. Carrying capacity for human beings can be defined as "the maximum rate of resource consumption and waste discharge that can be sustained indefinitely in a given region without progressively impairing the functional integrity and productivity of the relevant ecosystems" (Rees, 1992).

Environmental degradation is caused primarily by people who have the means or money to enjoy all the comforts of material life, such as automobiles and electronics, which contribute a great deal to pollution. Poor people, on the other hand, reuse most of the goods which wealthier people normally throwaway. They might overuse some natural resources, such as fresh water and wood or forests for fire, but the contribution per person to such problems as greenhouse gases and water pollution is often much less than those of their wealthier counterparts. Sustainability depends on people using as few resources as possible.

14.2 DEFINING THE PROBLEM

To sustain means to support without collapse. Sustenance is that which supports life. Currently, humans are unequally provided with sustenance, and many suffer actual deprivation. One way to address the problem is by increasing their economic activity, but unfortunately this is usually accompanied by environmental degradation. In addition, we know that the present economic activity level is already unsustainable.

14.2.1 Biodiversity

Probably the worst thing facing civilization is not energy depletion, economic collapse, limited nuclear war, or conquest by a totalitarian government. As terrible as these catastrophes would be for us, they can be repaired within a few generations. The one ongoing process that will take millions of years to correct is the loss of genetic and species diversity by the destruction of natural habitats. This is the folly for which our descendants are least likely to forgive us (Wilson, 1992). The world is losing about 150 species per day because of human activities such as deforestation, pollution, application of pesticides, and urbanization (Reid and Miller, 1989). Some will say that we have taken steps to prevent all this by creating national reserves and parks, placing limits on hunting, and other means, but despite our concentrated recent efforts to protect our natural resources and landscapes, results are not very encouraging. How then do we reconcile the unrelenting need to protect natural systems with the impulse to transform them into human systems? Perhaps we can achieve this through an inclusive view that nature and culture are, in fact, not merely "two sides of the same coin." Rather, we need to engage in nonlinear and cyclical modes of thinking about nature, culture, and landscape. This is a complex relationship, one which is best understood through clarification, rather than through simplification.

Biodiversity can be taken as an indicator of environmental health, as it is assumed to be essential for the resilience of ecosystems; only flexible systems can bounce back to steady state after being subjected to a shock. Almost everything humans do-such as agricultural practices, trade, and regional development-affects biodiversity, and every effort must be undertaken to preserve this diversity by making sure that no species are on the brink of extinction.

14.2.2 Impediments to Achieving Sustainability

It is clear that we cannot continue to consume resources as we have in the past. The main reasons for our inability to achieve sustainability are (Pearce, Markandya, and Barbier, 1989):

Resource scarcity. This is one of the most important reasons for society's lack of sustainability at present. We are using our natural resources indiscriminately and at a very rapid rate. If we continue to consume at such a rate and do not find new renewable resources, some resources will soon become scarce and our standard of living will deteriorate. Sustainability hurdles are discussed further later in this chapter.

Environmental problems. Overproduction and overconsumption in recent years are the fundamental causes of the accelerating destruction of the global ecosystems, which in turn is making society unsustainable. The 20 metric tons of waste which every American generates each year must initially come from the environment and will later be dumped back into it as pollution and waste. The greenhouse effect is another major environmental problem. Scientists agree that fuel use must be cut by at least 60 percent to achieve a sustainability goal. For a future population of 11 billion people, this means that the average per capita fuel use would have to be cut to 6 percent of the present industrialized nations' average. Continued growth and development is the top priority of all nations, and unfortunately even present levels of production and consumption are not sustainable.

Poverty and the Third World. There are enough resources to feed everyone on the planet, provided there is an equal and just distribution of the resources. But rich and developed nations control most of the world's resources, and even within Third World countries there is a wide gap between rich and poor. Recent economic development has usually resulted in indiscriminate growth, with a very small minority garnering profits and benefits. Unless all people have basic amenities and comforts, Third World countries and their people will remain apathetic toward the fate of the environment, a situation that will clearly prevent world sustainability.

Conflicts of interest between nations. If all nations continue the quest to raise production, consumption, and living standards there can be no reduction in conflicts of interest between nations and the concominant overuse of world resources.

Falling living standards. Despite the increase in real gross national product (GNP) of rich, developed nations, the quality of life has remained stagnant or has actually gone down in many countries. For example, the real GNP per capita in

Australia has tripled since World War II, but some surveys indicate that there has been a decline in the standard of living rather than improvement. Indexes of social breakdown (e.g., doubling of suicide rates, increased number of divorces) point to a significant reduction in quality of life. This might be due to a single-minded pursuit of affluence, growth, commercialization, and so on, which in turn brings destruction of the community and a production of social wreckage in the form of unemployment and poverty.

Inadequate economic systems. Neither socialist nor capitalist economies allow us to reduce production to the minimum levels sufficient to give all people comfortable living standards. If we were to cease production of unnecessary· goods and waste, there would be a jump in unemployment and bankruptcy. Present economic systems require an enormous amount of unnecessary production and waste. They are not suited for distributing goods according to need or for accomplishing critical policies.

Lack of technology. Despite large technological leaps during the last few decades, all major global problems continue to proliferate. Costs of acquiring resources escalate daily; in fact, they have been rising at almost 4 percent per year. The effects of the law of diminishing returns are already visible. Most people would like to provide the same living standards to people in Third World countries as we have in rich countries. However, to achieve this goal by 2060, world output has to increase by at least a factor of 10. Thus we must assume that within the next 60 years we must make the world sustainable, even though the present level of production and growth is unsustainable. Such a change cannot be acccomplished through technology alone; we will probably have to change our life-style and our attitudes to make this world sustainable.

Now, before we define sustainability more completely, let us go back in time and study how all this started and how the concept of sustainability became the buzzword of today.

14.3 THE HISTORY OF SUSTAINABILITY

One might be wondering, How could all this environmental damage have happened? In this section we discuss briefly some of the major factors that have contributed to our current situation. We also discuss some of the major international events that laid the foundation for the concept of sustainability.

The history of technological development and progress can be summarized as follows (Hatcher, 1996):

Environmental disconnection. As we moved from a hunter-gatherer to an agrarian society, our connection to environmental processes and ecological cycles gradually diminished. Hunter-gatherers generally used only what they needed and then moved on, allowing local species and the ecosystem to rebound from their harvest. But this changed as the first agriculturalists began to harvest and cultivate edible plants over other species, clearing land and planting areas with a single plant species. This disruption increased as agricultural technology improved, until almost continuous cultivation became the norm. Ecosystems no longer rebounded to replenish the soil. By disrupting the ecosystem, agrarian practices upset the ecosystem's robust nature and its ability to endure as a viable food-producing system, even in unfavorable conditions.

Social stratification. As agriculture developed, the social structure supporting it grew in parallel. As humanity proceeded from agriculture to industry, social stratification became increasingly intense and widespread. Stratification became international as industry sought cheap labor in the mostly agricultural countries of the Southern Hemisphere. All of this led to a class-based society where the powerful took ownership of the land, and the weak and poor became laborers to provide for their food and shelter (Sanderson, 1988).

Standard of living. As measured by health and the amount of time spent on food production, the standard of living for the overall population declined as a result of agricultural development. Increased agricultural intensity and production did not bring tangible benefits to the individual. However, the surplus did promote population growth, which in turn encouraged increased agricultural production. The same or more labor was needed to maintain increased demand for production, resulting in a poor standard of living for the laboring class, who now had to spend more time working on the land. On the other hand, the landowners spent much less time working, and their standard of living exceeded that of everyone else (Sanderson, 1988). Soon the Industrial Revolution, medical advances, safe drinking water, and sanitary disposal of wastes increased the average life span, but low-paying jobs in industry kept the average standard of living down. The gulf between the rich and the poor kept widening.

Population and technology growth. Technological development and population growth became locked into an upward spiral, each supporting the other. The spiraling growth continued, with the industrial revolution accelerating the problem in the mid-eighteenth century. New and more powerful machines made life easier, resulting in a population explosion, which in turn created more demand. The increase in demand for goods led to increased extraction of natural resources at the expense of the environment.

Momentum, lag, and uncertainty. The solution to environmental and ecological problems is exacerbated by our limited perception and understanding. Environmental effects build up slowly, gaining momentum as they build. The problem goes unnoticed at first, and by the time it is identified and detected, the problem is often so bad that even an immediate response cannot solve it. Even when we are able to measure the problem, our techniques and predictive models are inadequate or too inexact to give the degree of certainty we expect in order to make sound decisions. Good examples of this are damage to the ozone layer and global warming.

These and many other reasons have led us to our present state. If we don't take steps to alleviate this grave environmental situation, we are likely to see increased problems in the future.

14.3.1 Origin of the Sustainability Concept

The International Development Strategy of the First United Nations Development Decade of the 1960s was based on the belief that the fruits of accelerated economic growth would trickle down to the low-income population strata. This trickle-down effect did not occur and social justice became one of objectives of the Second Development Decade in the hope that it would lead to equitable distribution of the results of economic growth. The Third Development Decade of the 1980s realized that there were inequities and imbalances in international relations. The strategy, therefore, included the goal of establishing a "New International Economic Order." Unfortunately, this also failed. The latest attempts at an International Development Strategy for the 1990s (i.e., in the Fourth United Nations Development Decade) again calls for the acceleration of economic growth (U.N. General Assembly, resolution 45/199). According to the U.N. resolution, the 1980s were characterized as a decade of falling growth rates, declining living standards, and deepening poverty, with a widening gap between rich and poor countries. Although the Fourth United Nations Development Decade calls for fast economic development, it also stresses the need to simultaneously eradicate poverty and hunger, and develop and protect the environment. It led to the United Nations Conference of Environment and Development (UNCED), which was held in Rio de Janeiro, Brazil, on June 3-14, 1992.

The Rio conference was a watershed in the worldwide development of the concept of sustainable development. The outcomes of Rio were:

- The Rio Declaration on Environment and Development.
- The Convention of Climate Change.
- Convention on Biological Diversity.
- Conservation and Sustainable Development of All Types of Forests (Forests Principles Program) and *Agenda 21.*

Initiatives by international organizations which have contributed to the concept of sustainable development were synthesized in the Brundtland Report (Reid, 1993), which is summarized in Table 14.1.

14.3.2 United Nations Conference on Environment and Development

On June 3, 1992, the United Nations Conference on Environment and Development (UNCED) began in Rio de Janeiro, Brazil. It brought together diplomats, politicians,

TABLE 14.1
Summary of activities leading to our current understanding of sustainability

1972	*The Stockholm Conference.*	The agenda of the United Nations Conference held in Stockholm was the human environment, and it expressed concern with the global spread of environmental damage. This led to the establishment of Environmental Protection Agencies in a number of countries. The remedial steps taken were aimed at controlling the extent of environmental damage by setting limits or by requiring restoration of environmental quality. However, such an approach neither took a holistic approach to the environment nor integrated the environment and development.
1980	*The World Conservation Strategy.*	The International Union of Nature and Natural Resources (lUCN) published its World Conservation Strategy (WCS). The strategy defined development as "the modification of the biosphere and the application of human, financial, living and non-living resources to satisfy human needs and improve the quality of human life." The WCS said that conservation is a process which must be applied "cross-sectorally," and not be seen as a separate "activity sector in its own right," if the fullest sustainable benefits are to be derived from the resource base. The WCS also calls for anticipatory environmental policies and national accounting systems which will include nonmonetary indicators of success in conservation.
1980	*A Programme for Survival.*	The independent Commission on International Development Issues published a report, *A Programme for Survival,* calling for a reassessment of the notion of development as well as a new economic relationship between the richer North and the poorer South.
1982	*The United Nations World Charter for Nature.*	The United Nations published its *World Charter for Nature,* which adopted the principle that every form of life is unique and should be respected, regardless of its value to humankind. It also called for respect for our dependence on natural resources and control of exploitation of them: "Ecosystems and organisms shall be managed to achieve and maintain optimal sustainable productivity."
1986	*The IUCN Ottawa Conference on Environment and Development.*	The mCN followed up the World Conservation Strategy with the Ottawa Conference on Conservation and Development. Sustainable development, the "emerging paradigm," is derived from two closely related paradigms of conservation: that nature should be conserved, which is "reaction against the *laissez-faire* economic theory that considered living resources as free goods, external to the development process, essentially infinite and inexhaustible"; and a second, derived from the moral injunction to act as steward, and responding to warnings expressed in publications such as *Silent Spring* and *Limits to Growth.*

and experts on environment and development from 172 of the 178 member states of the United Nations. The Rio Conference was not only a conference of governments. More than 1100 nongovernmental organizations (NGOs) were officially accredited to the conference and some 200 of them substantially influenced the documents which resulted from Rio. Moreover, in parallel with this conference, an environmental forum was held with 3738 NGOs from 153 countries participating. In general, the NGOs were able to reach more conclusive agreements than the diplomats at UNCED. The outcome of the forum was indicative of the trends that countries will have to follow in the future. During the last two days of the conference, the Earth Summit was organized.

