The Role of Life Cycle Assessment in Environmental Policymaking

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Introduction

Environmental protection has been recognized to be an important responsibility of the modern global state for more than 40 years. In Sweden, for example, the Swedish Environmental Protection Agency (SEPA) has been in existence since 1967. When first created, SEPA was a part of the Ministry of Agriculture. In 1987, however, it was elevated to cabinet status under a newly created Ministry of the Environment. In the United States, the Environmental Protection Agency (EPA) was created in 1970, one year after the creation of the Council on Environmental Quality within the Executive Office of the President (a part of the White House, in other words). The U.S. EPA does not have quite the same formal cabinet status as the other departments of the U.S. government (State, Defense and Treasury, for example) that are equivalent to ministries in Europe and Scandinavia. Nevertheless, the EPA has been treated as a de facto cabinet department for at least the last twenty years and its top official (the Administrator) participates in international environmental negotiations as if she/he were a minister.

In both countries, efforts to protect the environment—principally air and water quality, but also to a lesser extent land and even quietude (freedom from certain loud noises)—predated the creation of these national environmental authorities. Moreover, despite differences in the legal or constitutional status of lower-level governmental bodies, both countries assign certain important environmental responsibilities to them. Typically, for instance, both Sweden and the United States set the broad direction of environmental policy at the national level (at the direction of their respective national legislatures); this may include specifying both the goals of environmental policy, as well as the specific limits on the emissions of particular pollutants that will apply to a variety of sources. Both countries delegate such important responsibilities as the monitoring and enforcement of certain emissions limits to lower levels of government. In Sweden, the latter include county administrative boards and—for the smaller plants and other pollution sources—local authorities. In the U.S., the 50 states and a number of municipal and/or regional organizations (Southern California's South Coast Air Quality Management District, to take but one example) do much of the hard work in environmental regulation.

In much the same way that the laws and governmental organizations pertaining to the environment have evolved, so too have the *tools and techniques* used to analyze environmental problems and help make decisions about them. In the 1960s when the first laws were passed, relatively little analysis was done in support of them. In the United States, at least, this was because the problems were so palpable (a river catching fire, urban air quality so poor that streetlights had to be turned on at mid-day) that it did not take sophisticated analysis to know that it was time to take action. The only calculus required was a political one—were the votes there to pass the measures under consideration? Initially they were and they came from both political parties.

During the 1970s two other techniques came to play an increasingly large role in the evaluation of environmental problems and policy measures. The first could be referred to as "net energy analysis" and it was a response to the two major energy crises of the 1970s—the first in 1973, related to the Yom Kippur war in the Middle East, the second in 1979, related to the revolution in Iran. At the risk of oversimplification, net energy analysis (or "the energy theory of value," as it came derisively to be known) was premised on the view that alternative and competing technologies, products, production processes or other systems could be compared usefully by determining the energy expended in producing, using and disposing of the product or process (see Odum and Odum, 1976). It was useful in focusing attention on one of the important inputs to the production process—and particularly on an input that had become relatively much more expensive during the 1970s. (During that decade the real, per-barrel price of oil increased from $20 to $100, as measured in 2008 dollars.) Net energy analysis gradually fell out of favor, however, because energy prices began a long period of decline; by the late 1990s petroleum was back to $30/barrel (again in 2008 dollars). In addition, and to foreshadow a concern that will arise in a slightly different context later in this report, the technique ignored the labor, capital and raw material inputs equally as necessary for the manufacture of goods and services.

During that same decade, and perhaps not coincidentally, another technique—known as benefit-cost analysis (or BCA)--began to be used widely in environmental decision making. BCA has a much longer lineage than net energy analysis. Indeed, in its earliest form it can be traced back to the mid-1800s and a French engineer named Jules Dupuit who was concerned about the proper way to evaluate public investments in such things as bridges and water-supply systems. But it was really not until the 1930s (in the U.S., at least) that BCA began to be applied regularly. The Army Corps of Engineers, which was tasked with building dams, canals, locks and other waterways, used BCA--and sometimes misused it--to justify the construction choices it was making. Gradually BCA began to be applied by the federal government to decisions about such things as possible alternative health interventions, investments in education, and national defense strategies. Beginning in the late 1970s, and continuing until today, it has come to be used also for the analysis of environmental investments and/or regulatory decisions (see Boardman, Greenburg and Weimer, 2011.). In the U.S., these latter applications have been propelled in part by a series of executive orders issued by every president since Gerald Ford (and including Barack Obama) requiring the use of BCA for all major regulatory actions, environmental and otherwise. Subsequently and similarly, the 1992 European Treaty of Union called for the comparison of benefits and costs in all European regulation.

Briefly, BCA is a technique in which all of the favorable and unfavorable effects arising from a proposed policy change are identified and translated into a common *monetary* metric (euros, dollars, pounds, etc.). To oversimplify, it is a way to reduce all the "pros" and "cons" to a common denominator to facilitate decision making. While there is no particular reason why money has to be the metric used to compare otherwise incommensurable effects (one could use salt, cattle or acres of land, for that matter), monetary measures have been used almost exclusively because it is typical to measure the negative effects of a policy change—the costs, in other words—using money measures. For that reason, BCA has developed around the notion that the favorable effects of the policy change should also be expressed using a money metric.

BCA does not rely on the skills of the economist alone, however. Consider a proposal to reduce air pollution emissions from coal-fired power plants by requiring the installation of certain types of control equipment. First, we need to understand how much emissions will be reduced from the installation of the equipment, which might require the skills of an engineer. Next, the reduced emissions must be translated into reduced ambient concentrations of the pollutants and/or their by-products; this typically requires the skills of an atmospheric scientist. Then the reduced concentrations of pollution in the air must be mapped into improvements in human health, reductions in damage to exposed materials, increased agricultural and silvacultural output, and so on. These tasks will require the knowledge of epidemiologists, clinical health researchers, materials and crop scientists, etc.

Finally, all these effects must be translated into monetary terms (see Freeman, 2003 for the definitive reference). Some of this is surprisingly easy. For instance, if reduced air pollution means increased yields of corn and wheat, these can pretty easily be expressed in monetary terms because these crops trade in well-organized markets in which prices are quite evident. Similarly, if reduced pollution means that people don’t have to paint their homes as often as they did in the past, this, too, can be easily expressed in monetary terms. Other effects are more challenging to monetize, of course. These would include reduced damage to aquatic ecosystems, improvements to human health including both reduced morbidity and premature mortality, and—in some cases—even such things as the reduced risk of birth defects. Despite the formidable challenges associated with monetizing such benefits, nearly 50 years of research into how people attribute value to such things has yielded very valuable insights into benefit measurement.

