Life-Cycle Costing and Pollution Prevention

Paul E. Bailey

Life-cycle costing has been widely touted as an aid for exploring pollution prevention alternatives—paper or plastic bags, disposable or reusable diapers, glass or plastic containers. This article explains life-cycle costing, its historical applications, its potential applicability to pollution prevention, and some of its limitations. Examples are given of recent applications of life-cycle costing to environmental issues.

The concept of pollution prevention has much popular support, yet how to make it happen is often unclear. Alternative products and services are difficult to rate in terms of environmental "greenness," whatever that may mean. Which is better: plastic or paper bags? Disposable or reusable diapers? Electric or gasoline-powered vehicles? Without some rating scale, how can we choose?

Life-cycle costing is receiving attention as the kind of comprehensive "cradle-to-grave" decision aid that could foster greater strides in pollution prevention. The goal of this paper is to explain life-cycle costing and explore its applicability to environmental issues and pollution prevention. The paper presents the history and applications of life-cycle costing in nonmathematical terms. The limits of classic life-cycle costing are identified and contrasted with both "risk assessment" and "full cost accounting," two other approaches for environmental decision making. The paper concludes with an overview of some recent applications of these tools and suggested directions for the future.

Life-Cycle Costing

Twenty-five years ago in April 1965, the Logistics Management Institute in Washington, D.C., prepared a report for the Assistant Secretary of Defense for Installations and Logistics entitled "Life Cycle Costing in Equipment Purchase" that led to a revolution in guidelines for procurement of major defense systems and equipment. Spawned by the arrival of the "whiz kids" in Washington, life-cycle costing used the mathematical tools being taught in the nation's advanced business schools, recognizing that operation and maintenance (O&M) costs were substantial components of the total costs of owning equipment and systems.

In fact, "ownership costs" can far exceed procurement costs. As the government procurement process is oriented toward securing the best value from competing bidders, life-cycle costing was intended to

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Facilitate more intelligent choices. A device with relatively low purchase costs but high operations costs (e.g., energy-inefficient) and/or high maintenance costs (e.g., not very reliable) may not in fact be a better value. By considering the full costs over the life cycle of the system and the time value of money (e.g., discounting), better comparisons can be made. In addition, developing an overall quantitative picture of the life-cycle costs of an item increases the attention paid to operation and maintenance costs with the potential for improved design that reduces such costs.

Several trends combined to increase the costs of O&M through the '70s and '80s, including rising labor costs and decreased reliability due to increased system complexity, general price and wage inflation, and steep increases in energy costs. Thus, as the relative importance of ownership costs has increased compared to purchase costs, interest in life-cycle costing has grown. A recent bibliography has identified more than a thousand references on life-cycle costing.¹

Energy requirements of systems, equipment, and buildings are particularly amenable to life-cycle costing as these requirements are relatively easy to predict and easy to monetize. Both alternative product/system specifications and energy conservation actions (e.g., special lighting, insulation) are amenable to an analysis that calculates payback and return on investment. Recognizing this, Congress enacted the National Energy Conservation Policy Act in 1978, which requires that every new federal building be life-cycle cost-effective. Many states also enacted legislation making life-cycle cost analysis mandatory in the planning, design, and construction of state buildings.

Applications for life-cycle costing
Typical life-cycle cost analysis applications include:

- Aircraft
- Computers
- Military systems
- Heavy industrial equipment, tractors
- Automobiles and tires
- Ships
- Appliances (e.g., lighting, cooling, heating)
- Hospital facilities and medical equipment
- Buildings
- Office equipment
- Energy systems

All of these items are well suited to life-cycle cost analysis. Notably, for each, the government or corporate purchaser can define well-specified performance characteristics—speed, acceleration, capacity, accuracy, efficiency, and so on. Competing products and systems that satisfy the required performance criteria can then be evaluated and compared in terms of life-cycle costs. Low-tech, small-
scale items such as bags, diapers, and packing material have not traditionally been the subject of life-cycle cost analysis.