The Rio conference was the third main conference on the environment organized by the United Nations. The first, the Conference on the Human Environment, was held in 1972 in Stockholm, Sweden. The dominant idea was that environmental problems are essentially by-products of intense industrialization and use of technology by the society, and a scientific-technical approach would therefore be able to solve them. The second conference was held in 1982 in Nairobi, Kenya. It was marked by a growing awareness that environmental problems in fact have a much wider reach than their technical-scientific scope. Socioeconomic factors were already seen as essential co-determinants of environmental issues. All of this led to the publication of the report of the World Commission of Environment and Development in 1987. This commission, which was chaired by Norwegian Prime Minister Gro Harlem Brundtland, focused on sustainability as the main benchmark of environmental policy. Sustainability was defined as

> the rearrangement of technological, scientific, environmental, economic, and social resources in such a way that the resulting heterogenous system can be maintained in a state of temporal and spatial equilibrium.

Thus the Brundtland Report represented both a deepening and an elaboration of the ideas discussed in Nairobi in 1982.

We next discuss in detail some of the main documents that came out of the Rio Conference.

EARTH SUMMIT AND AGENDA 21. Agenda 21 (U.N., 1992a; UNCED, 1992) is a plan of action for the world's governments and citizens. It sets forth strategies and measures aimed at halting and reversing the effects of environmental degradation and promoting environmentally sound and sustainable development throughout the world. The agenda comprises some 40 chapters and totals more than 800 pages. UNCED has grouped Agenda 21's priority activities under seven social themes:

1. The Prospering World (revitalizing growth with sustainability).
2. The Just World (sustainable living).
3. The Habitable World (human settlement).
4. The Fertile World (efficient resource use).

5. The Shared World (global and regional resources).
6. The Clean World (managing chemicals and waste).
7. The Peoples' World (public participation and responsibility).

RIO DECLARATION ON EARTH AND ENVIRONMENT. At the Earth Summit in Rio de Janeiro in 1992, over 118 countries took up the battle cry for sustainability, calling for local government changes that would tie economic growth to environmental protection. A set of principles was adopted to guide future development. These principles define people's rights to development and their responsibilities to safeguard the common global environment. To a large extent, they build on ideas from the Stockholm Declaration at the 1972 United Nations Conference on the Human Environment.

The Rio Declaration states that the only way to achieve long-term economic progress is to link it with environmental protection. This will happen only if nations establish a new and equitable global partnership involving governments, their people, and key sectors of societies. They must build international agreements that protect the integrity of the global environment and the development system.

The Rio Declaration consists of a preamble and 27 articles, reflecting the general principles of Agenda 21, the conventions, and a deforestation statement. The principles included in the Rio Declaration are presented in Table 14.2.

It was at Rio that the concept of sustainable development as integrating concerns for economic, ecological, and human well-being was propelled into the arena of global decision making, after the Brundtland Commission had brought the issues to world attention five years earlier. The means of achieving sustainable development was further emphasized at the World Summit for Social Development at Copenhagen in March 1995. This summit acknowledged that people are at the center of our concerns for sustainable development and that they are entitled to a healthy and productive life in harmony with the environment. It was concluded that social and economic development cannot be secured in a sustainable way without the full participation of women, and that equality and equity between women and men is a priority for the international community and as such must be at the center of economic and social development. The Copenhagen Declaration on Social Development stated that economic development, social development, and environmental protection are interdependent and mutually reinforcing components of sustainable development, and that democracy is an indispensable foundation for the realization of social and people-centered sustainable development. Sustainable social development is an integrated process of building human capacity to fight poverty, create productive employment, and promote social integration.

14.4 SUSTAINABILITY AND WHAT IT MEANS

Definitions of sustainability have been based on both weak and strong concepts (Pearce, Markandya, and Barbier, 1989); they are most easily distinguished from one

TABLE 14.2
Principles of the Rio Declaration

People are entitled to a healthy and productive life in hannony with nature.
Development today must not undermine the development and environment needs of present and future generations.
Nations have the sovereign right to exploit their own resources, but without causing environmental damage beyond their borders.
Nations shall develop international laws to provide compensation for damage that activities under their control cause to areas beyond their borders.
Nations shall use the precautionary approach to protect the environment. Where there are threats of serious or irreversible damage, scientific uncertainty will not be used to postpone cost-effective measures to prevent environmental degradation.
To achieve sustainable development, environmental protection shall constitute an integral part of the development process, and cannot be considered in isolation from it.
Eradicating poverty and reducing disparities in living standards in different parts of the world are essential to achieve sustainable development and meet the needs of the majority of people.
Nations shall cooperate to conserve, protect, and restore the health and integrity of Earth's ecosystem. The developed countries acknowledge the responsibility that they bear in the international pursuit of sustainable development in view of the pressures their societies place on the global environment and of the technologies and financial resources they command.
Nations should reduce and eliminate unsustainable patterns of production and consumption and promote appropriate demographic policies.
Environmental issues are best handled with the participation of all concerned citizens. Nations shall facilitate and encourage public awareness and participation by making environmental information widely available.
Nations shall enact effective environmental laws and develop national law regarding liability for the victims of pollution and other environmental impacts of proposed activities that are likely to have a significant adverse impact.
Nations should cooperate to promote an open international economic system that will lead to economic growth and sustainable development in all countries. Environmental policies should not be used as an unjustifiable means of restricting international trade.
The polluter should, in principle, bear the cost of pollution.
Nations shall warn one another of natural disasters or activities that may have hannful transboundary impacts.
Sustainable development requires better scientific understanding of the shared global problems. Nations should exchange knowledge and innovative technologies to achieve the goal of sustainability.
The full participation of women is essential to achieve sustainable development. The creativity, ideals, and courage of youth and the knowledge of indigenous peoples are needed, too. Nations should recognize and support the identity, culture, and interests of indigenous peoples.
Warfare is inherently destructive of sustainable development, and nations shall respect international laws protecting the environment in times of anned conflict and shall cooperate in their further establishment.
Peace, development, and environmental protection are interdependent and indivisible.

another with reference to often unstated assumptions about how technology and human ingenuity can be assumed to substitute for natural resources and ecological services. Strong definitions of sustainability assume that the possibility for such substitution is limited enough, or at least uncertain enough, to make continued industrial growth ecologically precarious. Weak definitions tend to assume that efficiency in use of resources, reflecting the substitution of ingenuity for resources inputs, will continue to increase as in the past (Cairncross, 1993; Daly and Cobb, 1989). Historical patterns of technological change tend to support the second point of view (Ayres, 1989a), one that has been referred to as "techno-optimism." A weak and explicitly economic definition of sustainability would be organized around an industry's or a region's ability to continue providing income, either through employment or indirectly through the multiplier effects of local spending of that income. Stronger definitions of sustainability are less likely to consider the imperatives that sustainability and competitiveness be compatible or reconcilable. This is at least partly because strong definitions of sustainability tend to assume limits on carrying capacity, which in turn imply constraints on continued increases in economic output in the rich countries.

14.4.1 **Definitionsof** Sustain ability

Many definitions of sustainability have been proposed. Following is a sampling of a few of them.

> The word sustainable has roots in the Latin "subtenir," meaning "to hold up" or "to support from below." A community must be supported from below-by its inhabitants, present and future. Certain places, through the peculiar combination of physical, cultural, and, perhaps, spiritual characteristics, inspire people to care for their community. These are the places where sustainability has the best chance of taking hold. (Muscoe Martin, 1995)

> Sustainability refers to the ability of a society, ecosystem, or any such ongoing system to continue functioning into the indefinite future without being forced into decline through exhaustion... of key resources. (Robert Gilman, president of Context Institute)

> Sustainability is the [emerging] doctrine that economic growth and development must take place, and be maintained over time, within the limits set by ecology in the broadest sense-by the interrelations of human beings and their works, the biosphere and the physical and chemical laws that govern it ... It follows that environmental protection and economic development are complementary rather than antagonistic processes. (William D. Ruckelshaus, former U.S. EPA administrator, 1989)

> Sustainable development meets the needs of the present without compromising the ability of future generations to meet their own needs. (Gro Harlem Brundtland, former prime minister of Norway, 1987)

> Then I say the earth belongs to each ... generation during its course, fully and in its own right, no generation can contract debts greater than may be paid during the course of its own existence. (Thomas Jefferson, September 6, 1789)

Another way of describing sustainability can be seen in Figure 14.1.

Sustainability is:

Safe
Universally accepted
Stable
Technology that benefits all
Antipollution
Improvement in quality of life
Nontoxic
Awareness
Beautiful
Indi,enous knowledge
Least-cost production
Income
Total quality
Youth

FIGURE 14.1 Factors influencing sustainability. (Source: Olaitan Ojuroye, Nigeria)

Sustainable development most commonly refers to ecological sustainability, but terms like social, economic, community, and cultural sustainability have slowly come into use. All of these should be combined when we talk about sustainable development. In this book, sustainable development and sustainability are used interchangeably.

14.4.2 What Is Sustainable Development?

Sustainability is basically made up of three closely connected precepts:

- The environment is an integral part of the economy; it is not a free resource.
- Equity between the developing and developed world is essential. The developing world gives more importance to the pace of development and wants to reach a high standard of living as soon as possible. This poverty issue must be addressed, and there has to some equity between these worlds.
- Every entity (from countries to individuals) should have long-term futuristic goals in mind and should not operate on the basis of short-term benefit. Longer planning horizons are needed, and policies need to be proactive rather than reactive.

In terms of the Brundtland Commission definition, sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. This definition contains within it two key concepts:

- The concept of needs, particularly the essential needs of the world's poor, to which overriding priority should be given.
- The concept of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs.

To better understand the concept of sustainable development, the term can be broken down into its individual components:

Sustain: Maintain; supply with necessities or nourishment; support.

Develop: Expand or realize the potentialities of growth; bring gradually to a fuller, greater state.

Thus the goals of economic and social development must be defined in terms of sustainability in all countries--developed or developing, market-oriented or centrally planned. Interpretations will vary, but they must share certain general features and must flow from a consensus on the basic concept of sustainable development and on a broad strategic framework for achieving it.

For the business enterprise, sustainable development means adopting business strategies and activities that meet the needs of the enterprise and its stakeholders today while protecting, sustaining, and enhancing the human and natural resources that will be needed in the future. The sustainable business has interdependent economic, environmental, and social objectives; its management understands that long-term viability depends on integrating all three objectives in decision making. Rather than regarding social and environmental objectives as costs, a sustainable enterprise seeks opportunities for profit in achieving these goals.

14.4.3 Conceptualization of Sustainability

ECONOMIC CONCEPT. Sustainability can be best conceptualized economically by the Hartwick's "cake-eating model" (Common, 1995). The origin of this appellation is the analogy with the problem of dividing up a cake between a large number of would-be cake eaters. Suppose that the only natural resource available is a finite stock of a nonrenewable resource, and recycling is impossible. Next suppose that humans directly live off this resource, which is essential to life. Also, for the sake of simplicity, suppose that the human population size is constant across generations. The question then is, What is the largest constant rate of per capita consumption that can be maintained indefinitely? What is the maximum sustainable rate of consumption? The answer, of course, is clearly zero. There is no positive use rate for a finite nonrenewable resource stock that can be maintained indefinitely. In a cake-eating world, sustainability is impossible.

ECOLOGICAL CONCEPTS. Before we look further into an economic conceptualization of sustainability, it is necessary to define some important terms. *Stability* refers to a propensity for return to an equilibrium level following a disturbance. According to Conway (1985), stability is the degree to which productivity is constant in the face of a small disturbance caused by the normal fluctuations of climate and other environmental variables. *Resilience* is a property of an ecosystem, rather than of a population within an ecosystem. It is the ability of a system to maintain its structure and patterns of behavior in the face of a disturbance. Note that resilience means the system remains unchanged. An *ecosystem* is an interconnected biotic assembly of plants, animals, and microbes, together with its abiotic physiochemical environment. A system is sustainable in the ecological sense if it is resilient. Complex ecosystems aren't necessarily more stable, and a low stability system can demonstrate high resilience. Basically, the concept of resilience is what characterizes an ecological approach to sustainability.

Sustainability, according to Conway (1985), is the ability of the system to maintain productivity in spite of a major disturbance. Clearly, this concept of sustainability is a resilience concept.

The transition to a sustainable society requires a careful balance between long- and short-term goals and an emphasis on efficiency, equity, and quality of life, rather than on quantity of output. It requires more than productivity and more than technology. It also requires maturity, compassion, and wisdom (Meadows, Meadows, and Randers, 1992).

Key characteristics of sustainability are as follows:

- Sustainability is a normative, ethical principle. It has both necessary and desirable characteristics. Because opinions may differ over what is desirable, there is no single version of a sustainable society.
- Both environmental-ecological and sociopolitical sustainability are required for a sustainable society.
- No one can or wants to guarantee the persistence of any particular system. We want to preserve the capacity for the system to change. Thus sustainability is never achieved once and for all, but is only approached. It is a process, not a state. It will often be easier to identify unsustainability than sustainability.

Common components of a sustainable society are listed in Table 14.3.