It should also be pointed out that the costs associated with government policies, whether environmental or otherwise, are not quite so easy to express in monetary terms as some people (and even some economists) seem to suggest. For instance, a requirement that all power plants install pollution control equipment generates some obvious costs—the number of pieces of control equipment times the cost of each. However, if some power plants are shut down because they are no longer economical to operate with the new equipment, the jobs that are lost and the higher prices for electricity are also costs of the regulation. In addition, when a regulation discourages an entrepreneur from building a new power plant she might otherwise have built with the new requirements, certain costs arise from this, too.

One final aspect of BCA bears mention before turning to the meat of this paper. Not all of the benefits and costs associated with a policy change occur at the same time. When talking about environmental rules and regulations, it is typical for businesses to incur costs up-front (pollution control equipment, more expensive fuels, use of more expensive recycled materials). The benefits of regulations, on the other hand, often are distributed across time, particularly in the case of carbon dioxide abatement where the major benefits may take many decades or even centuries to be felt. This is important because people are not indifferent to a euro in their pocket today and one they will not receive for many years. In other words, we need a way to discount both benefits and costs in later years in order to compare them to ones felt today. Selecting the appropriate *discount* rate to use to put benefits and costs on an equal footing is both difficult and controversial (see Lind, 1982, and also Portney and Weyant, 1999).

All this is prefatory, however, to a discussion about still another technique that has gained some favor for evaluation in environmental decision making—"life cycle analysis (or assessment)," often abbreviated as LCA. Briefly put, LCA attempts to shed light on competing alternatives—typically products that serve the same or similar functions—by cataloguing their energy and environmental impacts at virtually every stage of the process that brings them to life and sees them used and eventually discarded (or re-used) at the end of their life.

While it would be an exaggeration to say that LCA has become a dominant evaluative technique, its influence has certainly grown and may grow more. Indeed, there is a small but growing "industry" of consultants that has sprung up to assist both companies and governments in their respective applications of LCA. In fact, consultants, scholars and others have produced hundreds of books on LCA. There is also a growing group of academics and NGOs in both Europe and North America who spend considerable time either refining the technique or lobbying for its wider application. Standards for its practice have become part of the International Organization for Standardization (or ISO): the "14040 series" of ISO standards pertain to Environmental Management—Life Cycle Assessment. The well-respected international Society of Environmental Toxicology and

Chemistry (SETAC) has devoted a great deal of time to the development of the methodology of LCA. Finally, it is the subject of an international journal—fittingly, the *International Journal of Life Cycle Assessment*, now in its 16th year.

This is an appropriate time for a review of LCA and that is the purpose of this paper. It begins with a definition of the technique and a description of its constituent steps, briefly reviews some of its most common applications, identifies its strengths and weaknesses and, finally, discusses modifications and alternatives to LCA that might facilitate sound environmental decision making. Special attention is given in this report to what might be called an economic perspective on LCA.

While this report draws on a great many sources and attempts to cover a wide variety of points of view, it ultimately reflects the views of its author and should be read accordingly. Specifically, it should *not* be viewed as representing the position of the Expert Group on Environmental Studies within the Swedish Ministry of Finance.

1 The meaning of Life Cycle Assessment

LCA is defined somewhat differently by each of those individuals or groups urging its application, but it is perhaps best described by the International Organization for Standardization as "the compilation and evaluation of the inputs, outputs and potential environmental impacts of a product system through its life cycle" (Guinee et al, 2002). A contractor's report prepared for the U.S. EPA describes LCA as "…a 'cradle-to-grave' approach for assessing industrial systems" (SAIC, 2006). And a book designed to make LCA accessible to a broad audience defines it as "…a concept to evaluate the environmental effects associated with any given activity from the initial gathering of raw materials from the earth until the point at which all residuals are returned to earth" (Vigon, 1994). Perhaps the best description of LCA and analysis of the uses to which it has been put in the past, and may be put in the future, can be found in a recent issue of the academic journal, *Environmental Sciences and Technology* (Ekvall et all, 2011).

Almost every definition of LCA that one can find represents a variation on these three descriptions. Everyone agrees that LCA is intended to extend at least back to the stage at which the raw materials used in products or processes are harvested, mined or otherwise extracted from nature (the "cradle," in other words), and also that LCA should extend beyond the mere consumption of a good or service to include its ultimate fate in a landfill, a body of water or as waste heat and other pollutants in the atmosphere (the "grave"). Many explicitly identify the fuel sources and residuals as an essential component of LCA; indeed, LCA may be thought of as the next evolutionary stage following an exclusive focus on the energy content of various products and/or production processes as described briefly above.

There is also somewhat broad agreement about the constituent stages in an LCA. According to the International Organization for Standardization, these include (i) "goal and scope definition;" (ii) "inventory analysis;" (iii) "impact assessment;" and (iv) "interpretation" (see Figure 1). It should be noted, however, that ISO also provides guidance about which parties should be involved in defining these stages, particularly when the LCA will be used to make decisions that will affect multiple parties. In other words, ISO provides recommendations about the process by which LCA is scoped and conducted, as well as about the form that it should take.

It is extraordinarily difficult to summarize neatly the stages of an LCA, but an effort is made here to do so. The goal and scope definition phase is somewhat self-explanatory. With respect to the first (goal), this is the phase in which investigators ask themselves, "What are we trying to accomplish here?" Is the purpose to compare, say, two competing *products* (paper vs. plastic grocery bags, cloth vs. disposable diapers, electric vs. gasoline powered vehicles, for instance), or is it to compare industrial *processes* -- generating electricity from coal or natural gas, say, as opposed to from wind or solar power, or making transport fuels from petroleum as contrasted with biomass. The broader the goal, of course, the potentially more important the results, but also the more challenging the analysis will likely be. The goal phase might also specify how the results of the LCA will be used: for instance, it might be used by a corporation to source among competing suppliers, by a government agency to make a recommendation to consumers, by an NGO to certify products or processes, or even by an individual or household to choose among competing products.

The scope definition phase is especially important. In this phase of an LCA those conducting (or providing inputs to) the study must determine, among other things, which types of resource flows and residual discharges will be considered, which manufacturing processes will be employed, over what geographic boundaries will impacts be measured and during what periods of time? It must also be determined how resource flows and residual discharges will be measured (using what units, for instance). Assumptions must also be made about how products will be used, and how they will be disposed of at the end of their useful lives, including recycling if it is appropriate.

