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# AN EVALUATION OF
# ENVIRONMENTAL LIFE CYCLE ASSESSMENT

**Prepared Under Cooperative Agreement CR-820539-01**

**Provided by**

**Economic Analysis and Innovations Division**
**U.S. Environmental Protection Agency**

**Frank S. Arnold**
**Environmental Law Institute**

**May 18, 1993**

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## 1. Introduction

Recent years have seen a surge of interest in conducting analyses commonly called "environmental life cycle assessments", which seek to determine which of several products or processes is the "greenest" from an environmental perspective. In the consumer-choice arena, various studies weigh the environmental costs of disposable and cloth diapers, of plastic and paper grocery bags, and of alternative packaging materials, such as foam and paperboard. Life cycle assessment is also used to assist producer decisions about alternative processes and inputs in their attempts to improve industrial environmental performance.

The central motivation of environmental life cycle assessment is the belief that products, processes, and other economic activities cause environmental harms that are not adequately controlled and use natural resources that are not properly priced. Therefore, the goal is to identify and quantify all of the environmental harms associated with alternative products or processes -- essentially, to provide environmental "report cards" -- so that consumers and producers can choose the environmentally more benign alternative. Pollution in the form of releases to air, water, and land, management of those releases, use of natural resources, such as forests and other habitats, and use of energy and water, all are of concern in life cycle assessments.

This study evaluates the theoretical underpinnings and practical applications of life cycle assessment. It is motivated by several observations. One is that life cycle assessment results are the subject of sometimes considerable dispute. Indeed, a study championing one consumer choice for a particular product or activity, e.g., cloth diapering, seems to be quickly matched by another touting the advantages of the alternative. The apparent lack of robustness of life cycle assessment results may suggest a deeper problem.

More importantly, although life cycle assessments are becoming increasingly complex and costly to perform, the caveats and cautions attached to these analyses do not seem to diminish. It is somewhat troublesome that more and more research resources appear to produce little increased confidence in the results. A perhaps related point is that from a purely theoretical perspective, the task of identifying and quantifying all of the possible environmental harms and natural resource use that could be associated with a product or process seems daunting at best. Hence, this evaluation is motivated primarily by the lack of robustness of life cycle assessment results despite their growing complexity and cost.

Unlike some other evaluations of life cycle assessment, however, this study does not question the central premise that prices of products, processes, and activities do not adequately reflect their full social costs, particularly their environmental impacts. Whether the environmental problems that motivate life cycle assessments exist is not the issue in this study. Rather, for purposes of this evaluation, it is assumed that many environmental problems are associated with various consumer and producer choices, such as pollution associated with energy use, habitat destruction, occupation of scarce landfill space, and so on. The focus of this study is on whether life cycle assessments can help to mitigate these environmental harms in practice. From a purely analytical perspective, do (or can) the results of practical life cycle assessments correctly guide consumer and producer decisions toward environmentally more benign alternatives?

This paper is organized as follows:

- Section 2 discusses life cycle assessment's goals and methods, both in the abstract and in practice;
- Section 3 explores what life cycle assessments must achieve to provide useful guidance to consumers and producers in making environmentally better choices;
- Section 4 summarizes the implications of the evaluation for practical life cycle assessment; and
- Section 5 discusses an alternative to life cycle assessment that is more likely to provide environmental improvement.

## 2. Environmental Life Cycle Assessment: Analytical Goals and Applications

This section first reviews the fundamental motivation behind life cycle assessment and its overall analytical goals. Next is a short review of the general condition of actual life cycle assessments in practice. While this section is relatively brief, it is sufficient for the evaluation of life cycle assessment that follows.

### 2.1 What Does Environmental Life Cycle Assessment Attempt?

Environmental life cycle assessment grows out of two types of analyses. One is the standard environmental assessment of industrial processes which seeks to identify and, where technically and economically feasible, reduce environmental impacts. The primary concern in these studies is to search out and minimize direct pollution caused by a particular process or economic activity.

The other historical root of life cycle analysis is the class of studies originating some 20 years ago that sought to measure the full "energy content" of specific products and processes. During the energy crisis, it was held that energy use carried a social cost in excess of its price, so that in addition to the price of a product or process, its total energy content was important to know as well. Those studies, consequently, sought to identify all of the energy inputs required for by a product not only directly, but also indirectly, e.g., the energy required to produce and deliver the inputs necessary to produce the particular product in question.

Environmental life cycle assessment's roots suggest terminology that is useful for the remainder of the paper: environmental problems caused by the particular activity under study, say water pollution from a plant that assembles automobiles, are called <u>direct</u> environmental "demerits"; environmental problems caused by any other economic activities necessary to produce the automobile, e.g., air pollution due to electricity generation or water pollution associated with mining and smelting ores to make steel, are called <u>indirect</u> environmental demerits. The key distinction between the two sources of demerits is not the type of harm caused, but rather the activities responsible for those harms.

Life cycle environmental assessments are thus the marriage of studies of direct environmental harms and the far more ambitious energy-use life cycle assessments of two decades ago. In essence, environmental life cycle assessment seeks to identify and quantify all of the environmental impacts of a specific product or process that occur directly, as well as indirectly through inputs to the product and through the product's use and disposal. By summarizing all of these direct and indirect environmental demerits of a product or process, life cycle assessments seek to assist consumers and producers in making environmentally more benign choices.

The literature describes life cycle environmental assessment as consisting of the following three steps:

- Step 1 is a life cycle <u>inventory</u> in which possible sources of energy and natural resources use, various emissions and wastes, as well as other factors that could lead to environmental harms, are tabulated;
- Step 2 is a life cycle <u>impact</u> analysis in which the actual environmental harms caused and the true value of the natural resources used are determined; and
- Step 3 is a life cycle <u>improvement</u> analysis in which changes in consumption or production decisions are defined and evaluated in an effort to reduce total environmental demerits.

Three key features of life cycle assessment are critical for understanding and evaluating it as an analytical and policy tool. The first is obvious, but important enough to repeat -- life cycle assessment seeks to identify the total environmental demerits associated with a product or process. Thus, they typically begin with a list of inputs that cause environmental demerits, including use of energy, water, and renewable and non-renewable natural resources, air and water emissions, and solid and hazardous waste generation. They then seek to identify and quantify all of the direct and indirect sources of these demerits.

While it is easy to list many conceivable environmental demerits, it is far harder to measure them accurately, especially the indirect sources. Direct environmental demerits are those visibly caused by the product use or production process, so identifying and quantifying these is conceptually clear cut, although often hard in practice. The indirect environmental demerits are harder to identify, for these are, essentially, environmental demerits in other production processes or activities necessary to the product or process in question. Tabulating the indirect demerits first requires that one identify all of these economic activities and then determine whether they cause any environmental demerits.

The second central point is that a key goal of life cycle assessment is to evaluate the excess environmental costs of a product or process that are not included in prices, largely because they are not addressed adequately by the environmental authorities. As a result, these assessments seek to measure environmental impacts and damages, not just to tabulate energy consumption, natural resources use, or solid waste disposal requirements. In the parlance of life cycle assessment, to be truly useful to consumers and producers, studies must eventually go beyond the inventory step to the impacts and improvements stages.

The third key point about life cycle assessment is important for this evaluation. Sponsors of life cycle studies do not commission them out of idle curiosity. Rather, they wish to use the results to make the "best" choice from an environmental perspective. Thus, the use to which these studies are put is invariably to juxtaposition two sets of environmental demerits associated with two different products or with two different versions of a process. The object is to determine which choice causes the least net environmental harm. Because life cycle assessments are intended to inform a choice, their value ultimately flows from providing a net decrease in environmental harms by guiding choices to greener alternatives.

To some extent, the life cycle community's definition of the final segment of analysis (Step 3) as the "improvements" stage tends to obscure the fundamental fact that life cycle assessment seeks to help in making choices between competing alternatives. Indeed, the term "improvement" conjures up the image of researchers identifying and mitigating direct environmental harms caused by a product or process, such as reducing direct air or water emissions. This, however, is only part of the story.

Often life cycle assessments explore the tradeoffs between two processes whose environmental differences are largely the result of indirect sources of demerits, not direct ones. One process might use more water and virgin materials, but less energy, than another. Thus, the "improvements" portion of life cycle assessment is really an analysis of tradeoffs involving environmental demerits from both indirect and direct sources. Trading off environmental damages from all sources is very different from attempting to minimize the direct pollution consequences of an activity, as will be shown later in this evaluation.

## 2.2 Environmental Life Cycle Assessment In Practice

The purpose of this section is to summarize the state of life cycle assessment in practice to gain some sense of what can be accomplished in reality. Hence, this discussion is not intended to be a review of the literature, only a glance at life cycle assessment in practice.

### General Approach

Environmental life cycle assessments typically arise from discussions about whether one type of product or major input to a product has fewer environmental demerits than another. Probably the most famous are recent studies of the relative environmental demerits of reusable and single-use diapers (which most would refer to as the cloth versus disposables question), paper and plastic grocery sacks, and foam and paperboard food containers. Most life cycle assessments begin with an understandable curiosity concerning which of two (or more) options does the least environmental harm. Of course, the hope is that one can calculate all of the environmental demerits of the options and then select the more environmentally benign one, thereby generating a net environmental improvement.

Life cycle assessments begin by specifying the "system" surrounding the activity or product in question. In general, the system is thought of as one requiring inputs from the earth, e.g., energy, natural resources, etc., and generating outputs of wastes, emissions of chemicals, and so forth. Activities in the system to be studied normally include raw materials acquisition, manufacturing, fabrication, distribution, use and reuse, and waste management. The majority of the effort in life cycle studies is on specifying numerous linkages from sector to sector, and activity to activity, to assess direct and indirect sources of environmental demerits.