In the United States, an environmental impact statement (EIS) is commonly required by the U.S. EPA for many construction projects or other initiatives in order to evaluate the impacts of the project on the environment before approval for the project is granted. The project may be rejected if significant negative impacts are predicted. Thus an EIS can be thought of as a device that could be used to ensure that a project meets the objectives of sustainability. However, an EIS usually is site-specific, takes into account only negative impacts of particular projects on a case-by-base basis, and does not consider alternative options. The EIS may not provide a clear picture of the

TABLE 14.3
Common components of a sustainable society

What sustainability is	What sustainability is not
Integrated decision-making process	Justification for business as usual
Research and information	Growth at all costs
Democratic values	Heavier command and control systems
Community participation	All things to all people
Collaboration	Static or declining economy
Equity, justice, and shared progress	Quick fixes and ad hoc solutions
Obligations to future generations	
Leadership in all sectors far beyond compliance	
Long-term solutions	

long-term impacts on the environment or on our natural resources. Sustainability, however, must also relate to equity between and within generations, biodiversity, and population issues. Trying to improve the basic efficiency of the EIS process should not be confused with the broader objective of integrating considerations of environmental impact with the basic principles of sustainability. The EIS process can't adequately assess the cumulative intergenerational effects of individual projects. More detailed and more complex evaluation processes are needed.

14.4.4 Hurdles to Sustainability

Essentially all sustainability efforts so far have failed because they lacked a sense of urgency and commitment or because sustainability is not commonly thought of as a long-term philosophy. Along with these difficulties are several other hurdles that a sustainability movement must face. Some of these are described here (Welford, 1995):

Level of consumption. Mass consumption is not possible indefinitely, and if we continue to consume the resources indiscriminately, there will be nothing left for the future. The way of life in the developed countries is often extremely expensive in terms of per capita resource and energy consumption. Every year each American consumes, on average, 20 metric tons of new materials, including energy equal to 12 tons of coal. If all people likely to be living on Earth during the latter part of the twenty-first century were to consume energy at such a rate, the world energy production would have to be 14 times its present level, and all potentially recoverable (as distinct from currently known) energy resources (excluding breeder and fusion reactors) would be exhausted in about 14 years (Trainer, 1985). Just to provide the present world population with the affluent world's diet would require eight times the present world cropland (which is likely to decrease in the future due to increased population and housing demands), or more than the world's entire land area (Rees, 1992).

Apathy. Wealthy people are often apathetic to the need for conserving, and affluent living styles commonly lead to mass consumption, as stated above.

Developing nations. Third World people aspire to higher standards of living and often disregard the importance of conserving the environment. Only one-fifth of the world's population now lives affluently. Half the world's population averages a per capita income one-sixtieth of that found in the rich countries, and more than 1 billion people live in desperate poverty. Deprivation takes the lives of more than 40,000 Third World children every day. There is much development going on in Third World countries, but the development is often of little benefit to the inhabitants. Throughout the 1980s, living conditions for many, if not most, of the Third World people deteriorated (Kakwani, 1988). Much of the time, the production capacity is being used for the benefit of rich countries, and as a result, the environmental status of the developing countries keeps on deteriorating because they have more urgent needs than environmental improvement. According to Trainer (1995), "The rich must live more simply so that the poor may simply live."

Lack of public awareness. Everyday choices people make have a bearing on the environment, and small steps will go a long way toward helping and saving the environment. The public needs to be provided with suitable information and needs to be made aware of the importance of achieving a sustainable world.

Lack of knowledge. Developed countries do not fully know how to achieve sustainability, and even less is known in the developing countries. More research is needed to overcome this deficiency.

Magnitude and number of uncertainties. There are so many uncertainties associated with the concept of sustainability that it is difficult to estimate and forecast "what if' scenarios. Human behavior is unpredictable, as are people's reactions under new, and possibly more stressful, conditions. These, coupled with inaccuracies of data and uncertainties and assumptions associated with predictive models, make the job all the more difficult.

14.5 ACHIEVING SUSTAINABLE DEVELOPMENT

Some of the critical objectives for improving the environment and for instituting better development policies result from the concept of sustainable development. These objectives include (ECWD, 1987):

- Reviving growth.
- Changing the quality of growth.
- Meeting essential needs for jobs, food, energy, water, and sanitation.
- Conserving and enhancing the resource base.
- Reorienting technology and managing risk.
- Merging environment and economics in decision making.

To achieve sustainable development, we must consider sustainable development in all its dimensions-ecological, social, economic, and political. Policies on wilderness preservation or pollution prevention instituted in isolation are not enough to achieve sustainable development. We need to consider poverty concerns, gender issues, institutional organization, and decision making under one umbrella and address them in unison in an integrated way (Dale and Robinson, 1996). A strategy or framework is required to guide us to the path of sustainability.

14.5.1 Sustainable Development Framework

The incorporation of environmental concerns in development planning and policy formulation requires the introduction of space as an explicit dimension of an integrative framework (Bartlemus, 1994). This spatial effect is introduced by the fundamental concept of ecosystems. Ecosystems represent the area of interaction of a biotic community with its nonliving environment (Odum, 1971).

The sustainable development framework shown in Table 14.4 introduces four strategic functions: assessment, research and analysis, planning and policies, and support. These four functions are then analyzed in terms of (1) sustainable economic growth and (2) development at the local, national, and international levels. Table 14.4

TABLE 14.4
A framework for sustainable growth and development

Strategic function	Development paradigm					
	Local Development		National Development		International Development	
	Regionally sustainable economic growth	Ecodevelopment	Sustainable economic growth	Sustainable development	Development of a supportive economic environment	Global sustainable development
Assessment	Integrated regional (monetary) accounting	Environment statistics	Integrated environmental economic accounting	Environment statistics	International (comparative) environmental accounting	International (integrated) databases, statistical compendia, and reporting
		Regional (physical) resource accounting Statistical ecology		Natural (physical) resource accounting National development reports		
Research and analysis	Modeling spatial disparities in income and growth	Modeling ecodevelopment	Integrated micro-, meso- and macroeconomic analysis and modeling	Models of integrated (physical) planning and development	International and global economic/environmental analysis and integrated modeling	International (physical) modeling of global environmental concerns and their socioeconomic implications
		Modeling carrying capacity Development of ecotechniques				
Planning and politics	Regional planning and policies of sustainable economic growth	Ecodevelopment planning and administration (decentralized planning and strategies)	Reorientation of macroeconomic policies toward sustainability	Integrated (physical) planning and project formulation	International strategies of sustainable economic growth	International standards for sustainable development
			Policies of structural change	Demographic policies on population, resources, environment, and development		International strategies and conventions (e.g., Agenda 21)

(continued)

TABLE 14.4 (*cont.*)
A framework for sustainable growth and development

	Development paradigm					
	Local Development		National Development		International Development	
Strategic function	Regionally sustainable economic growth	Ecodevelopment	Sustainable economic growth	Sustainable development	Development of a supportive economic environment	Global sustainable development
Planning and politics (*cont.*)			Economic (dis)incentives for microeconomic planning and management	Programs of human needs satisfaction		
Support	Extension service		Public awareness building and participation		Promotion of sustainable growth and development at international and global levels	
	Technical assistance (for local-level projects)		Programs and projects of education, training, and public information		Multilateral support for international (global) sustainable development	
	Public awareness building and participation (support to grassroots movements/organizations)		Institution building and environmental law/regulations		International institution building (e.g., UNCSD)	
			Technical cooperation, including transfer (import) of environmentally sound technology and capacity building			

Source: Bartlemus, 1994.

provides infonnation about particular strategy functions for all regional levels or, if read vertically, on comprehensive approaches to sustainable growth or development at national, subnational, and intemationallevels.

Sadler and Fenge (1993) described seven basic principles that must be considered when establishing a strategy for sustainable development. They are listed in Table 14.5.

This approach to creating a sustainable development strategy at the national level has been applied. Table 14.6 outlines the core elements of a Canadian national sustainable development strategy (Sadler and Fenge, 1993).

Once a sustainability framework is in place and strategies to achieve the goals of sustainability are fonnulated, it then becomes necessary to develop ways to implement these strategies.

TABLE 14.5
Seven principles of sustainable development strategy making

When developing a strategy for sustainable development, one should consider the following seven principles:

Integrative approach. Strategy should be integrative, forward-looking, cross-sectoral processes for linking and balancing environmental, social, and economic policy objectives.

Focus on issues. Strategy should directly address the major structural issues and constraints on achieving an economically viable, socially desirable, and ecologically maintainable future. This involves addressing current problems within a longer term policy horizon.

Goal orientation. Strategy should be based on clearly defined objectives and priorities with measurable targets and time frames for meeting them. A long-term vision of a sustainable society is a useful starting point, because it can be framed in terms of broad, shared values and hopes for the future.

Compatibility with policy processes. Strategies must be adjusted to the policy cycle and institutional culture and must initiate change in the direction and process of decision making.

Consensus building. Strategies should invite wide public involvement and consultation. To establish strategies regarding societal values and ethics, ensuring that they incorporate the visions and aspirations of citizens and facilitate life-style and behaviorial changes, is indispensable.

Action orientation. Strategies should lead to immediate, practical steps that lay the ground for a longer term, systemic transition in patterns of production and consumption.

Capacity enhancement. Strategies should be capacity-building processes that strengthen institutions, sharpen concepts and tools of sustainability, improve skills and competencies, and promote public awareness.

Source: Sadler and Fenge, 1993.

TABLE 14.6
Components of a Canadian national sustainable development strategy

- Introduction
  - The rationale and benefits of an NSDS
- State of the nation
  - Assessment of global trends, national issues, regional prospects
  - Canada in a global context
- Vision for tomorrow
  - Values and ethics of a sustainable society
  - Images and aspirations for the future
- Goals, objectives, and targets
  - Overall goal
    - To improve quality of life consistent with obligations to future generations

(continued)

TABLE 14.6 *(cont.)*

Components of a Canadian national sustainable development strategy

- Goals, objectives, and targets *(cont.)*
  - Objectives
    - To improve social welfare and individual well-being
    - To provide an equitable distribution of opportunities
    - To maintain natural capital at or above current levels
  - Targets for meeting economic, social, and environmental objectives
    - To adopt minimum standards to guarantee environmental sustainability
    - To pay down the environmental deficit through rehabilitation measures
- Guiding principles
  - To integrate decision making
  - To hamess markets
  - To share responsibility
  - To build consensus
  - To increase public awareness
  - To enforce accountability of decision makers
  - To ensure open decision making
  - To empower people
- Cross-cutting elements
  - Institutional reform
    - Harmonize environmental regulations
  - Greening the economy
    - Clean industry strategies
  - Resource and environmental stewardship
    - Biodiversity strategy
  - Healthy communities
    - Urban renewal; promotion of rural and traditional livelihoods
  - Individual action and initiative
    - Environmental citizenship
  - Population and immigration
    - Replacement and growth options
  - Scientific and technical innovation
    - Raw material substitution
  - Global commitments
    - Response to convention on climate change
- Sectoral plans and initiatives
  - Direction and dimensions for achieving sustainability in major policy and economic sectors
  - Detailed plans to be drawn up by each industry sector
    - Energy, transportation, agricultural, forestry, fisheries, tourism, chemicals, etc.
- Regional dimensions
  - Links to provincial and local sustainability strategies
  - Responses to regional issues and concems
  - The North and the national interest
- Indigenous peoples
  - Use of traditional knowledge and life-styles
  - Land and resource use
  - Community and economic development
- Means of implementation
  - Communication and outreach
  - Policy dialogue on cross-cutting sectoral issues
  - Monitoring progress on implementing the strategy
  - Supporting measures
    - Research agenda, information tools and technologies
  - Policy tools and instruments

Source: Adapted from Sadler and Fenge, 1993.

14.5.2 Application of Sustainability Strategies

The concepts of sustainability can be applied universally. We now briefly examine how they can be applied to various aspects of our environment, including land, water, air, housing, and energy.

LAND. Land is a major resource for agriculture, environment, society, and so on. Over time, land has been primarily used for grain and food production, but during the past few decades increased pressure has been applied to land for recreational uses and urban hous:~ Expansion of land use for agriculture, recreation, and housing resulted in a loss of wildlife habitat, ecological imbalance, and changes in watershed patterns. All of these land uses have resulted in soil degradation and a loss or removal of the top layer of soil, with a concomitant loss of soil fertility and reduction in grain production. Organic matter in soil, which is important for soil fertility, is also affected by different land uses, including cultivation. Diverting some of the land back for wildlife habitats can complement. the sustainability of agriculture.

WATER. Water is the most important resource for human survival, and much of the world is gripped by a short supply of usable water, be it potable water or water for agricultural or industrial use. Even though Earth is almost 80 percent water, usable water is only a small fraction of the total supply; hence the need for sustainability. Precious water resources are contaminated through seepage from agricultural lands, landfills, and indiscriminate pumping of groundwater. Greater scrutiny of water use and pollution is required.