An especially important decision to be made in LCAs pertains to what might be called the “starting and stopping points” of the analysis. Suppose, for example, a decision is made to start an LCA with an accounting of the comparative amounts of raw materials that go into the manufacture of two competing products—the water, timber, fuel- and non-fuel minerals, agricultural commodities if any, etc. One could immediately ask why not include the energy expended to produce those materials, the resources embodied in the equipment that was required to mine the minerals and the energy required to grow the crops. Of course, we could go back one more stage from this point, and then another and still another. There is a kind of “infinite regress” that one can get into when performing an LCA. It is sometimes assumed in LCAs that something called a “difference analysis” will be conducted, in which effects occurring before the starting point are assumed to be offsetting.

The next stage in the typical LCA is the inventory analysis. Once again at the risk of oversimplification, it is in this stage that the energy and raw materials flows of interest are identified, understood, perhaps diagrammed and, more importantly, measured appropriately. Energy and material flows that contribute not only to the product or process of interest but also to others (joint products, in other words) must be allocated to their competing uses in this stage of the analysis. The usual output of the inventory analysis is a table showing the measured quantities of inputs and outputs (including residuals discharged into the environment) associated with the products or processes of interest.

The units of measurement will depend upon the inputs and outputs being measured. Energy flows might be measured as tons of coal, barrels of oil or cubic feet of natural gas; in some cases they may simply be aggregated into calories, BTUs, joules or watts (or their equivalents). Land that is required could be measured in hectares or acres. Pollutants going into the ambient environment might be measured in tons (sulfur oxides and carbon dioxide, for instance), pounds (biochemical oxygen demand), grams (heavy metal residuals going into a landfill) or other units. Obviously, where heat releases or noise are a by-product of concern, degrees or decibels might be the units of measure.

This brings us to the impact assessment phase of LCA, in some ways the most important and also the most difficult. Still again at the risk of oversimplification, this is the phase of LCA in which the raw materials and residual flows into and then out of the production/consumption/disposal processes are translated into impacts on both living and non-living things. This phase is essential because, generally speaking, we do not care about how much raw material we extract from the earth nor how much residual material we generate when producing, using or disposing of the products these materials are used to make *except insofar as they have impacts of consequence on the living and non-living world*. Thus, for instance, the withdrawal of a very small amount of fresh water from a very large underground aquifer, or the release of a small amount of waste heat into the atmosphere, would be regarded as inconsequential if they had no effect whatsoever on either the supplies of fresh water that humans will have to depend on in the future or on the livability of the atmosphere for birds or other species.

The impact assessment stage of an LCA can itself be divided into various stages. Among others, these include: the selection of the types of impact categories that will be considered; assigning the impacts to these categories; determining the scale at which effects will be identified (global, regional or local); finding ways to compare the impacts; and weighting the most important of the impacts. Examples of types of impacts commonly used in LCAs are global warming, ozone depletion, acidification of soils and water bodies, depletion of stratospheric ozone, aquatic toxicity, resource depletion, and air and water pollution.

Of course these impacts are hardly the end of the story. We care about global warming, presumably, out of concern for the effects it will have on living and non-living things. For instance, if global warming causes sea levels to rise significantly, scenic coastal areas could be inundated and lost; higher temperatures may mean that species cannot move to cooler climes fast enough to avoid extinction, or that popular plants and trees are no longer able to grow where they do now; disease vectors could see greatly expanded habitats in a warmer world; and tropical storms could increase in frequency and severity. These are the reasons we care about global warming, or they are at least one step closer to those reasons. Even these descriptions are incomplete. For instance, we care about the expanded habitat of disease vectors not for their own sake, but because they are capable of causing illness or death in humans. We care about tropical storms because of the harm that they can do to people and to fragile ecosystems.

By the same token, other “impact categories” must be traced through to their final effects. In the case of conventional air pollution, for example, it is of concern because it has the potential to cause illness and/or death among humans, because it can harm fish and other aquatic organisms when it is deposited (especially in acidic form) into bodies of water, because it can corrode or destroy both natural and manmade “wonders,” because it can reduce agricultural and silvacultural output, and because it can impair our views of scenic vistas. Suppose the impact category under consideration was stratospheric ozone depletion. In that case, we would be concerned with the effects on plant, animal and human life of increased damaging ultraviolet (or DUV) radiation reaching the earth.

Depending on the degree of specificity of an LCA, one can imagine the range of skills needed to identify the impacts of interest. For instance, atmospheric chemists and physicists are needed to determine the warming effects of increased emissions of carbon dioxide, methane and other greenhouse gases. Aquatic and terrestrial biologists are needed to determine how the habitats for plants and animals will change for given changes in climate, precipitation, etc. Epidemiologists are needed to determine the consequences for human health due to changes in temperature. And so on for each of the impact categories. Of course, off-the-shelf studies could (and probably would) be used in lieu of original research to make such determinations. For instance, factors have been published showing the global warming potential (GWP) of various greenhouse gases and these could be used to convert emissions into predicted warming. But the point is that a very wide range of disciplines are required to complete an LCA if a great deal of specificity is required.

Note that one of the steps identified above as part of the impact assessment stage was called the *weighting* stage. This is the stage in which the various impacts are compared against one another. This could involve such things as comparing the effects of water pollutants in both low-oxygen and also oxygen-rich water bodies; it could also involve comparing human health effects to those among aquatic or terrestrial plants. The weights used to make such comparisons are not scientifically determined, but rather reflect the values of the stakeholders identified as mattering in an LCA (leaving open the questions as to whose preferences do not matter in such an analysis).

Some LCAs include a final step: life cycle interpretation. According to some experts, the purposes of this stage are two: (i) "analyze the results, reach conclusions, explain limitations, and provide recommendations based on the findings of the preceding phases of the LCA, and report the results of the life cycle interpretation in a transparent manner; and (ii) provide a readily understandable, complete, and consistent presentation of the results on an LCA study, in accordance with the goal and scope of the study."