Practical life cycle studies use public and private data sources on process technologies and their inputs and outputs, sector-by-sector, to generate a rough sketch of the total "cradle-to-grave" environmental demerits of a product or process. Given the nature and aggregation of the information -- national averages, "typical" process configurations, engineering process flows, and professional judgement -- what emerges from these studies is a list of the "typical" or "average" environmental demerits per unit of the product or process.

Life cycle assessment inventory results typically list the per unit energy requirements in Btus, water requirements in gallons, landfilling requirements in cubic yards, atmospheric emissions of chemicals in pounds, and water emissions in various units, including pounds or gallons, oxygen demand, suspended solids, and so on. Studies attempt to measure contributions to the environmental demerits from both direct and indirect sources associated with the product or process in question.

For the most part, existing studies indicate that one product may have lower average, or typical, levels of some environmental demerits than another product, but generate higher levels of other demerits. Because efforts so far have only focused on the inventory portion of the assessment, rarely do any of these studies attempt to supply methods for trading these demerits against one another. From the perspective of the three stages of life cycle assessment, tradeoffs must await the "impacts" and "improvements" stages of the analysis.

The Grocery Sack Example

A typical example of life cycle assessment is a recent report on plastic and paper grocery sacks prepared by Franklin Associates.[1] Motivated mostly by reference to scarce landfill capacity, this study sought to inventory all of the energy and environmental inputs of these two types of sacks by performing a "cradle to grave" analysis. The authors explicitly targeted energy use, emissions to air and water, and solid waste requirements. According to the study:

> (t)he analysis involves all steps in the life cycle of each grocery sack, including extraction of raw materials from the earth, processing these materials into useable components, manufacturing the package materials, distribution of the package, and final disposition of the package (whether recycled, incinerated, or landfilled). (p.2-1)

In terms of methodology, the study adopts what might be thought of as a process-engineering approach whereby producing each type of sack is conceptualized as a series of

[1] Franklin Associates, Ltd, Resource and Environmental Profile Analysis of Polyethylene and Unbleached Paper Grocery Sacks, prepared for The Council for Solid Waste Solutions, June 1990.

processes which lead to the ultimate manufacturing, use, and reuse or disposal of the sacks. Again, quoting from the study:

> (A)ll processes and subprocesses were first considered to be separate, independent systems. For each process or subprocess such as oil extraction or ethylene production a standard unit, such as 1,000 pounds of output, was used as a basis for calculations. A complete materials balance was first performed. If marketable co-products or by-products were produced, the materials inputs were adjusted to reflect only the input attributable to the output being considered. The wastes and energy were adjusted also. (p.2-3)

Results reported in the Franklin study list the total energy requirements of the two types of sacks at various ratios of polyethylene-to-paper sacks and at different assumed recycling rates. On a "per 10,000 uses" basis, the report lists landfilling requirements, the amount of incinerator ash generated, total energy requirements in Btus, and the various emissions to air and water associated with the life cycle of making, using, and reusing or disposing of these two types of sacks.

The Franklin study is also only the "inventory" stage of the analysis, which is clear from the following:

> The scope of this analysis is to identify where and what wastes are generated through a cradle-to-grave analysis. No attempt is made to describe what the effects from these wastes may be. In other words, no attempt has been made to determine the relative environmental effects of these pollutants such as fish kills or groundwater contamination as there are no accurate data available. (p.2-8)

The report goes on to clearly detail the numerous assumptions made and omissions necessary in conducting the analysis.

<u>Observations</u>

In examining actual examples of life cycle assessments, one is struck by the complexity of the tasks required to comprehensively measure the indirect sources of environmental demerits. Numerous complex flow diagrams of industrial systems appear in these studies, along with a host of input data and assumptions, and page after page of numerical results. Sensitivity analyses also figure prominently in life cycle assessments, especially regarding key disputed parameters. For example, in the Franklin study, precisely how many plastic grocery sacks are needed to replace a paper one is very important to the analysis and results. Similarly, exactly how many cloth diapers are needed to replace disposables is critical in that evaluation.

Nevertheless, the picture that recent examples of life cycle analysis paint is one of researchers attempting to compute the total environmental demerits for a product or process to the best of their ability using whatever data are available. It is understandable that their results then reflect the level of aggregation of information realistically available and that various complexities are simply not addressed.

While life cycle assessments seek to be internally consistent and generally attempt to be as comprehensive and detailed as possible within time and budgetary constraints, one aspect of these studies is somewhat troubling, even to the researchers involved. Actual examples of life cycle assessment always seem to contain a long list of caveats, limitations, and data deficiencies. Repeated attempts to remedy these by delving deeper into details and expanding the sets of economic activities incorporated suggest that the results are not robust. That is, it seems easy to find new sources of significant environmental demerits, or radically alter their magnitude, and thus change the latest "answer" by expanding the scope of the analysis or by refining and disaggregating the input information.

## 3. Requirements for Accurate Environmental Life Cycle Assessment

To evaluate the prospects for practical life cycle assessment, it is best to return to the fundamental questions these types of analyses seek to answer. Doing so provides a clear sense of the nature of the analytical and empirical efforts required to provide information that is useful to consumers and producers in making environmentally better choices. This section introduces and analyzes several fundamental propositions concerning life cycle assessment which, taken together, point to fairly strong conclusions about the likelihood that these analyses will ever be sufficiently robust in practice.

### 3.1 There is not usually a single "correct" set of environmental demerits for a product or process

Life cycle assessments are extremely data-intensive tasks, especially in their attempts to identify and quantify the indirect sources of environmental demerits. Understandably, these analyses begin with the information normally available, supplementing this with a variety of different data elements from many sources. Life cycle assessments in practice demonstrate that trying to sketch even a preliminary picture of the total environmental demerits for a typical example of a product or process can be a time-consuming and difficult undertaking.

<u>More Than One "Right" Answer</u>

The natural tendency to use whatever data are available to gain some sense of total direct and indirect environmental demerits has obscured a very important fact. Indeed, a fundamental problem with life cycle analyses is the failure to recognize that normally there is no single "correct" and complete tabulation of the environmental demerits of a product or process.

For example, the "correct" product decision concerning diapers may be different for people in different situations. The environmental concerns associated with diapers normally consist of water use, pollution resulting from energy production, and effluent discharges of waste water for cloth, and use of oil, occupation of scarce landfill space, and the risks of human feces in landfills for disposables. But the intensities of these environmental harms depend on many different factors, such as the water body into which the effluent is discharged, the type of fuel used to heat the water for washing, the location of the energy production, and the degree to which the social cost of landfill space and water use exceed their prices.

All of the environmental concerns associated with diaper use (and any others one cares to include) may vary significantly by geography and even the time of day, <u>and</u> they will change over time. Hence, the relevant question is not "Which diapering choice is better for the nation?", rather it is "Which diapering choice is environmentally better for a particular set of circumstances?". Because the existence, extent, and intensity of the various environmental problems associated with alternative diapering choices can vary so widely, the number of sets of unique circumstances for which the correct choice should then be ascertained is very large. Moreover, the right answer today for a particular person may be the wrong answer tomorrow as economic and environmental circumstances change.

It is easy to see that the correct environmental demerit levels concerning consumer products vary depending on people's individual circumstances. The same is true of producer decisions concerning process changes and other choices. The correct answer for one producer could be different for another in other circumstances. A process that uses less water but generates more solid waste may be best for a producer in the west, but not for one in the east, where landfill space may be relatively more scarce.

Some might argue that the goal of life cycle analysis is not to indicate the "correct" answer, but rather simply to provide extra information to consumers and producers in making their choices. This may be true, but the usefulness of this additional information critically depends on it being correct. Hence, if the actual levels of the various environmental demerits depend on a variety of specific circumstances, then individuals situated in those varying circumstances will need environmental demerit information relevant to them to make correct choices. Seeking a single, national-average tabulation of environmental demerits misses the essential texture of the problem.

Seeking One "Answer" Could Do Harm to the Environment

Clearly, the nature of this limitation is not fully appreciated in the life cycle literature. Providing a single set of estimated environmental demerits when the correct answer really does vary across individuals will suggest the environmentally correct option for some people and the wrong one for others. Where the guidance is wrong, acting on a life cycle assessment's advice will cause increased environmental damages. Yet, it is tempting to argue that overall, the net impact on the environment will be positive even though the single set of estimated environmental demerits will be correct for some people and incorrect for others. That is, surely we will not do net damage to the environment if the national average levels of demerits point to one product over another.

Unfortunately, it is possible that this focus on estimating a single set of environmental demerits for a product or process could actually harm the environment, not help it. The key issue here is that one should not compare the overall environmental consequences of everyone choosing one product with those that would result if everyone chose the other. Rather, one should compare the environmental effects of any life cycle assessment-induced changes in consumer or producer decisions with the environmental effects of their current choices.

To illustrate the importance and implications of this problem, consider the following highly simplified example of the diapering decision. Table 1 lists the levels of environmental demerits caused by two different people's decisions about diapers. Mary, who uses disposable diapers, owns an electric washer and dryer system in an area where water tends to be relatively more valuable and power generation involves relatively more pollution than in other locations.