AIR. Like water, air has been polluted by the activities of society. Indeed, the probability of air becoming polluted is great, because misuse of free goods is more likely than that of expensive resources. If, somehow, a charge could be applied on the use of this free resource, we would come closer to solving the problem. The atmosphere now has a relatively large concentration of greenhouse gases, which are causing global warming, resulting in the uncertainty of climate as more and more fossil fuels are being burnt. Diverting more land to forest cover would fulfill the needs for sustainability of both land and air resources.

HOUSING. Buildings designed, renovated, constructed, operated, and demolished in an environmentally sound and energy-efficient manner benefit the environment, building owners, and the community. For example, increased energy and water efficiency will enhance resource conservation and reduce the need for utilities to build new facilities. Increased allowance for daylighting in building design can improve productivity and occupant health. Implementing source reduction and waste recycling policies can reduce disposal costs and prolong local waste disposal capacity. Carefully considering public transportation access to buildings will reduce traffic congestion and improve air quality. *The Sustainable Building Technical Manual: Green Building Design, Construction and Operations*, produced jointly by the U.S. Department of Energy and Public Technology, Inc. (USDOE, 1996), shows how to design, operate, and maintain environmentally friendly buildings.

ENERGY. Although many of us only think about reducing our energy use during an energy shortage, the choices we make about our everyday energy activities-how we get to work and school, what kind of lighting we buy, and what kind of appliances we purchase-have a significant impact on both the economy and our environment. In fact, many organizations such as Worldwatch believe that energy will be the most important subject of the next decade. If we are to help ensure a sustainable future for ourselves and our global neighbors, we must work together. We need to discuss problems and share examples of successful environmentally sustainable energy initiatives in both rural and urban areas and demonstrate how communities, environmentalists, businesses, and government agencies can become partners in promoting sustainable energy choices (e.g., where conventional grid supply systems cannot be extended economically to remote villages, renewable energy sources offer the greatest promise).

14.5.3 Indicators of Sustain ability

Once we take steps to achieve sustainability, we need some indicators to tell us if we are on the right track. Indicators are required to make any necessary midcourse corrections.

> Trying to run a complex society on a single indicator like the Gross National Product is literally like trying to fly a 747 with only one gauge on the instrument panel ... imagine if your doctor, when giving you a checkup, did no more than check your blood pressure. (Hazel Henderson, 1991)

What are the indicators by which health, well-being, and improvement of a community can be measured? Traditional measurements often analyze an individual issue, for example, the number of new jobs in a particular community. But such a one-dimensional approach does not reveal the quality of those jobs or their impact on the local economy. Other indicators measure the number of children living in poverty, indicating the relationship between social health and local economic performance. It is evident that many indicators can be chosen, but few of them will provide an overall picture of our multidimensional world.

Nontraditional methods, such as "indicators of sustainability," are designed to provide information for understanding and enhancing the relationships between the economic, energy use, environmental, and social elements inherent in long-term sustainability. For example, sustainability indicators can serve as valuable tools for profiling local energy consumption patterns as a sustainability benchmark. Communities such as Seattle, San Francisco, and Toronto are using indicators to gather and evaluate information on both current energy use and future alternatives for the residential, commercial, industrial, and transportation sectors. This information is vital in planning for and managing the energy resources that will support sustainable development.

The concept of sustainability indicators has been derived from the concept of natural ecosystem indicators. The sustainability indicators should

1. Consistently represent a critical ecosystem component.
2. Be amenable to isolation in the environment.
3. Be measured accurately and repeatedly.

4. Be understood in terms of the health of the ecosystem.
5. Be well understood and accepted by the community.
6. Have the potential to be linked to other sustainability indicators.
7. Represent and relate to important community values.

Sustainability indicators identify key characteristics of the existing human and natural ecosystems. The role of an indicator is to make complex systems understandable or perceptible. An effective indicator or set of indicators helps a community determine where it is, where it is going, and how far it is from chosen goals. They provide perspective on a community's progress and guideposts for changes in its activities. Indicators of sustainability examine a community's long-term viability based on the degree to which its economic, environmental, and social systems are efficient and integrated.

To measure the degree of efficiency and integration, a set of indicators is often required. These indicators can incorporate several broad categories such as economy, environment, society and culture, government and politics, resource consumption, education, health, housing, quality of life, population, public safety, recreation, and transportation. Examples of indicators currently in use from several of these categories are described in Table 14.7.

TABLE 14.7
Sustainability indicators

Indicator	Description
	Economy
Income	Distribution of jobs and income, gross domestic product (GDP), gross national product (GNP), stock market averages
Business	Percentage of wages earned within a community and spent within the community
Training	Employer payroll dedicated to continuing training/education
Human development! quality of life	Education, health care, cost of living, cultural diversity
	Environment
Air	CO_2 emissions from transportation sources
Drinking water	Percentage reduction in drinking water supplies from 1990
Land use	Percentage of development occurring annually within an urban area
	Resource use
Energy	Percentage of energy used that is derived from renewable sources
Hazardous materials	Consumption of pesticides
Water	Number of gallons of water saved through leak repair
	Society and culture
Abuse	Child abuse/neglect/abandonment
Diversity	Racism perception
Volunteerism	Volunteer rate for sustainability activities

Source: Hart, 1995.

The usefulness and accuracy of indicators of sustainability depend on their ability to create a snapshot of the community's economic, environmental, and social systems. Choosing the appropriate indicators and developing a program is a large-scale process requiring collaboration between many sectors, including government agencies, the public, research institutions, civic and environmental groups, and business. The indicator programs profiled by Hart (1995) offer a wealth of information on the process of indicator program development, rationale for specific indicator selection, and ongoing challenges communities face in using indicators.

For sustainability to be successful, economic, environmental, and social equity issues must be considered together, since they are inextricably linked. Government must provide direct and meaningful interaction among those affected; information delivery must undergo vast technological changes to enable citizens and institutions to participate more fully. New methods of governance that are more collaborative, such as private-public partnerships, must be instituted. Sustainability indicators help us in measuring the effects of our sustainability efforts.

14.5.4 What Is Being Done to Achieve Sustainability?

Let us now examine what has been done to achieve sustainability. Following are brief summaries of steps taken or being taken by several groups to achieve sustainable development.

The U.S. Environmental Protection Agency, under Project XL, is giving selected companies the regulatory flexibility needed to streamline their manufacturing processes to allow them to both reduce costs and produce superior results. Project XL is a national pilot program that tests innovative ways of achieving better and more cost-effective publie health and environmental protection. Through site-specific agreements with project sponsors, EPA is gathering data and project experience that will help the agency redesign current approaches to public health and environmental protection. Under Project XL, sponsors-private facilities, industry sectors, federal facilities, and communities--can implement innovative strategies that produce superior environmental performance, replace specific regulatory requirements, and promote greater accountability to stakeholders. XL projects are real-world tests of innovative strategies that achieve cleaner and cheaper results than conventional regulatory approaches would achieve. The EPA will grant regulatory flexibility in exchange for commitments to achieve better environmental results than would have been attained through full compliance with regulations. The EPA has set a goal of implementing 50 pilot projects in four categories: XL projects for facilities, sectors, government agencies, and communities.

The Nature Conservancy and Georgia-Pacific Corp. agreed in 1994 to implement a unique partnership to manage 21,000 acres of wetlands along North Carolina's lower Roanoke River that teems with animal life. Georgia-Pacific owns the land, but a joint committee-including representatives of the U.S. Fish and Wildlife Service, the Nature Conservancy, and Georgia-Pacific--decides where and under what conditions timber harvesting can occur.

One of the most successful pregnancy prevention programs in the country is Teens Teaching Teens. Started in Atlanta, Georgia, by the public schools and the Grady

Health System, the program trains high school juniors and seniors to encourage eighth graders to postpone sex. A study has shown that after participating in this peer counseling, students are less likely to be sexually active. Being sexually inactive is probably the best way to achieve population control, and this program means fewer births and a slower population growth. Most of the world's social and environmental problems are linked to excessive population; programs of this type are models of how population growth can be brought under control through education.

Several initiatives have been undertaken by states and communities to achieve sustainable development. Denver, Colorado's, Environmental Program is a comprehensive effort to protect the health and welfare of Denver citizens and the region's economy through protection and enhancement of environmental quality. Citywide environmental planning and implementation efforts are coordinated with the Denver Regional Council of Governments, the Regional Air Quality Council, and the Clean Air Colorado program.

The Minnesota Sustainable Development Initiative brought together 105 citizen-leaders representing local agencies and environmental, business, and civic organizations to prepare a sustainable development plan for Minnesota that would reconcile the economic and environmental goals of the state, ensuring environmental protection while allowing for economic and job growth. The initiative came up with 400 specific strategies for protecting the environment and developing the economy in the areas of agriculture, energy, forestry, manufacturing, minerals, recreation, and settlement.

Sustainable Urban/Rural Enterprise (SURE) is a civic nonprofit corporation promoting the dual goals of economic development and environmental stewardship for the City of Richmond and Wayne County, Indiana. SURE promotes enterprises that are consistent with its principles of sustainability: that the only development-related activities that are pursued are those that can be perpetuated continuously by future generations; that economic and agricultural systems should be both adaptable and resilient; and that no development activity should deplete the natural resource base. One of SURE's initiatives is directed toward agriculture: to reduce soil erosion and chemical use, maintain greenery and trees on farmland, study hydroponics in greenhouses, and maintain a diverse agriculture. Other SURE initiatives include recycling, recycled product manufacturing, and the development of neighborhood gardens.

14.6 SUSTAIN ABILITY IN THE UNITED STATES

14.6.1 President's Council on Sustainable Development

The President's Council on Sustainable Development (PCSD) was established by President Bill Clinton on June 29, 1993, by Executive Order 12852. The council adopted the definition of sustainable development as stated in the original Brundtland Commission report: "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." The 25-member council is a partnership, drawing leaders from industry and government and from environmental, labor, and civil rights organizations. It is charged with developing bold new approaches to integrate economic and environmental policies.

The mission of the PCSD is:

1. To develop and recommend to the president a national sustainable development action strategy that will foster economic vitality.
2. To develop an annual Presidential Honors Program, recognizing outstanding achievements in sustainable development.
3. To raise public awareness of sustainable development issues and participation in opportunities for sustainable development.

Council members serve on eight task forces. The task forces and their duties are listed in Table 14.8.

The council has adopted 10 national goals for a sustainable future. They are interdependent and must be achieved in unison, considering economic, environmental, and social equity issues:

1. Ensure every person the benefits of a healthy environment.
2. Sustain a healthy economy that affords the opportunity for a high quality of life.
3. Ensure equity and opportunity for economic, social, and environmental well-being.
4. Protect and restore natural resources for current and future generations.
5. Encourage stewardship.
6. Encourage people to work together to create healthy communities.

TABLE 14.8
The task forces and duties of the President's Council on Sustainahle Development

Task force	Duty
Eco- Efficiency	Identifies models of sustainable manufacturing, pollution prevention, and product stewardship that will enhance recommendations for policy change.
Energy and Transportation	Develops long- and short-term policies to contribute to a more sustainable energy future.
Natural Resources Management and Protection	Develops guidelines to better manage and protect the nation's natural resources.
Principles, Goals, and Definitions	Articulates sustainable development principles and goals.
Population and Consumption	Identifies the impact of population and consumption patterns on sustainable development and recommends actions to address these issues.
Public Linkage, Dialogue, and Education	Works to foster public dialogue and develop educational outreach activities.
Sustainable Agriculture	Examines and makes recommendations relating to sustainable agriculture production, practices, and systems.
Sustainable Communities	Explores the obstacles and opportunities for sustainable development at the community level.

7. Create full opportunity for citizens, businesses, and communities to participate in and influence the natural resource, environmental, and economic decisions that affect them.
8. Move toward stabilization of the U.S. population.
9. Lead in developing and carrying out sustainable development policies globally.
10. Ensure access to formal education and lifelong learning that will prepare citizens for meaningful work and a high quality of life and give them an understanding of concepts involved in sustainable development.

The PCSD has provided many recommendations for local government, industries, and individuals that will allow them to better do their part toward the goal of achieving sustainability. A few of these are listed in Table 14.9.

TABLE 14.9
PCSD recommendations for furthering sustainability

Build a "New Framework for a New Century."
Increase the cost-effectiveness of the current environmental management system by creating opportunities for attaining environmental goals at lower costs.
Create a new, flexible, and performance-based regulatory management system to achieve superior results and cost savings through innovation.
Adopt a voluntary system of extended responsibility for products through their entire life cycle where designers, suppliers, producers, users, and disposers work together to exercise environmental stewardship from procurement of raw materials, through. manufacture and distribution, to use, disposal, and reuse.
Expand market-driven pollution control programs, such as emissions trading.
Establish a national commission to review the effect of federal tax and subsidy policy on the goals of sustainable development and recommend changes.
Change tax policies-without increasing the overall tax burden-to encourage employment and economic opportunity while discouraging environmentally damaging production and consumption decisions. Tax reform should not place a disproportionate burden on lower income individuals and families.
Eliminate government subsidies that are inconsistent with economic, environmental, and social goals.
Revamp the federal government's method of collecting, organizing, and disseminating data on economic, environmental, and social conditions to improve its quality and accessibility.
Improve the collection, coordination, and dissemination of scientific and health information available via computers.
Promote widespread access to information through computers, by offering computer skills training, making information formats more consistent within and among government agencies, and improving computer networks.
Develop better natural resource and quality-of-life baseline information and methods to measure the quality and quantity of renewable and nonrenewable resources, such as forests, lakes, minerals, and fish, and develop indicators of progress toward sustainability goals.
Change the education system to teach students at all levels the interdependence of the environment, social equity, and the economy.
Revise business accounting practices to link products with their environmental costs.