In comparing competing trucks, for example, that have equivalent carrying capacity in volume and tonnage, a life-cycle cost analysis would consider:

- Expected lifetime of use carrying equivalent loads; the longer lasting vehicle would have an edge
- Fuel efficiency over the life of the truck; the vehicle getting more miles per gallon would look attractive
- Maintenance costs over the life of the truck; the vehicle designed for ease of maintenance (e.g., hours of mechanic time plus materials) would appear superior
- Reliability and repair costs over the life of the truck; both expected frequency and nature of breakdowns and costs of repairs would be important

By reducing these elements to comparable dollar terms, the buyer can assess potential tradeoffs: the lighter weight vehicle may get more miles per gallon but have a shorter expected lifetime; a vehicle may have lower maintenance costs but be less reliable. Life-cycle costing permits easy analysis of such variables by translating them into the common units of today's dollars.

**Key factors and limitations**

Life-cycle cost analysis requires thinking through and identifying all the cost-bearing activities associated with the item or system throughout its lifetime, from acquisition through disposal. Each activity must then be "costed" in the nominal dollars of the year(s) the costs are expected to arise. Existing cost data must be collected or created and, for some activities, projected into the future. Once the costs are developed, the analyst can "discount" them to presentday dollars to facilitate comparisons with competing goods and systems. There is likely to be a significant element of uncertainty in the cost estimates for many applications of life-cycle costing; the analyst must accept this as unavoidable, while striving to do the best possible job.

This paper will not go into the many mathematical formulas that can be used in life-cycle costing. But it is important to note the key variables:

- Procurement cost
- Delivery and installation costs
- Annual operating costs including the costs of energy, supplies, labor, materials, and insurance
- Annual maintenance cost
- Taxes
- Salvage value or disposal cost
The purpose of life-cycle costing is to measure or describe costs, not to minimize them. However, to minimize costs, one has to know what the costs are—which life cycle costing can provide.

Anyone familiar with capital investment evaluation methodology will recognize all these factors as the costs businesspeople consider in light of projected returns on a potential investment. (One difference between private and public sectors lies in the discount rate that ought to be used, a subtlety we need not address here.) Capital investment decisions resemble procurement decisions in many respects, particularly when there are several projects competing for capital funds. However, capital investment methodology also applies to an individual project using objective criteria such as return on investment, payback period, and cost of capital as evaluative benchmarks, whereas life-cycle costing is usually thought of in the context of competing expenditures, given a need or desire to buy.

Life-cycle costing should also be distinguished from “value engineering,” although there are some overlaps. Life-cycle costing can set the stage for value engineering, which aims to identify potential cost-sharing efficiencies from changes in the design, manufacture, or use of goods or systems. The purpose of life-cycle costing is to measure or describe costs, not to minimize them. However, to minimize costs, one has to know what the costs are—which life-cycle costing can provide.

Inherent in life-cycle costing are some subtle limiting assumptions. Key is the ability to identify all the potential costs and monetize them; costs that are omitted will skew the analysis. Also, life-cycle costing cannot be used to compare apples and oranges; that is, it is a tool for distinguishing among comparable items that meet basic performance requirements. Life-cycle costing is not appropriate for choosing among products or systems with different goals, say tanks versus helicopters, or paper bags versus diapers. And, whereas governments and businesses in their buying decisions may not care much about aesthetics or other subjective aspects of comparable goods, retail consumers may find such factors compelling regardless of comparative cost (for example, natural versus synthetic fibers). The applicability of life-cycle costing to consumer behavior at the retail level needs more thought. In fact, when product “quality” is involved, purely economic criteria may not be controlling. In addition, life-cycle costing focuses on the procurement and ownership costs expected to be incurred by the purchaser; so-called social costs or externalized costs are not covered. This is a very serious limitation that will be further discussed below.

Pollution Prevention and Life-Cycle Costing

The hope for life-cycle costing is that it can enable us to make the difficult choices to achieve pollution prevention. Pollution prevention is the reduction in toxicity and/or volume of pollutants released to the environment and includes:

- Life cycle in years
- Discount and escalation (anticipated inflation) rates
Life-cycle costing can help in pollution prevention decisions relating to products by ensuring that any O&M and disposal costs relating to pollution are considered in the analysis.