**Table 1**

**Diapering Demerits and Specific Circumstances**

**Numbers of Demerits**

| | Mary | | John | | National Average | |
|---|---|---|---|---|---|---|
| Category | Cloth | Disposables | Cloth | Disposables | Cloth | Disposables |
| Energy/Air | 20 | 5 | 10 | 5 | 15 | 5 |
| Virgin Materials | 5 | 20 | 5 | 20 | 5 | 20 |
| Water | 20 | 0 | 5 | 0 | 12.5 | 0 |
| Effluent | 10 | 5 | 10 | 5 | 10 | 5 |
| Solid Waste | 5 | 10 | 10 | 50 | 7.5 | 30 |
| Totals | 60 | 40 | 40 | 80 | 50 | 60 |

Note: **Example assumes that the results of a life cycle inventory can be translated to a common metric through an impacts assessment. This may not be at all easy in practice.**

John, who uses cloth diapers, lives in a crowded eastern city where the main problem is the high social cost of solid waste disposal. As the entries in the table indicate, each of these individuals currently makes the environmentally correct choice for their circumstances, Mary electing to use disposables and John cloth.

Now suppose a life cycle assessment produces environmental demerit results for typical, or national-average cloth and disposable diapers, and concludes that one of these options is more environmentally benign. In this example, averaging the environmental demerits for both Mary and John over the two choices yields a score of 50 for cloth and 60 for disposables, so such a study would recommend cloth over disposables. Clearly, starting from a situation in which both of our hypothetical people were already making the "right" choice (by accident or otherwise), if they both follow the advice of the study, one will switch from making the right choice to the wrong one.

The example generalizes to situations with more than two people, and of course, one can alter the assumptions to show that in other circumstances, acting on the advice of a life cycle assessment's single list of environmental demerits enhances environmental quality. Yet, the essential point is that it is possible for a life cycle assessment to increase environmental harms by neglecting the details and heterogeneity of reality. Even worse, there is no way to know whether a life cycle study that reports a single list of the environmental demerits will lead to overall environmental improvement or harm unless these details are explored. In the example, the life cycle researcher does not have the specific demerit levels for Mary and John individually, only the national average information is estimated. Hence, unless the specifics of different individuals' circumstances are investigated, it is not clear that the net environmental effects will be beneficial.

<u>Observations</u>

The fact that the actual environmental demerits of a product or process depend on a variety of factors that vary across the country and change over time helps to explain some of the frustration many life cycle researchers have experienced in recent years. In many examples of these analyses, the "answer" tends to shift from one product or practice to the other when sometimes small assumptions are altered and if more detail and disaggregated input data are used. Given that there isn't one right answer, however, this should not be at all surprising.

Unfortunately, the tendency in the life cycle research community has been to continue to assume that a single tabulation of environmental demerits for a product or process will suffice, rather than many sets that reflect varying circumstances. Life cycle assessment researchers further suggest that by using common rules and data sets, everyone will arrive at this single answer for a particular product or process. Codifying rules to obtain consistency is unproductive for it seeks to define a single correct set of inputs for the analysis, not to determine what the correct levels of environmental demerits are in different specific circumstances.

Some reluctance to recognize that there isn't one set of environmental demerit levels in most life cycle assessments is understandable. Once this is admitted, the number of different times the same products and processes, such as diapers and packaging, must be studied to account for location and other significant determinants of actual environmental harms becomes large and potentially open-ended. Even worse, however, is that as environmental and economic linkages evolve over time, all of these studies must be repeated.

Pursuing a single list of environmental demerits despite the fact that this conceals the true diversity of the problem has been abetted by the general unavailability of the disaggregated information required to tailor the analysis to specific circumstances. Because tracing the indirect environmental demerits for a product even at an aggregated, typical level is a challenging task, life cycle researchers have more than enough complexity to handle already, and they can generate large amounts of information. Thus, very discretely, what really amounts to a fundamental methodological problem is converted to just one of the many standard limitations and qualifications of life cycle assessments in practice.

Some might argue that the inventory stage of life cycle assessment supplies information that can then be applied in a disaggregated way by users of the studies to reflect their particular circumstances. This is a plausible idea, but ultimately not realistic. It is conceivable, for example, to imagine that consumers and producers could try to attach their own locality's environmental demerits associated with solid waste disposal to the reported landfilling requirements. It is harder, but still possible to imagine them determining the actual environmental impacts of their specific energy use and adjusting the life cycle assessment's results accordingly.

But these are the easiest problems people would face in trying to tailor life cycle assessment results to their specific circumstances. The hallmark of life cycle assessment is in cataloguing all of the indirect sources of environmental demerits of products and processes. These could well vary across individual consumer and producer circumstances in ways completely unknown to the users of life cycle inventory results, and involve demerits from activities that take place in locations far removed. Thus, to fine-tune a life cycle assessment's results to one's specific circumstances essentially requires one to trace all of the indirect environmental demerits again -- which is, of course, another life cycle assessment itself.

### 3.2 Life cycle assessments are costly, and obtaining robust results could be prohibitively expensive unless reasonable boundaries can be specified

Most of the examples of life cycle assessments discussed so far in this paper are highly simplified to illustrate some basic analytical points. Yet, accurate life cycle assessment for a given product or process that would correctly guide consumer or producer choices can be extremely complex and costly. A researcher contemplating conducting a life cycle assessment is confronted by numerous details, all of which are difficult to ignore given that the goal is to measure total environmental demerits, both direct and indirect. Moreover, as just demonstrated, the efforts necessary to define a product's environmental demerits for a particular set of circumstances will have to be repeated for the many different situations in which individuals interested in the product's demerits find themselves.

<u>Life Cycle Assessment is Expensive and Complex</u>

A useful example of how life cycle assessments can become very complex is provided by a discussion of setting boundaries for such analyses contained in EPA's <u>Life-Cycle Assessment:</u>

Inventory Guidelines and Principles.[2] On page 20 of that report, a figure (reproduced here) appears indicating an initial attempt to define the system's boundaries for a life cycle assessment of a bar of soap. The flow diagram lists a variety of activities related to soap manufacturing including grain production, cattle raising, meat packing and tallow rendering, salt mining, caustic manufacturing, forestry paper production, and postconsumer waste management. It is worth quoting from the ensuing advice in the guidance document on defining appropriate boundaries.

> [The figure] shows an example of setting system boundaries for a product baseline analysis of a bar soap system. Tallow is the major material for soap production, and its primary raw material source is the grain fed to the cattle. Production of paper for packaging the soap is also included. The fate of both the soap and its packaging end the life cycle analysis of this system. Minor inputs could include, for example, the energy required to fabricate the tires on the combine used to plant and harvest the grain. (p.20, emphasis added)
>
> If the life-cycle inventory were intended to analyze whether bar soap should be manufactured using an animal-derived or vegetable-derived raw material source, the system boundaries and units of analysis would be more complicated. First, the system flow diagram would have to be expanded to include the growing, harvesting, and processing steps for the alternative feedstock. Then the performance of the finished product would have to be considered. (p.20)
>
> Suppose an analyst wants to compare bar soap made from tallow with a liquid hand washing soap made from synthetic ingredients. Because the two products have different material sources (cattle and petroleum), the analysis should begin with the raw materials acquisition steps. Because the two products are packaged differently and may have different chemical formulas, the materials manufacturing and packaging steps would need to be included. Consumer use and waste management options should also be examined because the different formulas could result in varying usage patterns. Thus for this comparative analysis, the analyst would have to inventory the entire life cycle of the two products. (p.20)
>
> However, if the liquid hand soap also had a skin moisturizer in its formula, the analyst would need to include a moisturizing lotion product in the boundaries of the bar soap system on two conditions. The first condition would apply if the environmental issues associated with this component were germane to the purpose of the life-cycle assessment. (p.21)

Even in this simple example, the complexity of life cycle assessment is obvious. Many items of potential importance, such as whether the two soap products require different amounts of transportation or water, were not even explicitly mentioned. Moreover, the statement concerning the energy necessary to make the tires on the combine that harvests the grain to feed

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[2] Vigon, B.W, D.A Tolle, B.W. Cornaby, H.C. Latham, C.L. Harrison, T.L. Boguski, R.G. Hunt, and J.D. Sellers, Life-Cycle Assessment: Inventory Guidelines and Principles, prepared for U.S. Environmental Protection Agency, November 1992.