TABLE 14.9 *(cont.)*
PCSD recommendations for furthering sustainability

Identify key issues, create a vision for the future, and set goals and measurable benchmarks. This strategic planning process by a diverse group should identify unique local advantages and set goals to utilize them.
Create federal incentives to spur communities to deal with issues that transcend jurisdictions. Activities could include pooling local property taxes to increase equity in public services, improving education, and reducing economic incentives for sprawl.
Encourage builders, architects, developers, contractors, and community groups to design and rehabilitate buildings to use energy and natural resources efficiently, enhance health and the environment, preserve history and natural settings, and contribute to a sense of community.
Design new communities and improve existing ones by using land efficiently, promoting mixed-use and mixed-income development, retaining public open space, and providing diverse transportation options.
Manage the geographic growth of communities and create a plan for decreasing sprawl, conserving open space, respecting nature's carrying capacity, and protecting against natural hazards.
Revitalize "brownfield" sites (contaminated, abandoned, or underused land), making them more attractive for redevelopment by providing regulatory flexibility and incentives.
Issue executive orders (at federal and state levels) for agencies to use voluntary, multistakeholder approaches to manage natural resources and resolve natural resource conflicts.
Protect water quality, biodiversity, and other natural resources in unison through cooperative efforts across entire ecosystems, such as watersheds.
Create incentives to promote stewardship among landowners, corporations, government, and resource users to pursue stewardship or protection of natural resources.
Require commercial users of natural resources to pay the full cost of resource depletion.
Restore habitat and eliminate overfishing to rebuild and sustain depleted wild stocks of fish in U.S. waters.
Move toward stabilization of the U.S. population.
Create partnerships to enhance opportunities for women, with particular interest in curbing unintended pregnancy among teens and the disadvantaged.
Encourage the Commission 011 Immigration Reform to continue its work and support research to promote the implementation and fair enforcement of responsible immigration policies.

14.6.2 Role of Local Governments

Local governments hold a unique position as leaders in sustainability: They have an interest in promoting sustainable development, the facilities to act as "sustainability laboratories," the authority to initiate positive change, and the flexibility to tailor programs to specific local circumstances. Consumption practices cannot be reversed overnight; sustainability planning is an ongoing, dynamic activity requiring careful development, nurturing, implementation, and review. Sustainable development is a trial-and-error proposition. Local governments can be, and in many areas are, leaders in refining the vision for a sustainable community. This leadership requires finding tools and creating working programs with clear benefits at local, national, and global levels. A mayor of a large urban city remarked over four years ago that although the term "sustainability" is not entirely clear or without controversy, the concept of an effective and sustainable integration of economics and the environment is one that a local government can both understand and practice.

Cities and counties own, operate, and manage large numbers of buildings and facilities, as well as vehicle fleets and mass-transit systems; they design, plan, finance, and operate major water, wastewater, and solid and hazardous waste management systems; they enact local plans and policies that affect residential, commercial, and industrial development as well as land-use and transportation choices. Local governments have vital interests in improving and maintaining the quality of the air, water, and land resources essential to our economic and environmental well-being and quality of life.

Most cities and counties will implement sustainability measures incrementally and promote them in meaningful ways. The vision of sustainability is not limited to unique places: Communities across the country are involving residents, government officials, and businesspeople in dialogue and action toward the goal of fostering sustainable development. Citizens from all social and economic groups should take part in decision making. It is critical to their healthy survival.

Numerous cities and counties are designing and implementing sustainable plans. Others are in the midst of identifying indicators of progress or benchmarks of sustainability; many other programs are not specifically labeled as "sustainable" but are consistent with the vision of sustainable communities.

14.7 SUSTAINABILITY IN THE THIRD WORLD

The concepts of local and global sustainability sometimes are in direct opposition. For example, some of the world's wealthiest nations have been relatively successful in sustaining their economies, but they often rely heavily on another nation's capital (e.g., natural resources, labor) or use another nation as a global sink (e.g., disposing of hazardous wastes there because the host country is willing to accept the waste in exchange for needed capital). The consumption and production patterns more or less dictate exploitation of resources of poor nations. So, even though these practices may lead to local "economic" improvement, viewed holistically (including environmental sustainability), they may not really lead to sustainability. This implies that we may need some kind of international law which limits one nation's use of another nation's resources; however, most of the actions still need to be taken at the local level to achieve sustainability.

14.7.1 Barriers to Sustain ability in the Third World

Development efforts in the Third World can be classified into three categories-indigenous, Western, and a hybrid of indigenous and Western (James, 1996). These categories are prominently visible in all fields of life, including agricultural, economic, and social systems. Each of these systems has its own environmental benefits and disadvantages; the environmental state of the country depends, to a certain degree, on the categories in use there. Indigenous systems were not historically very harmful to the environment, but lately they have increasingly resulted in deforestation due to increased land clearing and farming. Western farming methods often result in more production per hectare, thus avoiding the need to bring more and more land area under agriculture to feed the increasing population, but they often result in loss of soil fertility and eutrophication due to excessive application of artificial fertilizers. Eutrophication, caused by the accumulation of nutrients from fertilizers in bodies of water, has destroyed many lakes around the world. Water pollution, soil erosion, and air pollution from increased agricultural and economic development activities have led to a decrease in biodiversity. Unplanned development is another major cause of loss of biodiversity.

It is often argued that resource exploitation is a necessary and unavoidable step for a Third World country striving to become prosperous and industrialized. However, it is also claimed that reduction of the level of poverty would reduce pressures on the exploitation of our natural resources because the forests would no longer be the primary source of food and income for the indigenous people of the developing world. Greater wealth would allow them the ability to more wisely manage their natural resources. Some of the developing countries are now tempted to import hazardous wastes from the developed nations to achieve quick economic gains, but the environmental ramifications of such endeavors are enormous, and the repercussions are unlimited. A wealthier nation would not need to allow its environment to be despoiled in exchange for needed capital.

Tourism is the basis of the economy of some countries. Many countries promote tourism because it attracts foreign investments, adds to the country's infrastructure (roads, hotels, etc.), and increases job potential. But the end result of this tourism development is often degradation of the environment, as the natural carrying capacity of resources is exceeded. Trash problems on Mt. Everest and a shrinking of wild animal habitats in Africa, which attract many tourists, are significant problems now.

Corruption is another major bottleneck for sustainable development in some Third World countries. Corrupt practices create an atmosphere of unaccountability and a distorted decision-making process, as well as being destructive to social, economic, and environmental conditions.

Another major problem facing developing nations is population growth. Increases in population translate into an increase in demand, which results in increased pressure on social and economic structure, ultimately resulting in degradation of the environment. The United Nations Population Fund (UNFP, 1991) blames population growth for two-thirds of the increase of carbon-dioxide emissions, 80 percent of tropical forest depletion, the dwindling and degrading of freshwater resources, and the degradation of coastal areas. To make matters worse, developing nations lack the resources and knowledge to tackle all these problems. Therefore, sustainable development collides head on with the idea of economic development. To make the world sustainable, harsh but necessary decisions must be made. This will be a very daunting task; whether humanity can achieve it remains to be seen.

14.7.2 Models of Macroeconomic Management for Third-World Countries

Several models that can be used for macroeconomic management of Third World countries have been proposed. These are discussed in this section.

The *revised minimum standard model* was developed by the World Bank and focuses on external debt. Based on a national accounts and balance of payments framework, it contains behavioral and technical relations among income, expenditure, investment, saving, and the domestic and foreign credit markets. The model has been tested and implemented in several developing countries.

Computable general equilibrium models are generally the extensions of social accounting matrixes in which behavioral equations are simulating the interactions of different economic agents. Due to their complexity, they have been the focus of research, rather than practical application.

A *public sector planning and management information system* is conceived as a mixture of a database, modeling, and management system, consisting of different interlinked modules. Among these modules are:

A policy analysis and planning system (for modeling at the macro-, meso-, and project level).

An economic monitoring system (database).

A financial management system (budget preparing and monitoring).

A debt management system (debt monitoring system).

A investment project bank (project monitoring).

A resource mobilization system (sources of project and program funding).

14.8 A FRAMEWORK FOR SUSTAINABILITY

14.8.1 The Role of Individuals

A sustainable society requires an open, accessible political process that puts effective decision-making power at the level of government closest to the situation and lives of the people affected by a decision (Dale and Robinson, 1996). In a sustainable society, all persons should have freedom from extreme want and from vulnerability to economic coercion, as well as the positive ability to participate creatively and directly in the political and economic system, thereby maintaining a minimum level of equality and social justice in a society.

Individuals can playa major role in achieving sustainability. Following are some actions that individuals can take categorized by the areas that they will influence.

Unemployment. To achieve a sustainable society, full employment is a requirement. This may mean reducing hours worked per week to ensure that jobs are available for everyone.

Life-style. We could have an impact on sustainability by making the following changes in our life-styles: sharing goods rather than owning them individually; increasing the energy efficiency of homes; landscaping with native vegetation, which requires little watering or chemicals, and which would contribute to energy conservation by reducing the exposure of houses to both heat and cold. We should start thinking "less is better," insist on efficient appliances, and accustom ourselves to smaller living spaces and increased use of common areas.

Education. Education for sustainability should be firmly entrenched in schools, colleges, and universities. Elementary and secondary schools should start acting as centers for developing sustainable society skills. All schools should adopt a "green school" program, which teaches students how to implement methods by which schools can operate more sustainably. In this way, the concept of sustainability will become instilled in the minds of students, who constitute a major part of the population.

Health and pharmaceutical companies. To achieve a sustainable society, we should hospitalize patients only for treatment of acute problems. People should be encouraged to recover at home and realize that home care is often the best opportunity for the individual to recuperate successfully. More leisurely lifestyles and healthier environments might help reduce the need for hospitalization. Reduced consumption of meat reduces burden on our livestock as well as promoting health. People who are healthy, both mentally and physically, have less demand for prescription and nonprescription pharmaceutical products. As a result, less waste and better utilization of resources by pharmaceutical manufacturers will be achieved.

Transportation. We could cut down on need for travel by using advancements in science and technology. Much business can be conducted electronically using videoconferencing, telephones, and computer links. Reducing long-distance travel for recreational purposes and requiring full-cost pricing of fuels would result in increased and more efficient use of public transportation. Using bicycles or walking wherever possible, and eventually using efficient small electric cars or cars powered by fuel cells, could also greatly reduce the environmental impacts of transportation.

Farming. Farmers can do their share by going back to natural pest control and nutrient recycling techniques, instead of relying on modem methods, thus eliminating the dependency on synthetic chemicals. Where possible, farmers should harness wind, solar, and biomass energy as a power source for the farm and use appropriate land preparation techniques for tillage and irrigation to reduce soil erosIOn.

Finally, individuals should be conservative and thoughtful in using all resources, even those commonly thought of as "free," such as water. In the end, no resource is free, because we all pay for environmental remediation through increased consumer goods prices or through taxation.

14.8.2 The Role of Industry

Industry can playa major role in achieving a sustainable society by shifting to cleaner manufacturing methods and instituting green marketing and ecolabeling, for instance.

Clean manufacturing and clean production have been the focus of this book. These terms must become a part of every engineer's lexicon because they provide for a combined environmental-economic benefit. Cleaner production focuses on the methods and processes which prevent pollution and emphasize waste minimization, and which work in concert to provide greater efficiency and energy conservation. This will require significant participation by all engineers, who can and must provide the critical nexus to achieve effective cleaner production implementation. The emphasis behind the cleaner production philosophy must be based on cradle-to-grave concepts. Industrial production systems require resources: *materials* from which products are made, *energy* which is used to transport and process materials, as well as *water* and *air*. Present production systems are usually *linear* (see Figure 14.2), often using hazardous substances and finite resources in vast quantities and at high rates.

The goal of clean production is to fulfill our need for products in a sustainable way; that is, using renewable, nonhazardous materials and energy efficiently while conserving biodiversity. Clean production systems are *circular,* rather than linear, and use fewer materials and less water and energy (see Figure 14.3). Resources flow through the production-consumption cycle at slower rates. The clean production approach questions the very need for the product or looks at how else that need could be satisfied or reduced.

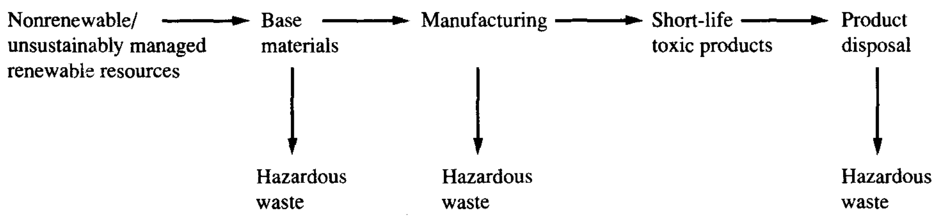

FIGURE 14.2
Linear structure of the industrial economy.