2 Some exemplares of Life Cycle Analysis

After this rather abstract discussion of the steps in an LCA, it is useful to describe briefly some of the ways that technique has been used in the past so as to give it some concrete shape. Perhaps the best known application of LCA has come in the comparison of cloth versus disposable diapers. The basic shape of the argument here is simple, with manufacturers on both sides of the issue insisting that their product is environmentally more benign. On the one hand, disposable diapers are just that—disposable. This means that the used diapers, and their malodorous contents, end up in landfills (3.4 million tons of waste annually in the U.S., according to the U.S. EPA, or about 2 percent of the total tonnage going into all landfills) or are burned in incinerators, principally the former. On the other hand, re-using cloth diapers means that they must be washed, either by a diaper service or by the family. This means water consumption and, assuming the diapers are dried indoors rather than on a line, the consumption of electricity, too. There are also competing claims about which type of diaper is best for avoiding diaper rash for infants, with the evidence seemingly mixed.

Even if we restrict our attention to studies done independently (that is, by someone without an economic stake in the argument), it is very difficult to conclude from the existing studies which diaper is best on environmental grounds. A recent study done by the U.K.'s Environment Agency came to the same conclusion as that of the consulting firm A.D. Little 20 years ago—that there is little environmental difference between the two, with cloth diapers having perhaps a slightly larger "carbon footprint" if the diapers are washed using hot water (one would hope so) and if they are dried in an electric dryer. Other studies bitterly contest this conclusion.

Regardless of the facts, it is worth pointing out that in the U.S., at least, disposable diapers currently enjoy a 95 percent market share.

Life cycle analysis has also been used to compare the internal combustion gasoline engine against battery power for passenger vehicles on environmental grounds. Here, too, there has been controversy. In the late 1990s, Lester Lave and colleagues at Carnegie-Mellon University suggested that because of lead emissions from lead-acid batteries both during the life of an electric vehicle and when it comes time to dispose of the spent battery, electric vehicles would not represent an environmental improvement on internal combustion gasoline powered vehicles, at least for new vehicles with relatively low emission rates. More recent analyses, of which there are a large and growing number, have suggested that even for electric vehicles powered by coal-generated electricity, their emissions of both carbon dioxide and conventional air pollutants will be lower than those from gasoline-powered vehicles. For instance, an all-electric Tesla roadster will emit about 48 pounds of CO2 for each 100 miles traveled, while a relatively fuel-efficient Toyota Corolla getting 31 miles per gallon will emit about 63 pounds. The exact numbers depend, of course, upon which fuel is used to generate the electricity; in states in which coal is the principal fuel source, the Tesla will emit only slightly less CO2 than the gasoline powered Corolla.

Still another application of LCA has been in the evaluation of the use of paper versus plastic bags in grocery stores (the ubiquitous question, "Paper or plastic?"). Here, too, considerable analysis has gone into the environmental pros and cons associated with the two choices, and here, too, there seems to be no consensus opinion. However, analyses by researchers Georgia Tech University and Lawrence University, as well as a recent comparison by writers at *The Washington Post* newspaper all conclude that—perhaps surprisingly—plastic bags have a slight edge in terms of environmental impact. Plastic bags require one-sixth the energy to manufacture as paper bags, and emit only 2 percent and less than 50 percent, respectively, of the water and air pollutants used to make paper bags. Plastic bags do result in the discharge of more heavy metals and carcinogens than paper bags according to Georgia Tech and they do have longer lives in landfills than paper bags.

Hard to believe as it may seem, some proponents of LCA have extended its use to the analysis of burial, cremation and other forms of disposal for those who have passed on. Specifically, a sort of LCA is being used to determine the most environmentally benign way to dispose of human remains at the end of one's life. According to *The Economist* (2010), traditional burials produce 39 kilograms of CO2, as opposed to 160 kg for a cremation. However, once one allows for the gasoline consumed in mowing the lawns in cemeteries, the carbon footprint of a traditional burial grows to exceed that of cremation. Two new alternatives to these standard techniques involve alkaline hydrolysis, developed by an Australian company (which turns the body into a liquid that can be used as fertilizer), and nitrogenic freeze-drying that ultimately results in a (mercury-free!) powder that can be applied as mulch. The latter technique has been developed by a Swedish firm, Promessa. These two latter applications bring new meaning to the term "cradle-to-grave" analysis.

3 Strenghts and Weaknesses of Life Cycle Analysis

As currently practiced, LCA has a number of advantages. By far the most important of these is that it focuses attention on one consequence of the production, use and disposal of goods and services that was for far too long ignored—their environmental impacts. Indeed, LCA focuses *exclusively* on these impacts, a point to which we will later return. By reckoning not just the emissions from driving an automobile, for example, but also those involved in every stage of its production process, as well as those that might occur when the auto is eventually scrapped or otherwise disposed of, we get a much more complete picture of its life-cycle impacts. Hence the name, of course. The early-stage impacts include those from mining the iron ore to make the steel that will go into the car; extracting and refining the oil that will be used to make the tires that go on the car; and the emissions of the volatile organic compounds released when the car is painted. End-stage impacts include the lead that may leach into the air or to groundwater when the car's battery is discarded and the environmental consequences (either for the air or for land) when tires are used for the last time and must be discarded. There are, of course, literally thousands of other steps related to the manufacture, use and ultimate disposal of the car that might be included in a LCA. By focusing explicitly on these various routes and linkages, LCA enables us to understand the *full* environmental impacts of products and production processes.

In doing so, LCA is useful also in reminding us of the unintended consequences of making changes in a product or production process. For instance, removing sulfur dioxide from the emission stream of a coal-fired power plant reduces subsequent ambient concentrations of sulfur dioxide and fine particles (sulfates) and reduces, as well, acidic deposition into lakes, streams, rivers and the ocean. All these are good things for human health and ecological sustainability. However, we have become aware recently that reducing sulfate particles in the air also reduces the reflectivity of the atmosphere; this in turn leads to increased incoming ultraviolet radiation and inadvertently increases global warming. Moreover, using flue gas de-sulfurization (FGD) equipment—also known as "scrubbers"-- results in the accumulation of scrubber sludge that must be disposed of. By some accounts, each ton of sulfur dioxide gas removed leaves three tons of scrubber sludge that must go into a landfill or other location. LCA can be very useful in identifying these unintended environmental consequences of certain pollution control strategies.

Turning to the weaknesses or limitations of LCA, it is best to start with those within its acknowledged framework. First, as alluded to above, one must specify at which point in time to begin "counting" environmental impacts. To repeat, does one start with the removal of raw energy and non-energy minerals from the ground at what might be called Stage 1, with the removal of the materials needed to make the equipment to conduct the removal at Stage 1, or go further back in time? It can be very difficult to answer this question, as well as questions like: Within what geographic areas do we count environmental impacts? Which impacts are significant enough to count and which are not? Over what time horizons do we count impacts? Once one has identified, say, human health and ecological impacts in physical terms, how does one compare them so as to indicate which product or process is to be preferred? Apropos of this point, one how-to book on LCA makes the point, "As such, it [LCA] provides information for decision support. LCA cannot replace the decision making process itself" (Guinee, 2002, p. 9).