Figure 1

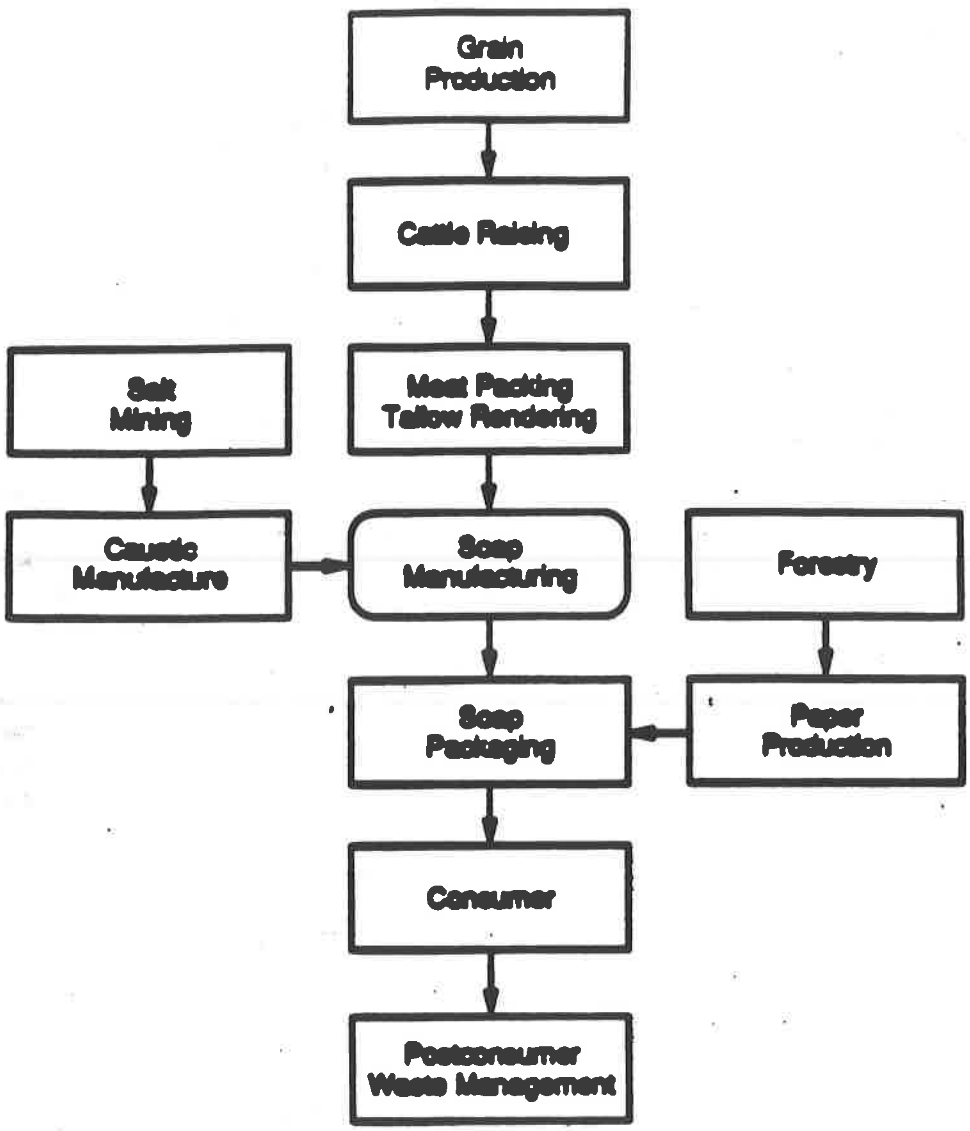


**Figure 3**
**Example system flow diagram for bar soap**

Source: Reproduced from Life-Cycle Assessment: Inventory Guidelines and Principles, p.20

the cattle whose tallow is used as an input to soap manufacturing should give one pause. The complexity of the analysis appears to be limited only by the ingenuity of the researcher and his or her research resources.

Thus, what at first seems to be a simple tallying of environmental demerits instead escalates into a major data-intensive investigation. First, one specifies the list of potential environmental demerits, which normally consist of a variety of pollution possibilities typically associated with energy use, chemical emissions, primary resource extraction, natural resources use, and waste generation and management. These demerits are assumed to be generated at a variety of points in the entire economic system.

Next, the really hard work begins. As suggested in the guidance document's example, the analyst must work backward from the product or process in question through its inputs and the activities necessary to make those inputs, pausing along the way to measure any environmental demerits. It is useful to think of this process as one in which the economic activities associated with the product or process and its inputs "fan" outward to more and more distant processes, each of which causes indirect environmental demerits through energy use, natural resource use, chemical emissions, and waste generation. Of course, not only the nature of these activities and their potential demerits are important, but their locations are as well, for the intensity and damages of the various environmental demerits can depend on many site-specific factors.

The analysis also must investigate indirect environmental demerits that might be caused by activities "downstream" from those specifically under study, such as a product's use, and reuse or disposal, because these activities could also create environmental demerits. In most cases, a number of layers of activities may happen sequentially before matters finally end, so the same "fanning out" of possible activities occurs here as well. Similarly, the intensity of the environmental demerits caused by use, and reuse or disposal, will generally vary by location and other factors, so this also must be taken into account in the tabulation.

Actual Demerits Caused is the Goal

Obviously, the life cycle assessor faces a daunting challenge in tracing through from activity to activity to identify and measure indirect sources of environmental demerits. Yet, another hurdle exists that is often ignored in the life cycle literature. Specifically, it is not enough to identify environmental demerits "associated with" products or processes. Instead, one must conceptualize changing a consumer's or a producer's choice, deciding between plastic or paper grocery sacks for example, and then determine to what extent the environmental demerits change in response. This is not an easy task because often the actual changes in economic activities that result, and the environmental demerits caused by them, can be different from what one might expect based on casual analysis, and require significant detailed information to predict.

For example, if a less energy-intensive product is selected over a more energy-intensive one, less power will be required. But exactly what fuel will be saved and what environmental demerits will be avoided are difficult to determine. Electric power is routinely traded across power grids, so it is not clear precisely where less electricity generation will occur much less what environmental harms will be avoided. Worse still is the fact that sometimes the energy use reduction is in the home, say, hot water heating in the case of diapers. Here, because the environmental demerits of electricity and another fuels, such as natural gas, are different, one needs to know what type of hot water heater is used to estimate the reduction in environmental demerits.

A similar complication is that sometimes the reduction in an environmental demerit promised by a life cycle assessment doesn't actually materialize. Suppose significant environmental demerits are the land erosion and water quality effects of logging in the U.S. But if the U.S. timber industry sells into a large international market, it is not at all clear that a life cycle assessment's prediction that altering choices toward products that use less virgin timber will actually reduce the amount of U.S. logging and its associated damages. Under plausible conditions, the same amount of U.S. logging continues regardless of any changes in consumer and producer choices guided by life cycle assessments. Thus, predicting what will actually happen to the levels of economic activities remotely connected to the decision under study, and the environmental demerits they cause, can be a very tricky business.

Life cycle analyses in practice are thus confronted with numerous conceivable sources of environmental demerits associated with a product or process, including indirect ones that can be quite remote. The length of the list of environmental demerits of concern, along with any reasonable estimate of the number of economic activities conceivably associated with the product in question, require setting reasonable boundaries to make life cycle assessment practical, otherwise these studies face enormous difficulties. From an epistemological point of view, identifying and measuring all possible changes in environmental demerits, especially indirect ones, caused by changing a consumer or producer product or process decision is "knowable". Actually "knowing" them all, however, would involve a preposterous level of effort.

<u>Complexity is Unavoidable</u>

That seeking to catalogue all (or at least "enough") of a product's direct and indirect environmental demerits is complex and costly should not be surprising. Life cycle assessors essentially seek to develop an information system that provides the same type of data normally summarized and communicated by the price system. Prices of economic goods and services summarize the costs of their supply regardless of how remote those costs are from the product or service in question. As goods move through the chain of production and commerce, the cost of the inputs required to convert primary inputs (labor, capital, land, raw materials, etc.) into successive stages of a product's supply are added to its price. All of this information transmission is accomplished without the guidance or direct analysis of any single entity, but as the result of the anonymous functioning of the market and the price system.

Life cycle analyses, however, are motivated by a fundamental belief that many environmental demerits are not adequately captured in prices, or at least that social concern for these environmental problems and natural resources surpasses merely their prices. As a result, they must attempt to trace from products and processes back through layer upon layer of other economic activities associated with them to identify and quantify indirect sources of environmental demerits.

Thus, the real problem for life cycle assessment is not just measuring environmental demerits for known processes and activities, for one can reasonably expect that once the activity, its location, and other relevant features, are specified, experts can judge whether it causes significant environmental degradation or other harms. Instead, it is the need to trace through so many of the economic activities connected to a product or process, stopping to determine whether demerits exist at each point, that makes life cycle assessment so complex and difficult.

Central Tension of Setting Practical Boundaries

Clearly, life cycle assessments must set reasonable boundaries in order to be at all feasible in practice, for the pursuit of indirect sources of environmental demerits cannot extend to every conceivable economic activity even remotely associated with the product or process being studied. The central issue here is the ability to establish practical boundaries for these analyses within which the conclusions reached can be considered robust, in that one has confidence that they will not be overturned easily.

The acknowledged necessity of establishing boundaries to avoid being overwhelmed by complexity and details has created a serious tension in life cycle assessment today, one that pits details, scope, and accuracy of such studies -- which determine whether their results have any real value -- against the cost and feasibility of conducting them -- which govern their practicality.

On the one hand, practical life cycle assessment researchers labor hard to incorporate whatever details and complexity they can, and generate large amounts of information. Despite the inevitable caveats, limitations, and omissions, it is assumed that what can be (or, perhaps, might be) accomplished in practice still has value to consumers and producers in helping them choose environmentally more benign products and processes. This is the sense conveyed by many statements concerning boundary setting in the life cycle literature. For example, in the section pertaining to the raw materials and energy component of life cycle assessment in SETAC's A Technical Framework for Life Cycle Assessments,[3] the following discussion is revealing:

> A fundamental concept that must be accepted by anyone undertaking an inventory is that the raw materials acquisition system not only extends all the way back to the source for each primary raw material, but also extends laterally to include all inputs of energy, materials, and equipment necessary for executing each step of acquisition. Obviously such an analysis soon becomes intractable without some methodology for screening insignificant contributions. It may be necessary to extend the analysis of material inputs beyond the first level to second or even multiple levels to identify all significant contributions. In some cases such secondary contributions are the source of the most crucial impacts of all.
>
> The issue from an analytical point of view is how to define the criteria that will determine what is insignificant and can be discarded or ignored. In the absence of superior logic, an analyst must rely on professional judgement or must establish an arbitrary threshold (e.g., components comprising less than 5 percent of the inputs will be ignored). (p.34, emphasis added)

[3] Society of Environmental Toxicology and Chemistry and SETAC Foundation for Environmental Education, Inc., A Technical Framework for Life-Cycle Assessments, January 1991.