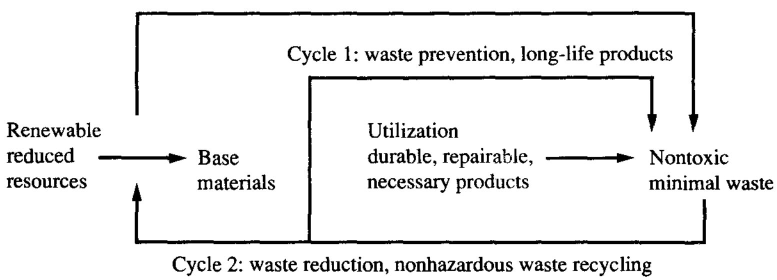

FIGURE 14.3
Circular structure of a sustainable economy.

14.8.3 The Four Elements of Clean Manufacturing

The clean production philosophy can be approached from four perspectives (Green-Peace International, 1995):

The precautionary approach. The precautionary approach puts the burden of proof on the potential polluter. Rather than communities having to prove harm, the potential polluter must prove that a substance or activity will do no environmental harm. This approach rejects the sole use of quantitative risk assessment in decision making because it recognizes the limitations of scientific knowledge in determining whether the use of a chemical or an industrial activity should proceed. This approach does not ignore science, but rather acknowledges that since industrial production also has social impacts, other public decision makers (not just scientists) must be involved.

The preventative approach. The preventative approach uses as its primary emphasis the fact that it is cheaper and more effective to prevent environmental damage than to attempt to manage or "cure" it. Prevention requires going upstream in the production process to forestall the problem at the source instead of attempting damage control downstream. Pollution prevention replaces pollution control. For example, prevention requires process and product changes to avoid the generation of incinerable waste streams, instead of more sophisticated incinerator design. Similarly, demand- and supply-side energy efficiency practices replace the current overemphasis on the development of new fossil fuel energy sources.

Democratic control. The democratic control approach says that access to information and involvement in decision making ensures more sound environmental decisions. Clean production should involve all those affected by industrial activities, including workers, consumers, and communities. Hence communities must have information on industrial emissions and access to pollution registers, such as the Toxics Release Inventory (TRI), toxic use reduction plans, and data on product ingredients.

Integrated and holistic approach. This philosophy says that society must adopt an integrated approach to environmental resource use and consumption. Currently, environmental management is fragmented, which results in the transfer of pollutants from one medium to another (i.e., between air, water, and soil). Reductions in polluting emissions from production processes lead to the hazard being transferred to the product. These dangers can be minimized by addressing all material, water, and energy flows; the whole life cycle of the product; and the economic impact of the change to clean production. The tool used to assist in maintaining a holistic approach is the life-cycle assessment, described in Chapter 6. An integrated approach is essential to ensure that as hazardous materials like chlorine are phased out, they will not be replaced by materials that pose new environmental threats.

Clean production systems are energy efficient and nonpolluting, and they make efficient use of both renewable and nonrenewable materials. As a result, products manufactured using these systems are durable and reusable; easy to dismantle, repair, and rebuild; and minimally and appropriately packaged for distribution using reusable or recycled and recyclable materials. Table 14.10 compares the traditional way of manufacturing goods with cleaner production approaches.

Clean manufacturing is both a process and a goal. Clean production processes can be broadly divided in two steps: changing the production process and changing the product. These topics were covered in Chapters 5 and 9.

Since the advent of the industrial age, new mass production techniques have increased the supply of goods to the point where, in some instances, they have overtaken the demand. Therefore, industries had to fmd new ways of selling their goods to keep their mass production systems at full capacity (Peattie, 1989). Marketing is a social process by which individuals and groups obtain what they need or want through creating and exchanging products and values with others (Kotler, 1984). Marketing is so basic that it cannot be considered a separate function. Green marketing and ecolabe1ing were described in Chapter 6.

TABLE 14.10
A comparison of pollution control and cleaner production attitudes

Pollution control approach	Cleaner production approach
Pollutants are controlled by filters and waste treatment methods.	Pollutants are prevented at their sources through integrated measures.
Pollution control is evaluated when processes and products have been developed and when problems arise.	Pollution prevention is an integrated part of product and process development.
Pollution controls and environmental improvements are always considered cost factors for the company.	Pollutants and waste are considered to be potential resources and may be transformed into useful product and by-products, providing they are not hazardous.
Environmental challenges are to be addressed by environmental experts such as waste managers.	Environmental improvement challenges should be the responsibility of people throughout the company, including workers and process and design engineers.
Environmental improvements are to be accomplished with techniques and technology.	Environmental improvements include nontechnical and technical approaches.
Environmental improvement measures should fulfill standards set by the authorities.	Environmental improvement measures should be a process of working continuously to achieve higher standards.
Quality is defined as meeting the customers' requirements.	Total quality means the production of goods that meet customers' needs and have minimal impacts on human health and the environment.

Source: Stahel. 1992.

14.9 INDUSTRIAL ECOLOGY

The concept of industrial ecology is still evolving and can be best explained with the help of the following example (Cote and Plunkett, 1996). In Kalundborg, Denmark, 10 industries are engaged in a system of mutually beneficial symbiosis. From the oil refinery and the power plant to the fish farm and the pharmaceutical company, one firm's waste is another's feedstock and one firm's by-product is another's raw material. The Kalundborg case, as seen in Figure 14.4, is a model of industrial ecology, because as a system it mimics, albeit in a limited manner, the cycling of materials and energy that occurs in a natural ecosystem (Knight, 1992).

Ecology is the study of the interrelationships of biota with their physicochemical environment. An ecosystem is a bounded system of dynamic, interdependent relationships between living organisms and their physical, chemical, and biological environment. The system has mechanisms by which nutrients are disseminated and replenished. Through the co-evolution of species, ecosystems acquire self-stabilizing mechanisms and a dynamic internal balance (McMichael, 1993). The goal of industrial ecology is to integrate production systems and product cycles with natural ecosystems and material cycles. The processes of the natural ecosystems have evolved over long

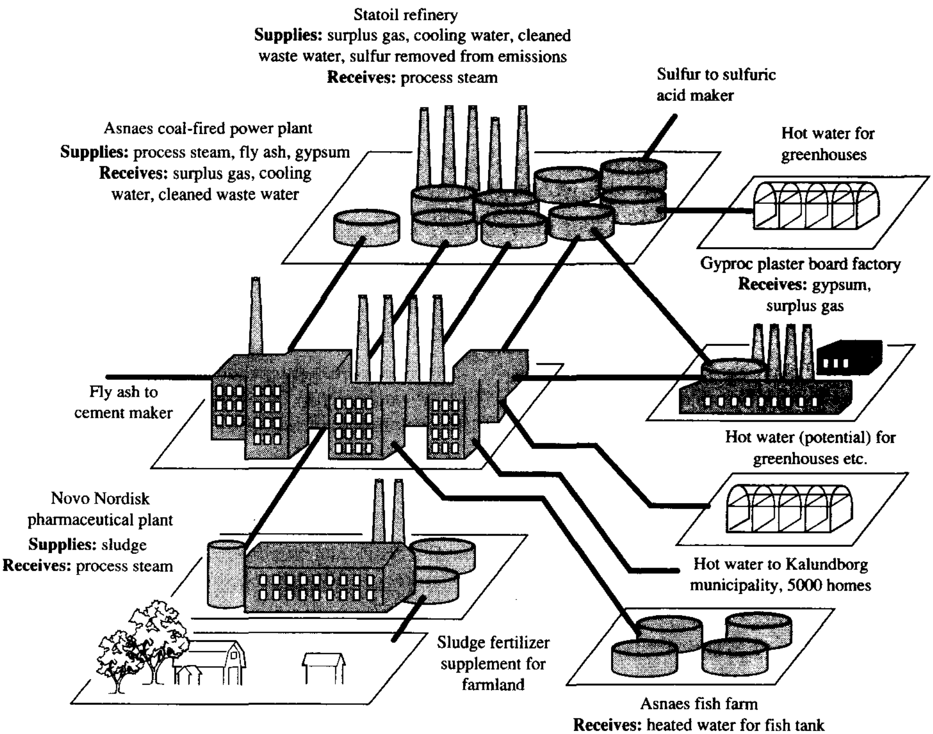

FIGURE 14.4
The Kalundborg, Denmark, industrial park.

periods into more or less stable communities because they are efficient, meaning that materials are not wasted but rather are conserved and reused in various forms (Odum, 1993). This is in sharp contrast to the increasing burden of waste that the industrial economy has imposed on the natural environment in the air, soil, and water through its linear, once-through pattern of material use.

As in natural systems, the cycling of materials must become the underpinning of industrial ecosystems. The various cycles should be maximized for recycling material in new production, optimizing use of materials and energy, minimizing waste generation, and reevaluating wastes as raw materials for other processes (Tibbs, 1992). Materials webs must be established linking producers, consumers, and scavengers; and multimaterial, multidimensional recycling must begin to emulate the complex webs in nature. Wherever possible, symbiotic relationships should be encouraged.

Another important feature of an ecosystem is diversity, which allows an ecosystem to recover after a stress is imposed. Industries that rely on a single source of supply or option for' waste disposal are at greater risk of collapse than those that have diverse sources of materials or waste disposal options.

Industrial ecology can be defined as the study of industrial development policies and practices and the interrelationship of industrial and natural systems. It is a framework for designing and operating industrial systems as living systems interdependent with natural systems (Graedel and Allenby, 1995).

Tibbs (1992) outlines six principal elements of industrial ecology:

1. Fostering cooperation among various industries, so that the waste of one production process becomes the feedstock for another.
2. Balancing industrial input and output with the constraints of natural systems by identifying ways that industry can safely interface with nature, in terms of location, intensity, and timing, and developing indicators for real-time monitoring.
3. Striving to decrease materials use and energy intensity in industrial production.
4. Improving the efficiency of industrial processes by redesigning production processes and patterns for maximum conservation of resources.
5. Developing renewable energy supplies for industrial production by creating a worldwide energy system that functions as an integral part of industrial ecosystems.
6. Adopting new national and international economic development policies by integrating economic and environmental accounting in policy options.

14.9.1 Ecoindustrial Parks

Ecoindustrial parks are being developed to test and implement industrial ecology. Ecoindustrial parks, like standard industrial parks, are designed to allow firms to share infrastructure as a strategy for enhancing production and minimizing costs. The distinguishing feature of ecoindustrial parks is their use of ecological design to foster collaboration among firms in managing environmental and energy issues. Company production patterns, as well as overall park maintenance, work together to follow the principles of natural systems through cycling of resources, working within the constraints of local and global ecosystems, and optimizing energy use. Ecoindustrial parks offer firms the opportunity to cooperatively enhance both economic and environmental performance through increased efficiency, waste minimization, innovation and technology development, access to new markets, strategic planning, and attraction of fmancing and investment.

14.9.2 Industrial Ecology Principles

An ecological industrial park is primarily based on two principles: to drive down pollution and waste while simultaneously increasing business success. Other ecological and economic green manufacturing concepts are related to industrial ecology. These principles are discussed next, with respect to their influence on industrial ecology and pollution prevention.

THE PRECAUTIONARY PRINCIPLE. During the 1990s, the precautionary principle has emerged as an increasingly popular theory. It has been applied to the areas of environmental law and resource management on both a national and international level. Basically, the precautionary principle holds that the existence of scientific uncertainty regarding the precise effects of human activities on the natural environment constitutes legitimate grounds for constraining such activities, rather than for pursuing them. In essence, this principle calls for a reduction of all inputs to the environment. The precautionary principle was first referred to in an official setting at the Second International Conference on the Protection of the North Sea, held in London in 1987. Regulation of marine pollution was the subject, and the precautionary principle was advanced in an attempt to shift the burden of proof from the regulatory authority to the polluter.

The precautionary principle is also the basis of Principle 15 ofthe June 1992 Rio Declaration:

> In order to protect the environment, the precautionary approach shall be widely applied by states according to their capabilities. Where there are threats of serious or irreversible damage, lack of scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

In 1992, many governments signed the Intergovernmental Agreement on the Environment, which also adopted the precautionary principle. It defines the precautionary principle as follows:

> Where there are threats of serious or irreversible damage, lack of full scale scientific certainty should not be used as a reason for postponing measures to prevent environmental degradation.

In the application of the precautionary principle, public and private decisions should be guided by (1) careful evaluation to avoid, wherever practicable, serious or irreversible damage to the environment and (2) assessment of the risk-weighted consequences of various options.

The precautionary principle addresses a problem central to sustainability: the inability to predict all the future consequences for human interests of current actions with environmental impacts. The precautionary principle describes one theory of how the environmental versus regulatory communities should deal with the problem of true uncertainty. The principle states that rather than waiting for certainty, regulators should act in anticipation of any potential environmental harm to prevent it. The precautionary principle states that where there are threats of serious or irreversible damage, lack of scientific certainty will not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

THE INTERGENERATIONAL EQUITY PRINCIPLE. This principle requires that the needs of the present generation be met without compromising the ability of future generations to meet their own needs. This depends on the combined and effective application of the other principles for sustainable development.