- Waste reduction at the point of generation
- Recycling and reclamation of waste materials
- Materials substitution or process changes

In the realm of pollution prevention, less is usually and clearly more; that is, less waste means more pollution prevention. And recycling and reclamation seem clearly better than disposal of pollutants in the environment. But *substitutions* are much more difficult to evaluate. PCBs were originally hailed for use in transformers as substitutes for materials of less stability. Asbestos likewise appeared to be a fiber of miraculous properties. Advances in medical science for a variety of conditions brought some new forms of radiation treatment that are now recognized as worse than the disease itself. Currently, advocates of pollution prevention encourage the substitution of water-based cleaners (or pigments) for solvent-based ones; but many aqueous cleaners can have adverse impacts on wastewater treatment plants and water bodies due to high BOD (biological oxygen demand) and metals. Can life-cycle costing help in fostering pollution prevention and avoiding perverse outcomes?

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In the paper versus plastic bag question, many of the classic life-cycle costing elements such as maintenance and repairs are not applicable due to the short shelf-life and technical simplicity of the articles. Here, assuming equivalent performance (e.g., carrying capacity) of the bags, a supermarket chain or government procurement officer might consider the cost differential resulting from the greater bulkiness of paper bags—more storage space needed or more frequent refilling of storage bins. And, if paper bag storage areas attract insects, costs of pesticide application or monitoring of infestation would arise; and so on.

In deciding between stocking disposable or washable diapers (for example, in military hospitals or child care centers), a procuring agency such as the Department of Defense (DOD) would need to consider the costs of collecting and cleaning washable diapers, wastewater treatment and/or disposal, and the diapers' useful lifetime (and ultimate disposal) versus the costs of using and disposing of nonreusable diapers for an equivalent population of children.

By adding in the appropriate missing costs to the life-cycle costing approach described earlier, we can achieve the "full-cost accounting" that is likely to be necessary for evaluating pollution prevention projects. Such an expanded accounting forms the core of the Environmental Protection Agency's (EPA) *Pollution Prevention Benefits Manual.* The *Manual* helps the user identify the costs involved in hazardous materials and hazardous waste management and describes how to estimate the net present value, internal rate of return, and annualized cost savings of pollution prevention projects.
The *Manual* distinguishes among four levels of costs:

- **Usual Costs (Tier 0)**—Equipment, materials, labor, etc.
- **Hidden Costs (Tier 1)**—Monitoring, paperwork, permit requirements, etc.
- **Liability Costs (Tier 2)**—Future liabilities, penalties, fines
- **Less Tangible Costs (Tier 3)**—Corporate image, community relations, consumer response, etc.

The *Manual* includes worksheets and data to assist in cost estimation. The *Manual* also presents an illustration applying the methodology to a hypothetical firm that is an electroplater of gold jewelry. Currently, the firm uses 1,1,1-trichloroethane (TCA) in a precleaning step that generates spent solvents; the firm could avoid generating such hazardous waste by replacing the TCA precleaner with a mechanized aqueous cleaner. Unless liability costs and less tangible benefits are considered, the economic justification for the change is not strong enough.

Existing references on life-cycle costing and related research described in this article have yet to factor in these important considerations. Notably, some major corporations, including General Electric, Dow, and General Motors, take liability exposures so seriously that many now forbid off-site disposal except at approved facilities. GE has even developed its own costing model including liability exposure.

In general, waste management costs for materials would be subsumed under annual operating and maintenance costs and final disposal costs, so long as there are costs involved. Solid waste and much liquid waste generate waste management costs depending on how they are handled, but disposal of some liquid waste and certain types of air emissions may be relatively costless to industry. For example, waste oil from truck maintenance may carry some management cost (so long as it is not dumped down the drain), but the emissions from exhaust trigger no costs to the truck owner. Bags impose no waste management costs on supermarket owners because their customers cart the bags away, but preventing or treating insect infestation of bag storage areas will impose costs. The DOD will likely incur solid waste management and wastewater treatment costs due to diaper use at their bases, although on-site disposal of diapers, for example, may be considerably cheaper than off-site disposal where the DOD has had the use of land for free. This raises a related point. The costs to the user of the good or system of its solid waste and air and water emissions may not fully reflect their cost to society. Economists have invented a term for such real costs to society that do not belong to anyone—they are "externalized" or "external costs."