On the other hand, the guidance literature states that setting arbitrary boundaries on life cycle assessments imposes limitations on the accuracy and comprehensiveness of their results. Therefore, when arbitrary boundaries are set, one cannot make statements about the total level of, or change in, any environmental demerit categories that might be affected outside the system examined. For example, the EPA's Life-Cycle Assessment: Inventory Guidelines and Principles states the following:

> Depending on the goal of the study, it may be possible to exclude certain stages or activities and still address the issues for which the life-cycle inventory is being performed. For example, it may be possible to exclude the acquisition of raw materials in a life cycle inventory without affecting the results. Suppose a company wishes to perform an internal life-cycle inventory to evaluate alternative drying systems for formulating a snack food product. If the technologies are indifferent to feedstock, it is possible to assume the raw materials acquisition stage will be identical for all options. If the decision will be based on selecting a drying system with lower energy use or environmental burdens, it may be acceptable to analyze such a limited system. However, with this system boundary, the degree of absolute difference in the overall system energy or environmental inventory cannot be determined. The difference in the product manufacturing stage, although significant for the manufacturer, may represent a minor component of the total system. Therefore, statements about the total system should not be made. (p.19)

The source of the tension is obvious. What can be done in practice necessarily involves setting limitations on the study's boundaries, reining in the scope, and neglecting the immense complexity and details of the real world. Still, one would think that what can be done in practice, albeit imperfect, is still valuable. However, if one cannot make statements about total changes in the levels of particular environmental demerits if changes in them occur outside the boundaries set for the study, what does this mean for the value of practical life cycle assessments? Can non-arbitrary and defensible boundaries be set to make life cycle assessment both practical and accurate?

### 3.3 It may not be possible to define rational boundaries that will ensure that practical life cycle assessments are also robust

The key issue in setting analytical boundaries for a life cycle assessment is whether in doing so, one has any confidence that the excluded elements, or lack of disaggregation and detail, could harbor environmental demerits large enough, or sufficiently different, that consumers and producers would wish to know them before making their product or process decisions. Of course, questions concerning what level of disaggregation and detail are required to be confident that the results are robust are common ones for all economic analyses.

Analytical Boundaries in Principle

The intellectual process of how one decides the scope and depth of conventional analyses is important to appreciate. Ordinarily, decisions about whether further disaggregation of input data or additional analysis of certain aspects of a problem are worthwhile are guided by balancing the value of the extra information gained against the costs of acquiring it. In conventional analyses, the magnitude or importance of the additional information one could obtain through more study is generally correlated with elements of the problem that are known.

For example, one might decide not to disaggregate an industry sector in calculating compliance costs for a regulation because the likely variation in costs is small based on inherent similarities of their activities. Hence, having started by investigating first the broad determinants of the total regulatory costs, additional disaggregation is not likely to significantly alter the results. The key to this process is that one begins with what one already knows are the largest determinants of the question -- economic size, activities subject to the regulation where compliance will be particularly costly, economic costs of the regulated activity relative to the total product, and so forth -- and works down a list of less and less significant factors.

Of course, surprises can occur in the process, just as statistical confidence intervals allow for small probability events in the "tails" of their distributions. Nevertheless, the defining feature of conventional information gathering and analysis is that decisions about levels of disaggregation and further data collection can be made rationally on the basis of an observable set of factors that help predict the influence and importance of elements not investigated.

Boundaries in Life Cycle Assessment

There is a subtle difference between ordinary analyses and life cycle assessment, however, that makes it far harder to set boundaries that are both feasible and defensible for life cycle analysis. The critical element that makes setting boundaries problematic for life cycle assessment has to do with the information the researcher can use to establish rational expectations regarding the potential influence on the results of adding details and expanding the scope.

The fundamental problem is that there is no a priori basis for assuming that the elements excluded from the assessment are necessarily smaller than those included. This is because the indirect sources of demerits that life cycle analysis seeks to quantify are usually not incorporated into prices. Hence, economic measures of "remote" or "small" activities related to a product do not translate directly into conclusions about the "significance" of the environmental demerits associated with those activities.

It is therefore much harder to safely ignore details and remote activities in life cycle assessments because the researcher has no clear basis for assuming that accounting for them will not reveal substantial environmental demerits, or levels of demerits significantly different from those already estimated. For example, while it is true that the amount of electricity used in an activity very remote from the product or process in question will be a small input, it still might not be safe to exclude it from the analysis. The ultimate demerit of interest is not the electricity use per se, but the environmental damages it causes. It is entirely possible for an activity that constitutes a small portion of the overall cost of a product to harbor a particular environmental demerit of great significance, indeed, far out of proportion to the activity's cost contribution to a product.

Hence, the essence of the problem in using practical boundaries to make life cycle assessments feasible is that one generally does not know whether exploring a set of activities currently excluded, or disaggregating and developing location-specific information, will not uncover environmental demerits of sufficient importance to warrant their inclusion. Measures of "small" and "remote" inputs based on cost or other information known to the researcher do not provide a logically sound basis for assuming that the possible environmental demerits associated with that input are small as well. Since what is sought is not signalled by elements of the problem known to the researcher, such as costs, it is difficult to decide rationally when to exclude sectors from the analysis or when to cease disaggregating information.

In light of this difficulty, boundaries that render life cycle assessment feasible in practice will generally be far more restrictive than those necessary to inspire confidence that the details ignored and the elements excluded from the analysis will not harbor environmental demerits significant enough to warrant inclusion. Because the levels of environmental demerits caused by activities many steps removed are not known or necessarily signaled to the researcher through prices or costs, it is hard to defend their omission from the analysis. But practical life cycle assessments must satisfy realistic constraints on funding, so they will always be haunted by unexplored details and hidden indirect sources of environmental demerits that could be important to the results.

The problem of boundary setting, or deciding the degree of disaggregation, is not simply an academic one in life cycle assessment, for it largely explains the character and outcomes of real-world attempts to conduct them. For example, several recent reports[4] assessing the relative life cycle environmental impacts of cloth and disposable diapers devote considerable effort to tracing the indirect impacts of each alternative in greater depth than previous studies, although they arrive at mixed and different conclusions. Moreover, the study prepared for the National Association of Diapers Services, which concludes that the overall environmental impact of cloth diapers is less than disposables, devotes nearly six pages (out of a total of 40 pages in the summary report) to describing why its results are superior to previous attempts -- because its boundaries are more expansive than earlier assessments.

Another anecdote on the diapers controversy is illuminating. According to one observer of the debate, researchers investigating cloth diapers are said to have used the national average amount of water required to grow cotton, which is a major input for cloth diapers. Yet, according to this source, the cotton required to manufacture cloth diapers is a particular variety grown only in the southwestern U.S. The social cost of water in this region is presumably far higher than for the nation as a whole, so the environmental demerits of cloth diapers were probably severely underestimated.

This also illustrates not only the difficulties of setting study boundaries and levels of aggregation, but also how life cycle assessment differs fundamentally from ordinary analysis. In conventional studies, one might seek to measure the divergence of the social and private costs of water use. Common sense suggests that examining these conditions in the desert southwest would clearly be one of the top empirical priorities. In life cycle assessment, however, what turns out to be a very significant determinant of cloth diaper environmental demerits is several steps

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[4] Lehrburger, C., J. Mullen, and C.V. Jones, Diapers: Environmental Impacts and Lifecycle Analysis, Report prepared for the National Association of Diapers Services, Philadelphia, PA, January 1991; and Franklin Associates, Energy and Environmental Profile Analysis of Children's Single Use and Cloth Diapers, Report prepared for the American Paper Institute and the Diapers Manufacturers Group, May 1992.

removed from the diapering decision itself, and would not be known without explicitly investigating cotton growing specific to diaper manufacturing.

Observations

It might be pointed out that it is possible to construct cases in which a life cycle assessment's practical boundaries based on feasibility are sufficient to impart robustness to the results as well. Just as it is epistemologically possible to imagine conducting a "perfect" life cycle assessment, there is no reason to doubt that one can imagine cases in which practical life cycle assessments are also accurate and robust. Nevertheless, the fact that one can construct such hypothetical conditions and circumstances does not mean that reality will conform to them. Most life cycle assessments target consumer and producer decisions that are connected to a wide variety of activities that potentially cause environmental demerits. These are not the types of situations one imagines when constructing hypothetical situations in which feasible life cycle assessments also provide robust results.

Some might also argue that surely the probability of excluding an environmental demerit of sufficient importance to the analysis falls as one successively analyzes smaller and smaller sectors ever more remote from the product or process in question, or when one continues to further disaggregate and incorporate more details into the analysis. Assuming one starts at a virtually perfect and complete life cycle assessment -- one that accounts for every nuance and detail, and for all of the many ways in which indirect environmental demerits can arise -- it does seem reasonable to think that excluding a few elements might not substantially alter the results.

The relevant question, however, is not so much the theoretical possibility of conducting less-than-perfect life cycle assessments that are still robust, but instead whether one can rationally and safely establish boundaries for these analyses given where life cycle studies really begin. That is, the central issue is whether the boundaries necessary to make life cycle assessments feasible in practice can be justified on the basis of well-founded expectations about the impact on the results of excluded sectors or added details. In general, life cycle assessments encounter the financial, analytical, and informational constraints of practical analysis far before they reach the point at which one has much confidence that added details and expanded boundaries will not substantially affect the results.

This problem is especially acute in light of the results normally generated in life cycle assessments. Most products studied are connected to a wide variety of activities, most of which use energy, involve a large set of emissions to air and water, require use of natural resources, and generate wastes. When comparing which version of a product to use, what type of diapers for example, both alternatives generally have many direct and indirect demerits, with some higher for one version and others higher for the alternative. One decides which of the two "evils" to select by netting the demerits out and trading off higher and lower levels of specific environmental problems. For practical life cycle assessments, it is highly likely that additional disaggregation or including more sectors and activities could alter the estimated levels of demerits for one or the other product enough to tip the balance. Indeed, this is exactly what happens in practice.

Life cycle researchers are aware that using practical boundaries based on real-world feasibility raises the issue of accuracy. Indeed, recent guidance documents have sought, but failed to find, rules for determining study boundaries that will make them feasible in practice but not sacrifice confidence at the same time. In light of the key points raised in this evaluation, it is not surprising that those developing life cycle guidance have not been able to articulate rules for setting boundaries.