In part because of the challenges associated with answering such questions, conducting an LCA can be very expensive. Obviously, this cost will depend upon the scope and intended level of detail in the LCA. Some analyses can be done for less than $100,000 though others can run into the millions of dollars. This makes it essential that practitioners think carefully about when and why they wish to make use of such analysis. Because one company, for instance, could make hundreds of decisions each day about product and process design, it would be impractical to conduct an LCA for each of these decisions.

By far, however, the biggest shortcoming of LCA has to do with its very limited scope. In the same way it was shortsighted for so many years to ignore completely effects on the environment when making decisions about products and processes, so too is it shortsighted to focus *only* on environmental effects when making those same decisions.

It helps in understanding this point to view things from an economic perspective for just a moment. In this perspective, what is important is that those producing a good or offering a service to consumers face the full costs of all the resources they employ in the production process. If they do, then all these costs will be reflected in the prices that consumers ultimately pay; consumers will then decide whether the benefit they expect to receive from the good or service is commensurate with the cost that they--*and society*-- must bear.

The same thing holds true with respect to the consumption of goods and services. Suppose, for instance, a homeowner's new wood-burning stove emits air pollution that sickens her neighbors. Even if the price she paid for the stove covered all the costs of its production, including environmental costs, things would still not be right because her use of the product results in uncompensated costs. The homeowner would be comparing the benefit she receives with less than the full social costs. Economists refer to such things as negative consumption externalities. By the same token, if she took measures to enhance the beauty of her house that also made neighboring properties more valuable, she would under-invest in such measures because the benefit she receives from the beautification (and equates with the cost of such measures) is less than the full benefits that society receives.

Having established, then, why ignoring environmental effects in production and consumption leads to a poor allocation of society's resources, it should be easy to see why considering *only* these effects in decision making is equally shortsighted. For the fact is that while environmental resources are scarce relative to the uses to which they might be put, so too are labor, capital and raw materials—what we might call more traditional factors of production. In the same way manufacturers use the latter three factors to make things, they also make use of another factor—an environmental factor we might call the assimilative capacity of the environment (whether air, water or land). This is the ability of the ambient environment to absorb with few ill effects at least some level of air and water pollution and solid wastes. Producers combine all these factors of production when making things, and the relative amounts of each used depend upon both their prices and their respective contributions to the manufacture of the good. And environmental policies—whether regulations that limit the amount of pollution that can be discharged, or those that assign an explicit price for each ton (a pollution tax, in other words)—are the mechanism through which the "price" of the environment is established. This must be done via regulation because no market exists in which either producers or consumers can purchase units of assimilative capacity, as they can hour of labor, tons of raw materials or amounts of capital.

By choosing between products or production processes only on the basis of their environmental costs, we would be making the same mistake made in the past when we looked only at the labor, capital and raw materials inputs to production. To use but one example, suppose we elected to build a concentrating solar-thermal (CST) electricity generating station rather than a combined-cycle natural gas turbine plant solely because the CO2 emissions associated with the former were significantly less than those with the latter. (In fact, solar thermal plants can be voracious consumers of water, but let us ignore this for the moment.) But what if the capital costs associated with the CST plant were three times those associated with the natural gas plant? What if it required more skilled labor to operate than the gas plant? Perhaps surprisingly, according to data from the U.S. Energy Information Administration, it *does* cost about three times as much to build a CST as opposed to a combined-cycle natural gas plant with the same capacity.

By concentrating only on environmental impacts in deciding among power supply options, we risk making the very same mistake we would make by ignoring them altogether: the true costs to society of the electricity consumption decisions they would be making would be less (and perhaps much less) than the costs they faced. In other words, society would be using its available resources in a way that generated less well-being than could be the case.

In one respect there is an inconsistency in LCA that bears mention. As indicated above, the typical LCA includes not just an identification of the air and water pollution externalities that results from a product or production process, but also the raw material inputs that are required. It is easy to understand why the former are identified, especially in the absence of laws and regulations that require producers to internalize at least some of these costs.

But why should those conducting LCAs have to identify the raw materials inputs (but not the labor or capital inputs) when these raw materials generally have well-established market prices? Proponents of LCA might argue that certain minerals will one day be exhausted, hence LCAs should count them because that way we can keep track of their status. However, that is precisely one function of prices in a market economy, especially for resources for which ownership rights are very clear. (This would not be as true for renewable natural resources where property rights are poorly defined, as with certain fisheries or sources of fresh water.)

To be sure, the price of oil, for example, fluctuates seasonally and in response to relatively short-term changes in aggregate demand related to overall global economic activity. But that same price also reflects longer term trends such as changes in population growth, income growth in the developing world, extraction technology (enhanced oil recovery, say) and changes in the technologies that can compete with oil, particularly in the transportation sector. These latter include such things as alternate fuels (ethanol, e.g.), advances in the battery technologies that will facilitate electric vehicle penetration, as well as hydraulic fracturing of shale to increase the recoverable natural gas that could be used in heavy-duty truck transportation. A strong argument could be made that, externalities aside, prices do a much better job of reflecting the true long term scarcity of both fuel and non-fuel minerals than some people think.

4 An alternative approach

There is another way that decisions could be made when choosing between products and/or production processes, one that would give the assimilative capacity of the environment equal (but not greater) place among the more traditional factors of production. It is the logical extension of the path that Sweden, the United States and other developed countries have been pursuing for the past 40 or so years. Under this approach, regulatory authorities would continue to establish "prices" for the assimilative capacity of the environment so that it could be evaluated alongside labor, capital and raw materials. Once this has been done, choices between products, for example, would be based heavily (though not necessarily exclusively) upon their price, with the knowledge that these prices reflected the relative scarcity of all the inputs that went into their manufacture.

Authorities could establish these prices in one of several ways. First, they could simply require manufacturers to install particular types of control technology at their facilities ("scrubbers" for sulfur dioxide emissions, selective catalytic reduction equipment for nitrogen dioxide emissions, electrostatic precipitators to remove particulates, etc.). Second, they could set firm quantitative limits on the emissions of air or water pollutants or the disposal on land of both hazardous and non-hazardous wastes—either in aggregate amounts or in relation to output of the good in question. (For instance, some air pollution regulation takes the form of a limit on the amount of sulfur dioxide that can be emitted per BTU of electricity generated.) Neither of these methods, referred to usually as "command-and-control approaches," would price assimilative capacity directly, but they would (and do) increase the cost of producing of polluting goods; in this sense, these two approaches force manufacturers to price their products as if they were paying directly for assimilative capacity.