THE INTRAGENERATIONAL EQUITY PRINCIPLE. This requires that *all* people within the present generation have the right to benefit equally from the exploitation of resources, and that they have an equal right to a clean and healthy environment. This principle applies to the relationship between groups of people within a country and between countries.

THE SUBSIDIARITY PRINCIPLE. This requires that decisions be made by the communities affected, or on their behalf, by the authorities closest to them. This principle encourages local ownership of resources and responsibility for environmental problems and their solutions.

THE POLLUTER-PAYS PRINCIPLE. This principle, also known as PPP or the 3Ps principle, requires that the polluter bear the cost of preventing and controlling pollution. It forces polluters to internalize all the environmental costs of their activities so that these are fully reflected in the costs of the goods and services they provide.

THE USER-PAYS PRINCIPLE. This is an extension of the polluter pays principle. The user-pays principle (UPP) requires that the cost of a resource to a user include all the environmental costs associated with its extraction, transformation, and use.

ENVIRONMENTAL PERFORMANCE BONDS. This is a variation of the deposit-refund system. It is designed to incorporate both known and uncertain environmental costs into the incentive system, as well as inducing positive environmental technological innovation.

Assume there is a firm that wants to proceed with a project, but it needs the permission of a regulatory agency, such as the EPA, in order to proceed. Under this system, the EPA would charge the firm directly for any known environmental damages and levy an assurance or performance bond requirement to the firm equal to the current best estimate of the worst conceivable environmental consequences of the project. The bond would be kept in an interest-bearing account for a predetermined length of time, defined as the longest lasting conceived consequence of the project.

In keeping with the precautionary principle, this system requires a commitment of resources up front to offset the potentially catastrophic future effects of current activity. Portions of the bond (plus some proportion of the interest) would be returned if and when the firm could demonstrate that the suspected worst-case damages had not occurred or would be less than those originally assessed. The withheld portion of the interest is to cover the EPA's administrative costs and to finance EPA research. If damages did occur, portions of the bond would be used to rehabilitate or repair the environment and possibly to compensate injured parties. The firm would get back the remainder of the bond, with appropriate interest adjustments, at the end of the bond's life. If all the funds are required for remediation, the firm would get nothing back, forfeiting the full value of the bond. Funds tied up in bonds could still be used for other economic activities. The only cost would be the difference (plus or minus) between the interest on the bond and the return that could be earned by the business had it invested in other activities. On average, this difference should be minimal. In addition, the "forced savings" that the bond would require could actually improve overall economic performance in economies that chronically undersave, like that of the United States.

By requiring the users of environmental resources to post a bond adequate to cover uncertain future environmental damages (with the possibility for refunds), the burden of proof and the cost of the uncertainty are shifted from the public to the resource user. The advantages claimed for such an instrument are in terms of the incentives it creates for the firm to undertake research to investigate environmental impact and means to reduce it, as well in terms of stopping potentially damaging projects. This plan also promotes innovation, which is required for betterment of hl1man life and sustainable development.

CONSERVATION STRATEGIES. The industrial ecology approach is acknowledged in the 1991 update of the World Conservation Strategy (WCS). The revision calls on industry and govemment to identify as one of their priorities the task of committing business to sustainability and environmental excellence, expressed in high performance standards and advanced by economic instruments. In satisfying this goal, there will be a need to consider the occupational health and safety of workers; energy, material, and water efficiency of practices, processes, and products; control over the life cycle of manufacturing; and integrated approaches to pollution prevention and control (IUCN, 1991).

SOFT MATERIAL PATHS. The operating principle of this philosophy is efficiency: meeting people's needs with as little as possible of the most appropriate materials available.

INDUSTRIAL METABOLISM. This principle views an industrial process as being similar to the metabolic process of a living organism. The industrial process has inputs, such as materials and energy, and outputs, such as biomass and work. This term was coined by Ayres (1989b), who has great concern for the fact that the inputs and outputs of living organisms are in balance with the ecosystem and the inputs and outputs of the industrial processes are not. He also introduces the materials balance concept, a means of identifying the dissipative elements within an industrial process in order to reduce that dissipation.

E-FACTOR. This tenn was coined by Makower (1993) to describe a bottom-line approach to environmentally responsible business. The e-factor encompasses economics, enforcement, empowennent, education, efficiency, and excellence. In Makower's view, emphasis should be placed on excellence, thus linking this philosophy to total quality management (TQM). The common themes between the e-factor and TQM are (1) improvement in productivity and profits; (2) new corporate culture and leadership; (3) emphasis on long-range planning; (4) more flexibility within organizations; (5) improvement in infonnation exchange, training, and accountability; and (6) continuous self-auditing.

3RS. This stands for reduce, reuse, and recycle; practicing the 3Rs is a precondition for industrial ecology. The 3Rs represent a move toward nature's hallmarks of efficiency and material cycles, and they represent the most obvious means of achieving economic benefits for industry. Contributing to the implementation of the 3Rs and the creation of industrial symbioses are a number of tools and concepts, such as life-cycle assessment (see Chapter 6) or ecobalancing, ecoauditing, and total environmental quality management. Ecoauditing requires a holistic approach, rather than the traditional mechanistic one, to evaluating the impact of an industrial process on the environment. Total environmental quality management refers to the expansion of traditional approaches, emulated in TQM and ISO 9000 standards of quality assurance, with implementation of ISO 14000 standards, in order to incorporate environmental issues.

14.10 MEASURES OF ECONOMIC GROWTH

To progress toward the goal of sustainability, we need an effective way to measure economic growth that is in line with the concepts of sustainable development. But before we discuss some of the green accounting and economic activity measurement techniques, let us examine some of the traditional economic indicators and problems associated with business-as-usual measurement methods.

14.10.1 Gross Domestic Product and Gross National Product

The most widely used measures of national income are gross national product and gross domestic product (U.N., 1992b). *Gross domestic product* (GDP) measures total domestic demand for goods; it also measures the output produced to meet that demand of the country's population. Therefore, GDP is seen as a measure of economic perfonnance. An increase in GDP means that more is being produced; it commonly is used as an economic status indicator. Three methods are used to measure GDP:

1. The total output sold by finns, measured by value-added techniques. It is not the total value of sales by finns, because this would result in double-counting.
2. The sum of the incomes earned by persons in the economy. This is the most obvious rationale for calling GDP the "national income." The sum of incomes is equal to the value of total output produced by finns by virtue of the convention that output is measured in tenns of value added.

3. Total expenditure by individuals on consumption plus expenditure by firms on capital equipment (investment). Note that firms' expenditures on intermediate goods is not included here; only their expenditure on items of durable capital equipment is considered.

Theoretically, each of the ways of measuring the GDP should produce the same numerical result; in reality, errors arise in the collection of data from the very large number of ftrms and individuals in an actual economy. Thus a residual error term usually is included to account for these errors and differences.

Gross national product (GNP), which measures a nation's total production including exports, is often considered to be an obsolete measure of progress in a society striving to meet a nation's needs as effectively as possible and with the least damage to the environment. What counts is not growth in total output, which may beneftt primarily people in other countries, but rather the quality of the services rendered to the population in question. Bicycles and light rail, for example, are less resource-intensive forms of transportatin than automobiles and contribute less to GNP, but a shift to mass transit and cycling for most passenger trips would enhance urban life by eliminating traffic jams, reducing smog, and making cities safer for pedestrians. Switching to these modes of transportation would cause the GNP to decrease, but overall they would increase the well-being of the public (Anderson, 1989). Gross national product is further distorted by the fact that it absorbs, as positive adjustments, the costs of environmental disasters, natural disasters, and medical expenditures associated with them. The costs associated with remediation of environmental disasters, such as the Bhopal gas leak disaster in India, or with natural disasters such as the earthquake at Kobe City, Japan, will result in a sharp increase in GNP for these countries. The only losses registered by the GNP are lost production and lost working hours. Thus striving to boost GNP is often inappropriate and counterproductive. As ecologist and philosopher Garrett Hardin puts it, "For a statesman to try to maximize the GNP is about as sensible as for a composer of music to try to maximize the number of notes in a symphony" (Hardin, 1991).

From the standpoint of macroeconomic stabilization, GDP is a reasonable measure of economic performance, but it neglects environmental considerations. Hence it also is not satisfactory. The GDP measures neither sustainable income nor maximum consumption possible during a period which would leave the society with the same wealth at the end of the period as at the beginning of it. The society's wealth is its stock of capital and its productive assets. Capital equipment wears out as it is used in production processes; the extent to which it wears out in a period is known as *depreciation.* A measure of sustainable income for a period would therefore better be described as output less depreciation. Thus GDP overstates sustainable income.

Gross national product measures the value of the output produced by domestically owned factors of production, regardless of the physical location of production. Like GDP, GNP does not take environmental factors into account, and hence is not suitable for measurement of sustainable development. There are many other factors which make either GDP or GNP unsuitable for this purpose; a detailed discussion of these can be found elsewhere (Common, 1995).

It is now nearly universally agreed that the proper measure of national income, for the purposes of monitoring national economic performance, is *net domestic product* (NDP), equivalent to GDP less depreciation. This can be further refined to account for effects on the environment. To do this, we must accept the following two points:

1. Defensive expenditures to offset environmental degradation actually increase national income.
2. National income measures do not reflect the depletion and degradation of environmental assets caused by economic activity.

We should modify the GDP in the following ways in order to make it more usable and acceptable for measuring sustainable income:

- Defensive expenditures should be subtracted from the conventional GDP (this is known as the *environmentally adjusted GDP).*
- Environmental cost (the reduction over a given period in the value of the total stock of environmental assets, measured by multiplying the physical damage in the size of each environmental asset by a corresponding unit price and then summing the values arising across the different assets) should be subtracted from the conventional GDP (this is known as the *sustainable GDP).*
- Depreciation of man-made assets should be subtracted from the sustainable GDP (this is known as the *proper net domestic product,* or PNDP).

14.10.2 Green Accounting

As has been discussed, GDP is not a good indicator of a country's level of sustainability. "A country could exhaust its mineral resources, cut down its forests, erode its soils, pollute its aquifers, and hunt its wildlife to extinction, but measured income would not be affected as these assets disappeared" (Uno, 1995). Here, "measured income" is national income calculated on the basis of existing accounting conventions, such as the GDP.

"Only if the basic measures of economic performance ... are brought into conformity with a valid definition of income will economic policies be influenced towards sustainability" (Repetto et aI., 1989). This quotation describes the national income estimating procedures in Indonesia. Similar critiques of current national income accounting conventions have also been ,reported by Daly and Cobb (1989), Jacobs (1991), Pearce, Markandya, and Barbier (1989), and Anderson (1991).

Hence sustainable income should be expressed as the maximum consumption possible during a period, such that the society has the same wealth at the end of the period as at the start of it. Wealth is the total value of society's assets, including both assets produced by economic activity and environmental assets. This sustainable income is also called proper net domestic product (PNDP) (Common, 1995). Green accounting, more properly *natural resource accounting* or *environmental accounting,* is the means by which PNDP data would be produced.

ENVIRONMENTAL ACCOUNTING. In order to take steps toward sustainability, we need a framework to measure or account for the environment which is consistent with the principles of sustainability. The accounting framework describes the state of the environment for a particular point in time, that is, environmentally related activities within a year. The dynamic change of environment and related activities can be described by time series comparisons using such a framework. One example of indicators which can be derived from the accounting framework is what is called "green GNP."

The relationship among various factors or components of the environment can be formulated as follows:

$$\frac{Z}{A} = \frac{N}{A} \times \frac{Y}{N} \times \frac{E}{Y} \times \frac{Z}{E}$$

where A = geographical area
E = resources (e.g., energy)
N = population
Y = income (product)
Z = pollutants

Thus environmental limits are expressed as the multiple of population density, per capita income, resources intensity, and efficiency of resource use.

A NEW PRODUCE, CONSUME, AND RECYCLE ERA. Throughout history, man has largely indulged in a produce-consume-forget cycle, and as a result has made our growth unsustainable. We need to look beyond this concept and start working toward a produce-consume-recycle era. We should realize that exhaustion of natural resources and uncontrolled emissions of hazardous materials have created problems of global scope; one of the best ways to alleviate these problems is by recycling. The accounting framework should have provisions by which we can properly trace the flow of material inputs to our goods being produced and the amount of materials being recycled.

There is much disagreement within society as to what needs to be sustained and what does not. One point of view is that all natural resources should be sustained, and the commitment toward making sure that people's needs are met should be strengthened. Other groups say that it is more important to sustain different aspects of human development and activities, such as economic growth, human development, and social and political stability. This is often a social, moral, technical, and ethical debate, but the final decision as to what resources will be sustained will be a political one.