A careful reading of the guidance literature thus reveals considerable hesitancy in establishing and defending rules of analytical boundaries. In a sense, the search for rules to limit life cycle boundaries seems to be motivated mainly by unanimous agreement that without them, these studies are not feasible, rather than by the belief that such rules are rational and defensible. For example, in EPA's Life-Cycle Assessment: Inventory Guidelines and Principles, the following statements are interesting:

> A theoretically complete life-cycle system would start with all raw materials and energy sources in the earth and end with all materials back in the earth or at least somewhere in the environment but not part of the system. Any system boundary different from this represents a decision by the analyst to limit it in some way. Understanding the possible consequences of such decisions is important for evaluating tradeoffs between the ability of the resulting inventory to thoroughly address environmental attributes of the product and constraints on cost, time, or other factors that may argue in favor of a more limited boundary. Too limited a boundary may exclude consequential activities. (p.19)
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> In a traditional inventory, a material contributing less than 1% by weight of the total system typically contributes less than 1% of to the total emissions of a particular inventory item and can be omitted from the inventory. The "less than 1%" effect is generally considered insignificant. This approach is based on many years of conducting such studies and not on statistical or technical grounds. However, it does not make any assumptions regarding the environmental significance of the emission. Thus, one problem with a blanket application of this approach is that toxic materials could inadvertently be eliminated from the inventory analysis even though they present a serious potential environmental impact. (p.69, emphasis added)

Thus, the central problem with setting feasible boundaries in a life cycle assessment on the activities to be included, or failing to disaggregate to account for important details, is that this tends to rob them of robustness. Given the boundaries normally required to make life cycle assessments feasible in practice, it is hard to know the potential magnitude of what has been ignored in the analysis because the sizes of the environmental demerits sought are not explicitly signaled by information known to the researcher. This leads to the unusually awkward result that one cannot exclude sectors and activities, or ignore details and complexity, unless one has verified that it is "acceptable" to do so. This "verification", however, is very close to what it would take to actually include these details and sectors.

## 4. Implications for Environmental Life Cycle Assessment

A number of critical issues have been raised concerning the ability of practical life cycle assessment to provide accurate and useful results. Taken together and summarized below, they point to an unsettling conclusion.

Summary of Critical Issues

First, life cycle assessment's fundamental policy purpose is to guide consumer and producer choices toward more environmentally benign alternatives, where the environmental demerits of concern may be caused by a wide variety of activities in the economy. Therefore, an evaluation of life cycle assessment's usefulness as an analytical tool in the service of improving choices necessarily must gauge the degree to which life cycle assessments can realistically achieve this goal. Hence, the focus here is on the ability of practical applications of life cycle assessment to support claims of greater environmental friendliness based on both direct and indirect sources.

Second, the search for a single correct tabulation of a product's environmental demerits is at best problematic. In many cases, the environmentally best choice between two products or processes will be different depending on the specific circumstances of the chooser. Moreover, today's correct answer for a given location and individual may well change tomorrow as environmental and economic conditions and linkages evolve. This implies that many different studies for a single decision would have to be conducted and updated routinely to provide productive guidance to consumers and producers. Without these, it is not clear that the results of real-world life cycle assessments will generate positive environmental benefits -- indeed, they could be causing more harm than good.

It has been easy to avoid the fact that the correct levels of environmental demerits depend on specific circumstances because most practical life cycle assessments only address the inventory stage of the analysis. The actual environmental impacts and improvements stages are normally left for future research. Thus, because their goals have been to tabulate energy and resource use, air and water emissions, and landfill requirements, researchers have been willing to use aggregated information, to make a host of simplifying assumptions, and to assume that the national average amounts of these inputs that ultimately cause environmental demerits are sufficient.

But when researchers begin to extend the analyses to the impacts stage, a rude awakening is in store. It will take little time to discover that actual environmental harms are quite heterogeneous and that the same emission in one location may cause radically different harm than in another. It is only one small step beyond this to the realization that not only do the actual levels of environmental harms depend on these and other circumstances, but that all of the results of the inventory stage -- based on the notion that a single list of energy and natural resource use, waste generation, and other precursors to environmental harms, is acceptable -- might have to be revisited or scrapped.

Third, conducting a life cycle assessment that could confidently assist consumers and producers in making environmentally sounder choices will generally require a research commitment far larger than one would devote given the social value of the advice generated. By hypothesis, environmental demerits associated with a particular product or process choice could exist anywhere in the economic system, however remote. It is therefore difficult to set defensible and feasible boundaries on practical analyses because nothing known to the researcher provides clear support for assuming that effects outside of the boundaries are too small to matter.

As a result, any practical life cycle assessment will generally be vulnerable to attack on the twin grounds that (1) the underlying reality contains hidden details that are sufficiently different from the aggregated estimates and assumptions to alter the results significantly, and (2) layers of economic activities not explicitly analyzed could cause environmental demerits sufficiently large to reverse one's original conclusion concerning the greener choice.

Consider an interesting postscript for the diapers controversy. The recent reversal of the long drought in the western U.S. illustrates how underlying economic and environmental conditions can evolve over time, making previous life cycle assessments obsolete. If disposables were "better" in the west during the drought, they might not be "better" with more plentiful water supplies. Thus, even changes in weather can alter the environmental demerits of products and processes, rendering previous life cycle assessments out of date.

Finally, life cycle analyses have yet to address the environmental harms of concern. Most efforts continue to be devoted to tracing economic activities throughout the economy from the process or product choice in question back through their inputs and other associated activities. One could argue that the real work of locating and quantifying actual environmental demerits has yet to begin. Lists of hypothesized harms associated with energy and natural resource use, with various emissions to air and water, and with waste generation and management, are far from definitive measurements of actual environmental damages. Furthermore, the actual magnitude of the various underlying environmental demerits depends on a host of factors, such as location, that are not currently part of the inventory stage of existing analyses.

Summary Evaluation of Life Cycle Assessment

It is never easy to reach conclusions about the practical viability of a research program in which accuracy and usefulness is theoretically possible. Many analytical pursuits are difficult, so expense and a lack of rigorous results should not themselves cause one to conclude that these research activities are not worth continuing. Yet, to decide that a research program will eventually yield useful results requires more than simply the belief that what is sought is an epistemological possibility. Unfortunately, while life cycle assessment's underlying motivation is understandable, and researchers are capable of generating large quantities of numbers, the hope of ever obtaining accurate advice for consumers and producers at practical levels of effort is really just that, a hope, whose only basis lies in theoretical possibility, not in any empirical evidence of practical feasibility.

Realistically, in light of the current state of life cycle assessment -- seeking a single set of demerits when there are multiple ones, seeking demerits "associated with" rather than "caused by", setting boundaries based on practical feasibility rather than on the belief that a wider scope is not necessary for robust results, and so forth -- additional research using this approach is unlikely to result in any increased confidence in the results. It is not so much any one problem facing life cycle assessment that makes this type of analysis impractical. For example, if there really was a single correct set of direct and indirect environmental demerits for a product, and these did not change over time, and if it was not too costly to identify and quantify them, one might think that conducting such a life cycle assessment might be worth the cost.

The reality is that there generally is no single correct list of direct and indirect environmental demerits for a product or process -- there are many applicable to specific circumstances in our complex economy, and they will change over time as environmental and economic linkages evolve. Moreover, the level of detail and the inclusiveness of study boundaries required to inspire confidence in a life cycle assessment's results are generally far beyond those feasible in practice.

Hence, future life cycle assessments will become increasingly complex and expensive, but will never really deliver on their promise to confidently guide consumer and producer choices toward environmentally more benign alternatives. To be sure, more details will be included, and more pages of results will be generated, but the sense that any progress of significance has been made toward conclusive, widely-applicable, and durable results of value to consumers and producers will be an illusion.

A recent report on packaging prepared by the Tellus Institute is a case in point.[5] Obviously this was an expensive and time-consuming study. Indeed, in the Acknowledgements section, the report states that "(d)ozens of people have worked hard over the past three years to make this study possible" (p.i). A study of this magnitude and duration is representative of what can realistically be achieved even with large levels of effort. The Tellus researchers are to be congratulated on their tenacity and attention to details.

Unfortunately, it is not so much what is in the report that counts, it is rather what is not. Even a study of this magnitude still must admit that it is far from complete and accurate. Some of the limitations described in the report include out-of-date information, omission of the package forming, filling, and transportation stages, omission of the industrial solid waste sector, absence of the plastics recycling sector, and no explicit accounting for habitat destruction, old-growth forest cutting, and other considerations related to logging.

Regarding logging and other aspects of virgin materials use, the report suggests that "(r)eaders who are concerned about virgin materials depletion should consider that factor in addition to the analysis presented here, when evaluating materials recycling options." One wonders how the reader can do this if the voluminous and expensive study in his or her hands failed to do so. Note further that in light of this and other limitations noted in the study, it is not even necessary to press further on other important limitations identified in this evaluation, such as pursuing a single set of direct and indirect environmental demerits when there are, in fact, many depending on producers' and consumers' specific circumstances.

The point is that even an expensive and extremely data-intensive effort summarized by the Tellus report cannot arrive at the level of detail and comprehensiveness necessary to provide consumers and producers with useful information to improve their choices, and the Tellus effort is still only the inventory stage of the analysis, so the impacts and improvements stages still remain. To be sure, the report contains a very large set of results, and even attempts to monetize impacts.[6] But given the omissions and other limitations of the study, if one were to

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[5] Tellus Institute, CSG/Tellus Packaging Study, prepared for The Council of State Governments and the U.S. Environmental Protection Agency, May 1992.