Turning to more direct pricing approaches, regulatory authorities could first determine the maximum *total* amount of a particular pollutant that it is safe to emit, next allocate the permits consistent with that much pollution, either in proportion to sources' current emissions or in some other way, and then allow these permits to be bought and sold freely. Of course, the regulator would also have to ensure that no more pollution is discharged each year than the total amount the permits allow, but there would be no limit on emissions from any particular source (other than the cap on economy-wide emissions). This is the by-now well known cap-and-trade approach to pollution control, introduced in the United States in the 1990s for sulfur dioxide and nitrogen oxides and in Europe over the last decade to limit emissions of carbon dioxide. The interaction of buyers and sellers of permits establishes a market price for a permit, which in essence becomes the price of using the assimilative capacity of the environment.

The final and most direct approach to pricing assimilative capacity involves a tax on each unit of pollution discharged (sometimes called an effluent tax). Under this approach a price is assigned directly to each unit of pollution, that price being the tax. Dischargers would be free to emit as much air or water pollution, or solid waste, as they wished provided they paid the per-ton tax the authorities had established. As under any system, enforcement is required; in this case, authorities would have to be sure that those discharging pollution had in fact paid for each and every ton emitted. Pollution taxes have been used in both Europe and the United States, ranging from a carbon tax at the national level in Sweden, for instance, to a tax on the number of bags of garbage that households put out for curbside collection in a number of municipalities in the U.S.. Both cap-and-trade and pollution taxes are generally referred to as "incentive based" approaches because they create a financial incentive for individuals and corporations to use no more of the assimilative capacity of the environment than is necessary. The strengths and weaknesses of command-and-control as opposed to incentive-based regulation has been the subject of countless books and articles. That literature will not be reviewed here, other than to say that the former approaches are often preferred by those with a legal background while the latter generally find greater favor with economists and most policy analysts (see Kneese and Schultze, 1975, and Tietenberg, 2006).

Before discussing how decisions about products and production processes would be made in a world in which the assimilative capacity of the environment was priced, one question bears discussion first. How would one assign such a price? In other words, how much control technology should polluters be asked to install (under command and control), how many pollution permits should be circulated, or how high should a pollution tax be set? Needless to say, these decisions should not be made randomly or on the basis of political considerations alone.

First of all, and perhaps surprisingly to some, the price assigned to pollution generally should *not* be set so as to prevent pollution altogether. This would only be the case for extraordinarily toxic pollutants for which even the slightest amount let into the environment would create unacceptably great risks to human health and/or the environment. It is hard to think of pollutants for which this is the case; even for those such as mercury and cadmium, which are both bioaccumulative and neurotoxic at sufficiently high levels, very, very small amounts discharged into the environment probably do little or no harm. For most pollutants, the damage done by the very first emissions is small but grows as more and more pollution is discharged. This is generally referred to as the law of increasing marginal damages. Thus, the right approach ideally (under what we might call the economic approach to environmental protection, at least) would be to set a relatively low price on the first units of emissions because they put very little strain on the assimilative capacity of the environment, but increase the price as subsequent units begin to stress this capacity (i.e., do more damage) and thus create unacceptable risks. Because different pollutants vary in the harm that they do at various levels, the prices assigned to emissions of each would vary accordingly.

There is another reason why it makes sense generally to tax the first few units of pollution relatively lightly (assuming they are not of the unusually toxic sort). Not only do the first few units of almost all pollutants not pose very great risks, but these units are also generally very expensive to reduce. To see this, think of starting to reduce pollution in a very polluted world, one in which great demands are being put on assimilative capacity. Because there are likely very many sources of this pollution, when we begin to reduce it we would naturally start at those sources at which it is relatively inexpensive to control. This is almost always referred to as the "low hanging fruit" argument, meaning we do the easiest things first. As we begin to reduce more and more pollution, however, we tend to run out of low- and even medium-hanging fruit; in other words, as we reduce more and more, the cost of reducing each successive unit increases—this is what is referred to as the law of increasing marginal costs. Thus, to get to zero or even very low levels of pollution (the units that do the least harm), we must expend greater and greater sums.

Think about the implications of these two observations for just a moment. In a very polluted world, we can begin to reduce pollution inexpensively and the units we reduce are likely those that do great harm. These are the "no-brainers," in other words. As we begin to reduce more and more, the costs of additional removal go up and—gradually—the damage we avoid from the pollution removed begins to fall. In almost every case we can imagine, we eventually reach a point at which it becomes more expensive to reduce the next unit of pollution than the damage it does. Now, this point may not be reached until we have reduced a lot of pollution, but it may also be reached after relatively little removal. Just when depends on the relevant marginal cost and marginal damage functions.

To come back to the question that we posed earlier (what price should we place on assimilative capacity?), suppose that we had to set just one price on pollution, rather than a schedule according to which the per-ton price rises with emissions. The "right" price to set would be that at which incremental damage from the next unit of pollution is equal to the incremental cost associated with removing that unit. To remove less pollution than that would be to endure damages from pollution which exceed the costs of removing it. To remove more pollution than that would be to incur costs in excess of the damage that pollution does. In a world in which resources are scarce, as they are anywhere and everywhere, this would not make sense. To repeat, we might not stop reducing emissions until we have removed the overwhelming share of them, but that will not always be the case.

This process of setting prices on the assimilative capacity of the environment is often referred to as "internalizing negative externalities." The latter term is unnecessarily technical (as economists sometimes are); what it really means is "making people pay for the environmental damage they cause," where "people" can be acting as individuals, business managers or even government officials. To repeat, almost all the developed countries in the world, and many developing ones, have been going down the road to internalization for many years—and generally to very good effect. With the exception of pollutants for which no prices have been established (either indirectly or directly), the quality of the ambient environment has improved in most developed countries on almost every important dimension over the past twenty to thirty years.

To revisit the question that motivates this section, how would decisions be made about competing products and/or production processes in a world in which the assimilative capacity of the environment was appropriately priced, and thus given its due? *To put it directly, these decisions—whether made by individual consumers, corporate managers or government officials—would be made on the basis of price*. For a consumer, say, he would choose reusable diapers over disposable ones if they cost less to buy. The manager of an electricity generating station would choose natural gas over coal to fire her plant if that was the cheapest choice. And a government official charged with purchasing cars for the agency's car fleet would choose electric vehicles over ones powered by gasoline, diesel fuel, natural gas, bio-fuel or even hydrogen if they cost less.