14.11 STEPS FOR ADOPTING A SUSTAINABILITY APPROACH

Achieving sustainability will not be easy, but even minimal progress toward sustainability will not occur unless we begin soon. Following are some suggestions for the first steps of this new journey:

1. Define what sustainability means for you and your organization.
2. Begin research and conduct an internal survey to determine where corporate practices have an impact on sustainability. Establish the descriptors for these practices.

3. Develop a sustainability framework, followed by a strategy for achieving sustainability.
4. Decide on goals and set a time limit to achieve these goals.
5. Decide on sustainability indicators and their weights, if any.
6. Develop a method for analysis of the evaluation results.
7. Decide on tools for sustainability planning and practice, keeping in mind the following points:

   Safeguard biodiversity at all costs. Remember that biodiversity is not a conflicting claim for resources by creatures other than humans but rather is the basis for future life. Try not to reshape the existing ecosystem by intensively growing or raising only a few crops or animals, as this will result in biodiversity reductions.

   Minimize interference with the ecosystem. All sustainability tools and plans should ensure that they minimize interference with ecosystems and respect their carrying capacity. Human-induced waste should be avoided.
8. Evaluate your needs periodically. Make a balanced judgment on whether the consumption of certain goods or services adds happiness, and learn to say *enough.*

Sustainability initiatives should be pursued using a combination of tools, rather than a single tool or a one-dimensional strategy. Sustainable development is inherently cross-disciplinary, involving the integration of previously distinct fields. Sustainable development requires policies and management approaches that coordinate a wide variety of disciplines. It should be remembered that sustainability initiatives and programs require us to think "outside of the box" when it comes to implementation and finance. There is no blueprint for a sustainable society waiting to be discovered. The problem itself changes over time as the result of the economy-environment linkages and their repercussions in human societies. Any solution to the sustainability problem will require successful adaptation to changing circumstances.

14.12 THE OUTLOOK FOR SUSTAINABILITY

Change is inevitable and necessary for the sake of future generations and for ourselves. Beneficial change is that which leads to the mutually reinforcing goals of economic growth, environmental protection, and social equity. Economic growth based on technological innovation, improved efficiency, and expanding global markets is essential for progress toward greater prosperity, equity, and environmental quality. To improve environmental quality, the current regulatory system needs to provide enhanced flexibility in return for superior environmental performance and low costs. Environmental progress, in turn, depends on individual, institutional, and corporate responsibility, commitment, and stewardship. Hence a new collaborative decision-making process that leads to better decisions; more rapid change; and more sensible use of human, natural, and financial resources in achieving our goals is required.

Since economic growth, environmental protection, and social equity are linked, integrated policies to achieve these national goals should include programs that stabilize global population. This objective is critical to maintain the resources needed to ensure a high quality of life for future generations. Steady advances in science and technology should be directed toward helping to improve economic efficiency, protect and restore natural systems, and modify consumption patterns.

Above all, a knowledgeable public, the free flow of information, and opportunities for review and redress are critical to open, equitable, and effective decision making, and hence to sustainable development. Citizens must have access to high-quality and lifelong formal and nonformal education that enables them to understand the interdependence of economic prosperity, environmental quality, and social equity and that prepares them to take action to support all three. Finally, we can state that we know what we have to do and we know how to do it. But will we do it? If we fail to convert our self-destructive economy into one that is environmentally sustainable, future generations will be overwhelmed by environmental degradation and social disintegration (Brown, 1993).

REFERENCES

Anderson, V. *Alternative Economic Indicators.* London: Routledge, 1991.

Anderson, H. "Moving beyond Economism: New Indicators of Culturally Specific Sustainable Development." In *Redefining Wealth and Progress: New Ways to Measure Economic, Social and Environmental Change.* New York: Bootstrap Press, 1989.

Ayres, R. U. *Technological Transformations and Long Waves.* RR-89-1. Laxenburg, Austria: International Institute for Applied Systems Analysis, 1989a.

Ayres, R. U. "Industrial Metabolism." In *Technology and Environment,* ed. J. H. Ausubel and H. E. Siadorich. Washington, DC: National Academy Press, 1989b, pp. 23-49.

Bartelmus, P. *The Concepts and Strategies of Sustainability, Environment, Growth and Development.* London: Routledge, 1994.

Brown, L. R "A New Era Unfolds." In *State of the World* 1993: *A Worldwatch Institute Report of Progress toward a Sustainable Society.* ed. L. Starke. London: Norton, 1993.

Brundtiand, G. H. *Our Common Future.* Oxford: Oxford University Press, 1987.

Caimcross, E *Costing the Earth: The Challenges of Governments, the Opportunities for Business.* Boston: Harvard Business School Press, 1993.

Callenbach, E., Capra, E, Goldman, 1., Lutz, R., and Marburg, S. *EcoManagement: The Elmwood Guide to Ecological Auditing and Sustainable Business.* San Francisco: Berett-Koechler Publishers, 1993.

Carson, R *Silent Spring.* Boston: Houghton Mifflin, 1994.

Coddington, W. *Environmental Marketing: Positive Strategies for Reaching the Green Consumers.* New York: McGraw-Hill, 1993.

Common, M. *Sustainability and Policy: Limits to Economics.* Cambridge: Cambridge University Press, 1995.

Conway, G. R. "Agroecosystem Analysis." *Agricultural Administration,* 20 (1985): 31-55.

Costanza, R, and Cornwell, L. "The 4P Approach to Dealing with Scientific Uncertainty." *Environment, 34,* no. 9 (1992): 12.

Cote, R, and Plunkett, T. "Industrial Ecology: Efficient and Excellent Production." In *Achieving Sustainable Development,* ed. A. Dale and J. B. Robinson. Vancouver: University of British Columbia Press, 1996.

Dale, A., and Robinson, J. B. *Achieving Sustainable Development.* Vancouver: University of British Columbia Press, 1996.

Daly, H. E., and Cobb, J. B. *For the Common Goal: Redirecting the Economy toward Community, the Environment and a Sustainable Future.* Boston: Beacon, 1989.

Drucker, P. E *Management: Tasks, Responsibilities, Practices.* New York: Harper & Row, 1973.

ECWD, *Our Common Future.* World Commission on Environment and Development (ECWD). Oxford: Oxford University Press, 1987.

Graedel, T. E., and Allenby, B. *R1ndustrial Ecology.* Englewood Cliffs, NJ: Prentice Hall, 1995.

GreenPeace International. "What Is Clean Production." http://www.rec.org/poland/wpa/cpbl.htm.I995.

Hardin, G. "Paramount Portions in Ecological Economics." In *Ecological Economics: The Science and Management of Sustainability,* ed. R. Costanza. New York: Columbia University Press, 1991.

Hart, M. *Guide to Sustainable Development.* Ipswich, MA: Atlantic Center for the Environment, 1995.

Hatcher, R. L. *Sustainable Development: The Pre-Brundtland Commission Era.* Brussels: VUB Press, 1996.

Henderson, H. Paradigms of Progress. http://www.subjectmatters.com/indicators/htmlsrc/WhatIsAn Indicator.html.

International Union for the Conservation of Nature. *Caring for the Earth: A Strategy for Sustainable Living.* Gland, Switzerland: mCN, 1991.

Jacobs, M. *The Green Economy: Environment Sustainable Development and the Politics of the Future.* London: Pluto, 1991.

James, V. *Sustainable Development in Third World Countries: Applied and Theoretical Perspectives.* Westport, CT: Praeger, 1996.

Kakwani, N. *The Economic Crisis of the i980s and Living Standards in Eighty Developing Countries.* CAER Paper, University of New South Wales, 1988.

Knight, P. "Closing the Loop." *Tomorrow* 2, no. 2 (1992): 40-43.

Kotler, P. *Marketing Management: Analysis, Planning and Control.* Englewood Cliffs, NJ: Prentice-Hall, 1984.

Lowe, F. *Discovering industrial Ecology: An Overview and Strategies for implementation.* Oakland, CA: Change Management Center, 1992.

Makower, J. *The e-factor: The Bottom Line Approach to Environmentally Responsible Business.* Toronto: Random House, 1993.

Martin, M. "A Sustainable Community Profile," *Places* 9, no.3 (1995): 30.

McMichael, A. J. *Planetry Overload: Global Environmental Change and the Health of the Human Species.* Cambridge: Cambridge University Press, 1993.

Meadows, D. H., Meadows, D. L., and Randers, J. *Beyond the Limits: Global Collapse or a Sustainable Future.* London: Earthscan, 1992.

Morrison, W. 1. *Data and Modeling in the United Nations integrated Macroeconomics Development Planning and Management for Sustainable Development: Guidelines for island Developing Countries.* New York: United Nations, 1993.

Odum, E. P. *Ecology and Our Endangered Life Support Systems,* 2nd ed. Sunderland, MA: Sinauer Associates, 1993.

Odum, E. P. *Fundamentals of Ecology,* 3rd ed. Philadelphia: W.B. Saunders, 1971.

Pearce, D., Markandya, A., and Barbier, E.B. *Blueprintfor a Green Economy.* London: Earthscan, 1989.

Peattie, R. C. *Green Marketing.* M & E Handbooks. London: Pitman, 1989.

Rees, C. "The Ecologist's Approach to Sustainable Development." *Finance and Development,* December 1993.

Rees, W. E. "Ecological Footprints and Appropriate Carrying Capacity: What Urban Economics Leaves Out." *Environment and Urbanization* 4, no. 2. (1992): 121-36.

Reid, D. *From Nature Conservation to National Sustainable Development Strategies. A Review of the Literature of Nature Conservation, Sustainable Development and Sustainability--i966-93.* Centre for Human Ecology, University of Edinburgh, 1993.

Reid, W. V., and Miller, K. R. *Keeping Options Alive: The Scientific Basis for Conserving Biodiversity.* Washington, DC: U.S. Department of Agriculture, 1989.

Repetto, R., Magrath, W., Wells, M., Beer, C., and Rossini, F. *Wasting Assets: Natural Resources in the National Income Accounts.* Washington, DC: World Resources Institute, 1989.

Ruckelshaus, W. D. "Toward a Sustainable World." *Scientific American* 261 (1989): 166.

Sadler, B., and Fenge, T. "A National Sustainable Development Strategy and the Territorial North." *Northern Perspectives* 21, no. 4 (1993).

Sanderson, S. K. *Macrosociology.* New York: Harper & Row, 1988.

Stahel, W. "Product Design and Waste Minimization," In *Waste Minimization and Clean Technology: Management Strategies for the Future,* ed. W. Forester and J. Skinner. San Diego: Academic Press, 1992.

Tibbs, H. B. C. "Industrial Ecology: An Environmental Agenda for Industry." *Whole Earth Review,* Wmter 1992, pp. 4-19.

Trainer, F. E. *Abandon Affluence!* London: Zed Books, 1985.
Trainer, T. *The Conservative Society: Alternatives for Sustainability.* London: Ted Books, 1995.
United Nations. *Agenda* 21: *The United Nations Programme of Action from Rio.* New York: UN, 1992a.
United Nations. *Handbook of National Accounting, Integrated Environmental and Economic Accounting.* New York: United Nations Department of Economic and Social Development, 1992b.
United Nations Conference on Environment and Development. *The Global Partnership for Environment and Development, A Guide to Agenda* 21. New York: UNCED, 1992.
United Nations Environment Programme (UNEP). *Population and the Environment: The Challenges Ahead.* London: Banson, 1991.
Uno, K. *Environmental Options: Accounting for Sustainability.* Norwell, MA: Kluwer Academic Publishers, 1995.
U.S. DOE, *Sustainable Building Technical Manual: Green Building Design, Construction, and Operations.* Washington, DC: U.S. DOE, 1996.
U.S. EPA. *Status Report on the Use of Environmental Labels World-Wide.* Washington, DC: Abt Associates for the U.S. EPA, 1993.
Welford, R. *Environmental Strategy and Sustainable Development.* New York: Routledge, 1995.
Welford, R., and Gouldson, A. *Environmental Management and Business Strategy.* London: Pitman, 1993.
Wilson, E. O. *The Diversity of Life.* Cambridge, MA: Belknap Press, 1992.
World Commission on Environment and Development (ECWD). *Our Common Future.* Oxford: Oxford University Press, 1987.

PROBLEMS

14.1. Section 14.2.2 lists seven major impediments to achieving sustainability. Which of these do you think is the most significant? What could be done to alleviate this impediment?

14.2. The UNCED conference in Rio de Janeiro in 1992 was the last major international conference on sustainability. Research what has been done since the Rio conference to implement its recommendations, and prepare a paper summarizing your findings.

14.3. Can an open capitalistic market ever be truly sustainable? State and justify your views.

14.4. It is often argued that it is not important to do without some luxuries now for the sake of conservation, because future generations will find replacements for any resources that become depleted. Can you cite any examples of this for the college-age generation? Do you agree or disagree with this philosophy? Why?

14.5. "Underdeveloped countries should not be held to the same stringent sustainability standards as developed countries because they need to, at least temporarily, consume resources (e.g., timber, high sulfur coal, etc.) at a higher rate and use more polluting lower technology industrial processes in order to catch up with the developed countries." State and support your views on this philosophy. What could be done to alleviate this impediment?