**External costs**

So long as the prices of goods and services do not reflect their full costs to society (e.g., costs of pollution, environmental degradation),
the free market will operate to encourage relatively greater use of these goods and services and more resulting pollution. Due to externalities, “classic” life-cycle costing will not capture the full costs of pollution in its calculations. For organizations acting to minimize the costs of doing business, externalities are not their concern; but public agencies acting to improve public health and welfare and environmental quality need to incorporate the externalities into their decision making.

What are these externalities and can life-cycle costing be adapted to incorporate them? Cost externalities can include:

1. Potential legal liabilities; for example, for cleanup, damage to natural resources, damage to persons or property, and
2. Other costs incurred by society; for example, the costs of managing solid waste incurred by public agencies and other social costs not covered in (1) above because the legal system cannot or does not render them recoverable liabilities.

The state of the art is young, but the incorporation of externalities into life-cycle costing is feasible by building on past and ongoing work to monetize these externalities.

**Liability costs.** Development of methodologies for monetizing the potential liabilities associated with waste disposal was spurred by the enactment of the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA or Superfund) of 1980, which created the Post-Closure Liability Trust Fund (PCLTF) and required EPA to assess the adequacy of the Congressionally established waste end tax to finance expected demands on the PCLTF. EPA contracted with ICF Incorporated to develop a sophisticated “Monte Carlo model” to estimate in dollar terms the liabilities that would be channeled to the PCLTF.* The results of this pioneering analysis were used by EPA in its Report to Congress on the PCLTF. The PCLTF was later abolished by Congress due to policy and political reasons as well as financial concerns raised by the analysis.

Although the PCLTF died, the liability monetization algorithms were further refined in subsequent ICF studies. For the DOD, the monetization methodology was used to illustrate the “true costs” of waste disposal directly in landfills compared to other alternatives. By making explicit a more complete range of costs, the report for the DOD spotlighted least-cost waste management strategies for fifteen DOD waste categories. The report found that liability costs can and do influence the least-cost management options for five waste categories, including concentrated solvents and toxics. Liability costs tend to favor treatment and volume reduction over options with greater reliance on land disposal. Volume reduction is always part of the least-cost strategy.
In recent years, the monetization methodology has been expanded to include a more complete range of legal liabilities and better data on cleanup and compensation costs. Using its Bodily Injury and Property Damage Assessment Model (BIPDAM) to link the cost algorithms to radiation dose-response data, for example, ICF prepared risk/cost curves for the states of Washington and New York that described the probability that certain dollar amounts of damages will be exceeded for activities involving low-level nuclear materials and wastes. This allowed evaluation of alternative levels for financial assurance requirements.

**Other social costs.** In addition to legal liabilities, pollution may impose other costs on society that are not well internalized by the manufacturers, sellers, and/or purchasers of the goods. These can include, for example: the difficult-to-measure costs of environmental degradation and diminished quality of life due to air pollution; cleanup or compensation costs not adequately covered by liability laws; other easier-to-measure losses, such as productivity losses, that may not be recoverable at law for many reasons; and costs incurred by taxpayers to support the administration of pollution control activities, including the inspectors, the permit writers, the bureaucracy, and its equipment. The last category of costs is relatively easy to measure, but not so easy to allocate. Unlike liability costs, not much work has been completed in this area, although some studies are underway to measure and assign public waste management costs to materials that end up as solid wastes, as described later in this article.

**Risk Assessment and Life-Cycle Studies**

Many analysts have performed studies comparing the relative risks of different types of energy sources, such as coal versus nuclear, attempting in some cases to assess the risks from “cradle to grave,” a life-cycle concept applied to risk. In addition to assessing air emissions and wastes, such studies look at the mining, materials handling, and transportation risks associated with each energy source. In this way, a more complete “risk assessment” is produced, with the intention of informing policy makers to encourage substitutions.