[6] Essentially, the report uses regulatory control costs for monetization. This is very different from actually measuring real environmental harms, as the report admits, and it is far from obvious that this shortcut is analytically sound.

make different choices based on the study there is a good possibility that rectifying these shortcomings would provide new information important enough to cause one to reconsider.

Of course, the Tellus report does not claim to offer information that can conclusively guide consumers and producers to the environmentally correct choice. The report merely states that "(w)e believe that we have advanced the state of knowledge on packaging materials, raised a number of previously hidden issues that require discussion, and given the best answers possible based on the available data and resources. We are well aware that we are offering the first word, not the last, on these topics. We hope that our current study will be followed by further refinement and development of research tools and publicly available databases in this area."(p.5)

Observations

Ultimately, the problem is not that nothing can be done within practical limitations of financial feasibility, for the reams of results life cycle assessments can generate are a testament to the creativity and commitment of these researchers. The main problem is that what generally can be done within practical levels of effort does not provide conclusive results of any use in guiding consumer and producer choices. Instead, life cycle assessments generally show that all products and processes are associated directly and indirectly with a host of environmental demerits at various levels, so that choosing between two products is already problematic. They then so severely qualify the results with caveats, limitations, simplifications, and other potential problems, that one has no confidence that more details and wider boundaries will not reveal more environmental demerits of substantial importance to one's choices.

Some might protest that life cycle assessment should be evaluated only in terms of how well it identifies and tabulates environmental demerits of a product or process, not whether a consumer or producer can use that information to arrive at an environmentally correct choice. That is, despite admittedly inadequate data and scarce financial resources, surely the efforts of these researchers can provide interesting information about products and processes of use to someone.

Again, there is every reason to study product manufacturing and use to identify and minimize direct pollution and other environmental harms. To the extent that life cycle analyses do, so much the better. Seeking to minimize direct environmental consequences is socially beneficial, analytically coherent, and eminently reasonable in practice. But, this is not the underlying motivation of life cycle assessment, which is to tabulate the indirect sources of environmental demerits as well. Trying to quantify the indirect sources of environmental demerits of a product inevitably involves endless and detailed searches for remote sources of environmental impacts, and difficult to defend limitations on the boundaries of the study.

Similarly, there is nothing in this evaluation of life cycle assessment that indicts individuals' everyday common sense decisions to avoid harming the environment. Reducing litter, reusing resources such as grocery sacks and aluminum foil, and conserving on energy and other natural resources to minimize one's direct contribution to harming the environment, are all laudable and worthwhile pursuits. Traditional notions of environmentally-friendly consumer choices and actions are uncomplicated and are likely to result in the environmental benefits that motivate them.

It is the extension of this notion to product choices not involving obvious direct environmental demerits differences that causes problems. As soon as consumers try to purchase "greener" products based on both their indirect and direct sources of environmental demerits, they are confronted with a host of competing claims and counterclaims. Aware that "green" is also profitable, marketers then begin to expand the environmental and analytical criteria by which products are evaluated. Products' indirect environmental characteristics then become the weapons with which an expensive war is waged for the consumer's environmental conscience (and dollar).

Of course, all of this provides a perfect garden for a classical "prisoners' dilemma" to grow, one in which a manufacturer who does not engage in studies to prove the environmental passivity of his or her product will be at a disadvantage relative to competitors who do make these claims. Unfortunately, these parties probably all know that these "green claims" are on shaky ground, but they nevertheless must defend themselves.

Finally, some might argue that economists undertake projects that involve "mapping" the economy, sector-by-sector, in estimating input-output matrices for production. Hence, why is it not worthwhile to conduct similar analyses for life cycle assessments? While it is true that those who perform economic input-output analysis are attempting to trace economic activities to and from many different sectors, life cycle assessment is not quite the same exercise. In particular, input-output analysis can define for itself the level of aggregation sought, can rely on market transactions to provide the data required to perform the analysis, and is completely disinterested in where and how the various economic activities summarized in the ultimate matrix are carried out. Life cycle assessment's goals, however, do not allow self-defining disaggregation decisions, cannot permit arbitrary limitations on scope, require measurement of events and consequences largely not included in market transactions, and necessitate a careful focus on the specifics of an activity that determine the extent and magnitude of the actual environmental harms caused.

Thus, input-output researchers find it hard enough to trace and catalogue an economy's interdependencies even given their advantage of seeking national averages, relying on observable market transactions, and so forth. Life cycle researchers have none of the advantages enjoyed by input-output modelers, and face a task with a far larger scope and a less well-defined, and poorly documented by the market, set of concerns to be measured. Simply because economists attempt to conduct input-output modeling that bears some resemblance to the activities of life cycle researchers does not imply that the latter will meet with any success.

In the end, whether the attempts of practical life cycle studies to explore the indirect environmental demerits of a product or process have value to society independently of their use in improving the environmental results of consumer and producer choices is not clear, for it is not obvious from what source that value might flow. One might plausibly argue, for example, that the process of evaluating indirect environmental demerits of a process might happen upon a particularly acute problem that has eluded other attempts at environmental management and stewardship. But one could reply that a random search of different economic activities might provide the same probability of such a discovery at lower cost.

It is conceivable there might be good reasons for conducting life cycle assessments, perhaps on a limited basis and in certain very specific and important circumstances. This evaluation, however, focuses on whether practical life cycle assessments can generally be relied upon to provide information that really can be used to confidently guide consumer and producer choices toward environmentally more benign alternatives. Equivalently, it concerns whether practical life cycle analyses can confidently support the claim that product A is "greener" than product B based on both direct and indirect sources of environmental demerits. As a general matter, the answer is no.

The life cycle research community appears to be on the verge of realizing the conclusions reached in this evaluation. Indeed, the current debate about the possibility of establishing boundaries for practical life cycle assessments suggests that at least some practitioners are aware of the underlying problems. The sense of frustration with ever increasing levels of effort devoted to more and more detailed life cycle analyses that yield non-decreasing lists of limitations and caveats is quite evident. Establishing research rules and protocols, and seeking agreement on what are ultimately arbitrary limitations on life cycle assessment boundaries, however, are not the answer.

**5. Is There an Alternative Approach?**

The conclusions reached in this evaluation of life cycle assessment are essentially that conventional studies of direct pollution caused by economic activities can help to improve their environmental performance, but that life cycle assessment's attempt to go beyond direct environmental demerits to include indirect sources as well is unproductive. Unfortunately, this seems to leave researchers without any recourse for addressing the environmental problems that may be so serious and widespread.

For several reasons, this conclusion may seem somewhat depressing. First, and probably most obvious, is that the hope that life cycle assessment will generate meaningful and accurate guidance for consumers and producers, at least at some point in the future, will never come to pass. It is difficult to accept that all of the honest and diligent efforts to improve life cycle assessment techniques, data, and results will not yield beneficial results.

The evaluation's findings are all the more troubling because life cycle analysis might be viewed as the culmination of a long process of public education and awareness concerning the environment. The past several decades have seen a significant change in public attitudes about the natural world and the impact of human activities on it. Concurrent with this shift in public attitudes, many environmental improvements, large and small, have occurred. Life cycle assessment's ultimate motivation is to empower individuals so that they can help the environment by altering their choices. That life cycle assessment cannot fulfill that goal is sad, but true.

One should be cautioned against viewing the strong conclusions about life cycle assessment reached in this paper as any statement whatsoever about the underlying value of the attitudes and concerns that motivate life cycle assessment in the first place. This evaluation focuses on life cycle assessment as an analytical tool intended to help people achieve their goal of acting in environmentally more benign ways. The fact that life cycle assessment does not advance those goals says nothing about their underlying motivation.

The other, more subtle way in which some might find the conclusions of this evaluation depressing is the belief that if life cycle assessment cannot help to address the environmental problems that motivate these analyses, does this mean that we can do nothing at all about them? If so, this would be a most unfortunate outcome from an environmental perspective.

A Viable Alternative

Fortunately, there is an alternative approach for addressing these environmental harms, one that avoids the insurmountable difficulties of tracing the economic activities remotely associated with a product or process. While this alternative approach can successfully begin to address the environmental problems that motivate life cycle research, it nevertheless will not provide detailed environmental and natural resources information about products to consumers and producers.

This more productive approach for addressing the environmental problems that motivate life cycle research is simple and quite conventional: attack the environmental harms and inappropriate resource uses of concern where they occur using the variety of tools at the disposal of the environmental authority. That is, if one believes that these environmental demerits exist, they should be identified and corrected with the arsenal of regulatory and non-regulatory approaches normally used to mitigate or control pollution problems.

For example, if one of the important environmental demerits of concern is habitat destruction, erosion, and turbidity caused by logging of forests, the suggested approach calls for developing regulatory policies that strike at the heart of that problem directly. Limitations on logging, standards for cutting and preservation, even taxes on logging activities, all might be considered good candidates for addressing this problem. The result of applying corrective regulations and other incentives to mitigate the environmental harms directly will be both a reduction in the actual damages caused by logging and, in general, an increase in the costs and prices of products associated with logging.

Similarly, if another environmental demerit of concern is potential harms to human health and the environment caused by overuse of fertilizers and pesticides, the traditional approach would suggest attacking these problems at their sources by developing stronger regulatory and other programs to limit these risks. These might include additional restrictions on pesticide application procedures, limitations on using certain types of fertilizers and pesticides in particular areas or in certain circumstances, and so forth. Again, the result of these measures would be a reduction in the direct environmental harms caused and increased costs and prices of items into which these harmful activities and practices flow.

Advantages of the Alternative

Of course, the suggested approach offers no "magic wand" that will easily wipe away the many environmental problems that exist. It is no more and no less than the traditional recommendation that successful environmental management and stewardship generally flows from clear problem definition and careful development and application of regulatory and non-regulatory mechanisms to address them.