To some this may sound jarring. Does it mean, for instance, that electric vehicles would be chosen even if their emissions (once one factored into account the source of the electricity that powered them) were greater than those of the hydrogen-powered vehicles, say? Yes, it does. They would be preferred in this case because although they emitted more, their production entailed enough less use of other valuable inputs—labor, capital, raw materials—to compensate for the costs associated with environmental discharges. Remember, although the electric vehicle may emit more, in an "internalized world" its producers are paying for each unit of pollution required to produce them and those who drive them are paying for their environmental footprint, too. In this very persuasive view, it would make no more sense to choose a product solely because it results in fewer emissions than it would because it requires the least hours of labor, tons of minerals or dollars of capital equipment to make it.

5 The Challenges of internalization

Because the shortcomings of LCA were identified above, it is only fair to note the difficulties associated with what we have called the internalization approach, starting with operational challenges. The first concern that could be raised is that not all environmental pollutants are yet "priced." By definition, this is true of those pollutants of which we are unaware or those that may have adverse impacts we do not yet understand (and for that reason have not priced). But it is also true for some pollutants we have known about for some time and whose risks are at least somewhat understood. To take the best known example, there is as yet no comprehensive and global approach to the control of carbon dioxide (CO2) and other greenhouse gases, despite evidence that the accumulation of these gases in the atmosphere may pose serious risks to the health of human, animal and plant species. To be sure, the European Union has established a CO2 control program, as have a number of other developed and even developing countries. The United States is often held up as a laggard in this regard, and indeed it has proved impossible so far there to pass a federal approach to greenhouse gas control, based either on a cap-and-trade approach or a regulatory approach.

However, a variety of greenhouse gas control measures have been put in place in the U.S. at the local, state and regional levels. For instance, ten states in the northeastern part of the U.S. have formed the Regional Greenhouse Gas Initiative (or RGGI) under which CO2 emissions from electric utility plants will be reduced. Chicago, New York and eight other populous U.S. cities formed the Large Cities Climate Leadership Group to deal with CO2 and other greenhouse gas reductions, and this group has now expanded to include an additional 58 cities from around the world. Finally, the state of California, in which one out of every eight Americans lives, is moving strongly to control greenhouse gas emissions from the utility and transportation sectors. Even at the federal level in the U.S., significant subsidies have been established for renewable sources of electricity, electric and other clean-fuel vehicles, and energy conservation in buildings homes and factories. These, too, are having the effect of gradually de-carbonizing the U.S. economy. Nevertheless, it is hard to argue that CO2 and other greenhouse gases are priced to reflect the risks they pose; this is true not only in the U.S., but also in some other developed and in almost every developing country.

A second possible objection to internalization is that the prices assigned to the assimilative capacity of the environment might not reflect the true damages done by pollution. Another way to put this is to say that it isn't easy figuring out what tax to impose on CO2, at what level we should cap emissions of water pollutants or what types of control technologies to require of solid waste landfills. It certainly is true that we seldom have precise information on the shapes of the marginal cost and marginal benefit curves for pollution control (see the discussion of benefit-cost analysis, or BCA, above). This in turn means that it is very difficult to argue that we can easily set the price of the environment's assimilative capacity at the level that neatly equalizes the two the first time we try to do so. If the price is set too low, then those making decisions about competing products, for example, will be biased in favor of products that create too much pollution, a clear misallocation of resources.

Prior to the environmental awakening of the early 1970s, and in the years immediately after that, most pollutants were effectively assigned no price at all; not surprisingly, very poor care was taken of the environment then. On the other hand, since that time a very large corpus of laws and regulations pertaining to the environment has been put in place in almost every developed country. This has gone a long way to rectifying the imprudence of the previous period and to reversing much of the damage that was done.

In fact, because of the exuberance of the early environmental regulatory period, as well as the view at that time that it would not be overly expensive to significantly reduce pollution, some countries may find themselves in an unusual position with respect to some pollutants. Specifically, the price assigned to assimilative capacity in some cases, at least, is likely to be *too high*. More technically, this means that we have probably regulated some pollutants to the point where the marginal costs of pollution control are greater than the incremental benefits society gets at that level. For instance, in some markets the price for an allowance to emit one ton of nitrogen oxides (NOx) has reached as much as $120,000 (Burtraw, et al, 2005). When one looks at the estimated damages associated with NOx emissions, however, one seldom finds estimates above $10,000 (AEA Technology, 2005). In such cases, by relaxing standards somewhat (by allowing more pollution, in other words), society would save more in avoided control costs than the damage the extra pollution would do. In circumstances such as this—when pollution is overpriced, people buy too few of the products giving rise to pollution, counterintuitive as that may seem.

Do we really know enough about the damages done by pollution to price it confidently? Certainly not with complete confidence, of course. But because of very serious research efforts in Sweden, the U.S. and elsewhere—efforts that in some cases predate the 1970s, a great deal is known about the valuation of environmental damages. In some cases, making such calculations is actually very straightforward: to recycle the example used earlier, if air pollution reduces crop yields, damages exposed materials or requires others to install air filters in their home or workplaces, the economic losses can often be easily determined. Similarly, when water pollution from a farm or factory requires downstream users to spend more for water purification, or forces fishermen or campers to shift to a more remote and less polluted area, these damages, too, are easily translated into kroners or dollars.

What about the effects of pollution on human health? This is more difficult, to be sure. But because we have opportunities to observe at least some of the expenses that people incur to protect or enhance their health (go to the doctor regularly, join health clubs, purchase health insurance, or accept less risky jobs), considerable progress has been made determining what values to assign to reduced risk of illness or premature death. The use of sophisticated surveys in which people are asked questions about how they would vote in hypothetical but quite realistic referenda on programs that would reduce pollution-related risks has also contributed to understanding about the valuation of environmental health benefits (see Mitchell and Carson, 1989).

The most challenging prices to attempt to assign to the assimilative capacity of the environment are those having to do with its ability to nurture endangered species, contribute to our direct aesthetic enjoyment or to the satisfaction we might receive from knowing that truly unspoiled and pristine areas still exist. In such cases as these, the survey technique described above immediately above may be the best way to understand the values that humans attach to these environmental "services." In other cases, of course, we may not even know about an adverse effect associated with pollution until it is too late; here, even the survey approach would not provide useful information as to damages.