*Risk assessment* is a tool frequently used in developing environmental protection standards that accomplish risk substitutions through legal (as opposed to economic) incentives. The key is to identify all risk-posing aspects of chemicals or processes through their relevant life cycle. First, “baseline risks” are assessed for current practices of production, chemical handling, or waste management; subsequently, the risks of alternative practices are assessed. Usually, the latter risks are lower than the former—that is, the point of establishing or tightening environmental standards. In some cases, however, risks subsequent to a potential regulation may perversely be enhanced. For example, in establishing regulations for the land disposal restrictions under the Hazardous and Solid Waste
Amendments (HSWA) of 1984, the EPA evaluated whether the alternatives (e.g., incineration) to land disposal of hazardous wastes posed greater risks for certain hazardous wastes. The EPA has conducted and commissioned scores of risk studies that vary in goal, focus, and comprehensiveness.

Under such environmental laws as the Toxic Substances Control Act, Clean Air Act, and Clean Water Act, EPA has applied risk assessment to chemical production and handling operations to characterize worker exposure, emissions, effluent and solid waste, and by-products. Marine and highway transportation risk assessment has been used to evaluate routing decisions by assessing exposed populations and accident probabilities; such studies use probabilistic risk assessment techniques to account for uncertainty. Likewise, to implement the Resource Conservation and Recovery Act (RCRA) and CERCLA, EPA developed and applied risk assessment techniques to alternative waste management practices, waste mixtures, and environmental settings, both generic and site-specific. RCRA is a “cradle-to-grave” law, addressing the full life cycle from waste generation to ultimate disposal.

Despite the development of guidelines for performing risk assessments over the past ten to fifteen years, linking these various existing elements together to develop a life-cycle risk profile for chemicals or products is problematic due to inconsistent and incompatible assumptions and approaches. Particularly with respect to the products or systems that are the focus of life-cycle costing approaches, much work remains to be done to develop an approach that produces useful risk estimates.

Recent Applications of Life-Cycle Analysis to Environmental Issues

A variety of research has been conducted using life-cycle studies as a method to compare the environmental impacts of competing products. A 1989 “resource and environmental profile analysis” attempted to account for the total energy and environmental impacts associated with soft drink packaging systems for the National Association for Plastic Container Recovery. The study covered plastic bottles, aluminum cans, and plastic containers. Energy consumption and pollution were measured at many stages of each product’s “life cycle,” beginning at the point of raw materials extraction and continuing through processing, manufacturing, use, and final disposal, recycling, or reuse. Environmental impacts were expressed as air emissions, solid waste, and waterborne waste. The study concluded that polyethylene terephthalate (PET) containers are the most energy-efficient compared to aluminum or glass and that the PET containers contribute the smallest amount of solid waste by weight. Like all such studies, the assumptions, data, and analytic methodologies used must be carefully evaluated to have confidence in the results and their scope of applicability.
Another study, completed for the Council for Solid Waste Solutions, a plastics industry trade group, compared the energy and environmental impact of plastic bags with paper bags. The study concluded that plastic bags were environmentally superior to paper because they produce 74 percent to 80 percent less solid waste, 63 percent to 73 percent less atmospheric emissions, and more than 90 percent less waterborne wastes. This study, unfortunately, only considered the quantity of pollutants released, which is a major limitation. Other factors that can contribute to a product being considered environmentally superior were not taken into account, such as the degradation rates of paper versus plastic, population exposure, and health/environmental effects. The analysis does not claim to be a risk assessment; no attempt is made to quantify risk. A similar problem limits the usefulness of a study comparing foam polystyrene (PS) and bleached paperboard cups, plates, and hinged containers.

Also conducting extensive life-cycle analyses is the Tellus Institute, a nonprofit research group in Boston. The Tellus Institute, under contract to the New Jersey Department of Environmental Protection (NJDEP) and other agencies, is conducting a major life-cycle assessment of the environmental impacts of producing and disposing of packaging materials. Although the Tellus Institute is unable to draw conclusions regarding packaging materials at this point, they are looking ahead to the next step in their analysis, which will be to analyze the specific pollutants released from these products. NJDEP hopes that the study, which is expected to be completed next year, will provide the necessary data to prioritize products and packages in regard to their environmental impacts. In addition, the Tellus study will attempt to analyze the impacts of pollutants on human health. The issue of human health impacts is particularly important because, although one packaging material may produce less weight than another material, the pollutants released may be far more toxic (for example, the foam "peanuts" that off-gas ozone-depleting blowing agents).