But the advantages of the suggested strategy are many. First, it immediately focuses efforts directly on the problems of concern in life cycle analysis -- widespread environmental harms and inappropriate or underpriced natural resource use. Practical life cycle assessments never really ever arrive at the ultimate harms of concern. Instead, all of the resources are expended in attempting to trace from particular consumer and producer decisions back through the almost infinitely complex interconnections of the economy to those harms, and then hoping that the responses to the answer generated will wend their way back to the problems exactly as predicted. There are obvious advantages of beginning with the environmental problems to be solved rather than leaving their identification and measurement for later.

Second, by identifying, quantifying, and mitigating these environmental problems directly where and when they occur, the costs of the controls or environmental damages caused in even remote economic activities will be reflected in prices faced by consumers and producers. Moreover, these costs will end up being reflected in the prices of all products and processes associated with these environmental demerits, not just the few consumer and producer decisions that life cycle researchers elect to examine.[7]

Third, as actual sources of environmental demerits are identified and addressed, the underlying need to assist consumers and producers in making the "best" environmental choice among products and processes will fade. More confidence that environmental problems are being addressed and that the consequences of doing so will be incorporated into prices ultimately eliminates the original motivation for conducting life cycle assessments.

Fourth, the information requirements for the suggested approach are a small subset of those needed for accurate and definitive life cycle assessments. The traditional approach requires the environmental authority to locate and quantify environmental harms and inappropriate resource use. Armed with this information, regulators then can promulgate rules of whatever type seem appropriate to address these problems.

Life cycle assessment, on the other hand, requires that the input-output matrix of the economy be traced and retraced periodically, location-by-location, and that the ultimate environmental harms of concern be identified and quantified, in order to provide useful information to consumers and producers. In practice, the task of even crudely tracing economic activities and linkages consumes all of the resources in a life cycle assessment. The result is that practical life cycle assessments never really arrive at the environmental harms that motivate them in the first place.

Finally, the suggested approach allocates responsibilities for environmental stewardship more appropriately than does life cycle assessment. In essence, the traditional approach charges individuals -- in their roles as consumers and producers -- with ensuring that they cause as little direct environmental damage as is feasible. Thus, individuals should strive to reduce the environmental problems they cause directly based on their specific situations and activities. Though life cycle assessment is motivated by a distrust of prices and the market, consumers and producers nevertheless should accept prices of inputs and goods at face value in making their

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[7] A related point is that life cycle analysis today is concerned with environmental issues. Twenty years ago the focus was on energy use. Tomorrow, however, the concern could be safety or other problems of particular social concern. In any case, focusing directly on the problems, regardless of their nature, tends to correct them with greater certainty, and to price activities related to them more appropriately.

choices. To do otherwise throws one into the world of life cycle assessment, a world in which neither prices nor lists of environmental demerits can be trusted to guide one to environmentally more benign alternatives.

The inability to make rational choices in a world in which one does not trust prices is a particularly important point to understand. Suppose one identifies a cost-reducing change in an industrial process that also reduces its direct environmental damages. Ordinarily, this would be a clearly desirable process change to make. But suppose further, as does life cycle assessment, that there are many indirect environmental demerits that are not accounted for in prices. In this event, one cannot decide rationally that undertaking the process change will reduce total environmental demerits. Presumably the process change will affect many other activities throughout the economy, so until one investigates these indirect sources of environmental demerits, the conclusion that the process change is environmentally beneficial overall cannot be supported. Of course, this is a ridiculous situation, but precisely what results from a lack of confidence in prices. Hence, the role allocated individuals under the suggested approach allows them to trust prices.

The environmental authority, under the traditional approach, is charged with ensuring that people do actually act in environmentally responsible ways. Its obligation is to correct failures of the market to adequately protect the environment or to price resources to reflect their full cost or value to society. If the environmental authority accomplishes its part of the task of managing the impacts of humans on the environment, the trust that individuals must place in prices will be validated.

<u>Observations</u>

Several objections might be raised to abandoning life cycle analysis in favor of the more traditional approach to environmental regulation and stewardship advocated here. One is that it is difficult to attack the environmental demerits of concern via the traditional approach, so life cycle studies represent an alternative to doing nothing about them. This objection is understandable because it may indeed be difficult to address many of these environmental harms directly. Similarly, some regulators argue that the causes of the environmental demerits of concern are beyond their regulatory authority, so that life cycle analysis is viewed as their only viable means of doing something about these harms.

Nevertheless, life cycle assessment is not really a viable analytical or policy making alternative because practical analyses do not provide robust or useful results at justifiable cost levels. Moreover, without knowing it, practical life cycle assessments might be doing more harm than good for the environment. Hence, it does not seem reasonable to continue to allocate more and more funds to life cycle assessment with only the vaguest hope that someday they will generate reliable and robust results, especially if one suspects that they probably will not satisfy that goal. This might be true even if there was no alternative for addressing the environmental demerits that motivate life cycle research, but it is certainly so if there are other ways to try to address these environmental problems.

Another objection is that it is probably not possible to correct environmental problems perfectly using the traditional methods, hence the recommended alternative is also not perfect. This may be true, but perfection is not a requirement of the traditional approach to environmental regulation and stewardship. Real environmental problems are complex, difficult to identify and quantify, and controversial to value. But even imperfect strategies to address these environmental harms can provide clear social benefits. The same cannot be said for life cycle assessment, which generally yields large sets of results with no guarantee that any changes in consumer and producer decisions based on them will be environmentally beneficial.

One final objection to discarding life cycle analysis and undertaking the difficult, but ultimately more productive, traditional approach is that doing so still does not provide information to consumers and producers about the "environmental content" of the products and processes they choose. This complaint goes to the very core of the motivation of life cycle analysis. Because proponents of life cycle analysis assume that many environmental harms and natural resource use are not adequately reflected in prices, they seek to provide this information in parallel with the price system. Taken literally, the belief that prices cannot be trusted to reflect the social costs of products and processes, including their inputs, indicts all economic decisions, not just the few that are commonly the subject of life cycle assessments. That is, no economic decisions can be trusted to be socially correct if the prices upon which they are based do not reflect vital information about costs.

Unfortunately, it is not possible in practice to provide accurate information on the environmental "inputs" to processes and products or, for that matter, for any set of economic inputs. One can collect and disseminate information about the nature, seriousness, and extent of the environmental problems of concern. Environmental performance data are probably very worthwhile to collect, for they direct attention to monitoring, measuring, and perhaps mitigating these environmental harms at their sources. Recent suggestions that the national income accounts should be supplemented by information on the change in the nation's stock of natural and other environmental resources represent productive first steps in this direction.

What is not feasible in practice is to analytically allocate these environmental problems to particular products and processes, which is the goal of life cycle assessment. Some may think this an unfortunate limitation of reality. Perhaps so, but it is the inevitable result of the complexity and diversity of modern economies in which, fortunately, free commerce and the price system communicate necessary information efficiently, rapidly, and anonymously. Indeed, it is perhaps the most profound benefit of the price system that it accomplishes all of this coordination and communication of remotely and diversely held information and plans, for it could not be accomplished by a single entity.

While there is no analytical way to trace from products back through the virtually endless complexity of a modern economy to the environmental demerits of concern, there is one conceivable way to provide this information to consumers and producers. Suppose that, for some reason or another, using energy causes environmental harm that is not incorporated in its price, and assume that this harm is the same regardless of the form of the energy. If, on pain of death, one had to supply information to consumers and producers about the amount of energy embodied in specific products or processes, the only feasible way to do so would be to establish two colors of money, say, red and green. Red money would be the only currency accepted for purchasing energy and green money would be used for all other goods.

Under such a system, all goods and services in the economy would end up with two prices -- a red price summarizing energy inputs and a green price reflecting all other factors of production. This example could be extended to environmental demerits by simply expanding the number of colors of money, where each color would be used for a specific environmental demerit. In the end, products would have many prices, one for each color of money and its associated environmental demerit. This would supply the detailed environmental information required.

It is noteworthy that the multiple-currency method of obtaining the necessary information still fundamentally relies on the price system, not analysis of the economy and its interrelated sectors. It also emphasizes the fact that doing anything to mitigate the environmental demerits of concern requires one to begin with the sources of the harms themselves, not with consumer and producer choices about products and processes. It further reveals that, at its core, the ultimate solution to the environmental problems that motivate life cycle researchers lies not only in attacking these harms directly, but also in restoring confidence in prices. As shown above, if one does not believe prices, it is difficult to make any rational choices, environmental or otherwise.[8]

Finally, one might argue that recommending to consumers and producers that they accept prices as the basis for making choices still seems less than satisfying. Indeed, one might assert that the environmental authorities cannot be trusted to address the many environmental problems that still exist. This is a valid concern, but it still does not point to life cycle assessment as the solution because practical life cycle assessment will not reliably advance those goals. As an alternative, those who hold this view should consider other ways to affect policy outcomes, for these are likely to meet with greater success in improving environmental outcomes than conducting life cycle assessments.

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[8] To students of the history of economic thought, this may sound much like the "socialist calculation" debate during the 1920s and 1930s in which one issue was the ability of a central planning authority to successfully direct economic production activities in the absence of a price system. The conclusions reached in this evaluation of life cycle assessment are identical to those reached over half a century ago. In particular, it is theoretically possible to imagine computing the solution to the economy's production and allocation problem, but it would be absurd to contemplate actually trying. Similarly, it is possible to imaging calculating the full -- direct and indirect -- set of environmental demerits for a product or process, but one would never try to do so in practice. It is not impossible or self-contradictory to imagine computing total environmental demerits, it is just not feasible in practice.