Because the ultimate focus in this report is on LCA, it is important to remind the reader that these same effects can bedevil that technique, as well. If LCA is used not only to describe the possible environmental consequences of competing products or alternative production processes, but also to help make *choices* between them, it too must have a way to compare the reduced risk of species endangerment, say, with improvements in human health or reduced water treatment costs. In other words, it is not only the internalization approach to environmental management that struggles with such effects as these.

A third objection to internalization is more philosophical: some argue it is simply wrong to put a price—any price--on the degradation of the environment. Both sides of this argument have been thrashed out thoroughly before and rehashing these arguments here would only divert attention from the main purpose of the paper. Suffice it to say for now that until and unless the resources available to society become more plentiful than the countless uses to which they could be put, some method must be used to make difficult choices. It is hard to understand why society's resources would be used in such a way as to eliminate every single pollutant before they were used to address any other such needs as hunger, housing, education, health and so on. But this is the logical consequence of saying that the environment transcends economic thinking. While it is not absolutely necessary to price pollution in order to prioritize it alongside other pressing needs, doing so facilitates such decisions and in a transparent way.

6 Life Cycle Analysis in the Years Ahead

To this point, LCA has been contrasted to a more explicitly economic approach to environmental decision making. In fact, there are now serious efforts under way to marry the two approaches. Researchers at Carnegie Mellon University recently have modified of the use of "input-output analysis," a technique developed by Nobel Prize-winning economist Wassily Leontief, to facilitate the identification of environmental impacts (see Hendrickson, Lave and Matthews, 2006; also Suh, 2011). This technique was originally designed to show how, in matrix form, increased production (or output) from one economic sector would require inputs from the other sectors of the economy that supply it. Ideally, this would show the ripple effects throughout the economy of decisions to either increase or decrease the production of certain goods and services. The Carnegie Mellon researchers modified the conventional input-output matrix to include the emissions associated with the outputs of the various sectors. Thus, for instance, the increased output of aluminum would require not only increases in electricity and bauxite production, but also the additional emissions that electricity generation and bauxite mining entail. The intended advantage of this clever input-output approach to LCA is that it would make it much easier to do the calculations involved in an LCA by "mechanizing" the process. For that reason it is innovative.

However, while input-output analysis was developed by economists, it has come in for its share of criticisms from them and others, as well; and one criticism of input-output pertains to its application to LCA. Specifically, input-output analysis assumes that there is a fixed relationship between the various factors of production. That is, each ton of aluminum requires a certain number of tons of bauxite ore, so many kilowatt hours of electricity and certain other (fixed) inputs of other factors of production. Similarly, in the Carnegie Mellon adaptation of the technique, the assumption is made that each ton of aluminum produced implies certain emissions of air and water pollutants, solid and hazardous wastes, etc.

In reality, of course, the economy is always in flux. As the prices of raw materials rise and fall, the amounts demanded by those who use them do, too. Even subtle changes in resource prices can, in some cases, mean significant shifts away from their use—especially when there are close substitutes for them. To take but one current example, the electricity generation industry is currently taking advantage of record-low natural gas prices to substitute natural gas for coal as a boiler fuel. This has dramatic effects on pollutant emissions, especially for CO2. But input-output models cannot reflect constant changes in resource demands in response to prices changes—or, for that matter, in response to the almost constant technological innovation that is a given in modern industrial society. Thus, even this innovative effort to combine an economic tool with traditional LCA does not enable one to circumvent the problems we face.

How then might LCA best be employed and, when appropriate, be used in tandem with economic techniques like benefit-cost analysis? It is clear, first of all, that we have learned a good bit from the development of the LCA technique over the years and from its application to a variety of problems faced by individual consumers, businesses and governmental bodies. More than anything else it has rectified the almost complete lack of attention given to the environment in the past. In part because of LCA we better understand the resource demands associated with the production, sale and ultimate disposal of a wide variety of products. We better understand (although not completely, as shown by examples cited above) which products place great demands on the environment and which do not. Finally, we understand how to think more systematically and comprehensively about such comparisons in the years ahead. For these reasons, LCA should be embraced.

But that embrace needs to be a careful one. Simply because a LCA shows that—at one point in time—one product or process dominates another, it should not of necessity be used as the basis for endorsing that apparently favored product or process and banning the other. Whether pertaining to types of diapers, automobiles, grocery bags, fuels for electricity generation or light bulbs, this would be a mistake. For reasons vetted thoroughly above, we simply must understand that in an open, dynamic and global economy the prices of resources and other factors of production are changing all the time. This means that while cloth diapers might be preferred to disposable ones this year, the development of biodegradable materials that could be used in disposable diapers might make them preferable next year. In the same way that wind and/or solar powered electricity currently dominates that produced by coal combustion (from an environmental perspective, at least), so, too, might coal come to dominate renewable sources if a way can be found to safely and economically sequester the carbon dioxide that results. Things change all the time and the use of LCA to ban products that, for now, are less environmentally benign could be a major mistake when viewed from the perspective of even a few subsequent years.

Similarly, it is essential to repeat the other principal concern about the use of LCA to choose between products, much less to ban others. To reiterate, LCA focuses entirely on the resource and environmental impacts associated with competing alternatives. In the same way it was terribly wrong to ignore virtually all environmental impacts in the past, so too would it be a mistake to make decisions solely on the basis of these impacts. The labor and capital inputs to the production process are as scarce (and sometimes much more scarce) than either natural resources or the assimilative capacity of the environment. To exclude the former from any analysis that aims to choose a product or process that is "best" from society's standpoint simply would be as grievous a mistake as our previous exclusion of environmental impacts.

One of the goals of benefit-cost analysis (again BCA) as described above is to take such a comprehensive approach. While fraught with its own challenges, it has been used successfully to identify all the major impacts associated with a proposed decision, favorable and unfavorable, convert them to monetary units and then discount them to present values to see whether the good outweighs the bad. BCA should not be seen as an alternative to LCA. Rather, the careful application of LCA can identify environmental effects that might otherwise have been ignored so that they can be included in a thorough and comprehensive BCA. It is this marriage of LCA and BCA that is most likely to last and prosper. And one day, if and when "shadow prices" have been assigned to virtually all important adverse environmental impacts, an even simpler world could exist. This would be a world in which by the mere act of choosing the cheapest product available, consumers would know that they were at the same time choosing the one that best balances environmental protection against the many other important needs in our modern world. While it may take some time to meet that goal, it is one toward which we should all work.

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