A task force set up in New Jersey in response to growing concern over solid waste issues recommended establishing a 60-percent recycling goal for products and recommended establishing criteria to phase out products not meeting that goal. In response to these recommendations, the NJDEP began using life-cycle studies to determine which products are environmentally superior and which should be phased out. One such project currently being conducted involves consideration of predisposal fees for packages and, in the future, for products. In theory, because the costs of environmental degradation of packages and products are not reflected in their prices, predisposal fees would remove disincentives for people to purchase products that will generate less waste, can be recycled or reused, or do not pose a threat of environmental degradation. Such fees will "level the playing field" so that environmentally "good" products can...
Although waste-end fees may sound good in theory, in practice waste-end fees may provide a disincentive for proper dumping at landfills and waste may end up being dumped improperly or in environmentally sensitive areas.

Similarly, the State of California is in the process of developing recommendations (or legislation) for a disposal cost fee system to ensure that the individuals and organizations responsible for generating solid waste directly pay the full cost of solid waste management, including the costs of environmental degradation and state and local waste management programs. The California Waste Management Board has commissioned a study examining all types of goods and materials that are normally disposed in the state. Goods and materials with the greatest potential for environmental degradation will be determined using life-cycle approaches. These materials will then be charged an appropriate fee related to the material's solid waste management costs and costs of environmental degradation, as well as the current level of source reduction and recycling.

In summary, applications of the life-cycle concept to environmental issues have emphasized:

- Pollutant releases, rather than risks. Although risk assessment is more controversial due to its many necessary assumptions, it is the only analytic tool that can tell us whether less of one pollutant (i.e., fewer tons released) is preferable as a substitute for less of another.
- Alternative packaging systems rather than end-use products with substantial lives and significant ownership costs. However, because alternative packaging systems have little intrinsic value (we expect them to be rapidly disposed of once their function is complete), environmental impacts are a reasonable basis to establish preferences.
- Assessing and allocating externalized disposal costs to items comprising the solid waste stream, rather than the full spectrum of externalized pollution costs prior to disposal. However, it may be that much of the solid waste stream poses relatively minor environmental impacts prior to disposal. This needs more research.

**Summarizing the Issues**

Life-cycle studies are becoming increasingly popular methods for conducting cradle-to-grave analyses for particular products. However,
it is premature to consider life-cycle studies to be scientifically rigorous or comprehensive. Although researchers believe that life-cycle studies are necessary and important, particularly in regard to pollution prevention and control activities, and in helping to change people's habits, many researchers also believe that life-cycle studies can be inadequate and can lead to arbitrary conclusions. Life-cycle studies often have major methodological and data gaps, may be based on flawed assumptions, and currently do not fully portray a product's environmental effects. There is a need for more peer review.

Life-cycle costing is not itself costless. The gathering or estimation of cost data can be particularly time-consuming and burdensome. The mathematical analyses also must be performed and reviewed by specialists. Accuracy of results will often be questionable. Yet, although not perfect, life-cycle costing can be useful as a tool for comparing alternative products or systems, assuming rough equivalence in performance.

Many researchers believe that life-cycle studies are often misunderstood and consequently misused. Even though existing life-cycle studies do show certain comparisons between competing products, they are not yet comprehensive. Because the life-cycle approach to determining environmental impact is still growing and evolving, these studies cannot be accurately used to make broad generalizations regarding the environmental superiority of competing products. As research continues to evaluate the environmental impacts of various competing products and packaging systems, the methodologies of the life-cycle studies used to make these determinations need to be closely watched also.

Because pollution prevention should mean reduced risk, risk assessment must remain the primary analytic tool for assessing alternative practices, products, or systems. Thus, to substantiate government decisions designed to advance the public health and welfare and environmental quality by encouraging use of environmentally benign products and processes, a risk-based life-cycle methodology seems necessary to evaluate alternatives. Yet, absent legal compulsion or incentives, it is largely economics that will drive the decisions of businesses in purchasing and investment decisions. In this regard, the further development of life-cycle analysis in the direction of full-cost accounting is desirable, even if some externalities remain outside the frame of reference of the purchasing or investment decision. ♦

Notes


