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A REVIEW OF LIFE-CYCLE APPLICATIONS FOR ENVIRONMENTAL DECISION MAKING IN THE UNITED STATES[1]

D. Elcock

Argonne National Laboratory
Washington, D.C.
U.S.A.

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DISCLAIMER

ABSTRACT

The relationship between life-cycle assessment (LCA) and U.S. environmental regulatory policy is examined. LCA is the consideration of a product's inputs, outputs, and impacts over its entire life cycle. Background information on the U.S. environmental regulatory decision-making process is discussed, and several LCA "mini case studies" are reviewed. Each review identifies the purpose of the LCA and examines the link between the LCA and environmental policies or regulations. The discussion for each case identifies whether the LCA was used (1) to develop an environmental regulation or policy, (2) to respond to an existing environmental regulation or policy, or (3) for purposes not directly related to environmental regulations or policies.

Although some LCAs have been conducted with the intent of providing input to environmental policies, few, if any, cases show that LCA was actually used to develop an environmental policy or regulation. This situation can be attributed, at least in part, to the incompatibility between the LCA process and the U.S. environmental regulatory structure. Thus, while LCAs identify resource use and environmental releases to various media throughout a product's or process's life cycle (resource extraction, use, and final disposition), the U.S. environmental regulatory structure has traditionally required the application of specific technologies to limit releases to specific environmental media from specific release points.

A stronger tie appears to exist for LCAs conducted in response to environmental policies or regulations. However, many of these "responsive" LCAs were conducted in other countries as a result of European Union or individual country requirements. In the United States, the number of these responsive LCAs can be expected to increase.

While many LCAs are conducted with no direct environmental regulatory driver, they are often used for environmental decision making within an organization — frequently in response to broad national or international environmental goals, such as reducing fuel consumption.

INTRODUCTION

LCA Background

For more than 30 years, government and nongovernment organizations have used life-cycle assessment (LCA) to help identify environmental impacts associated with "cradle-to-grave" activities (resource extraction through final disposition) of products and processes. In the 1970s, the U.S. Department of Energy (then the Energy Research and Development Administration) used LCA to analyze energy, environmental, and cost impacts associated with alternative strategies designed to respond to energy issues related to oil shortages and rapidly increasing prices. After the energy crisis abated, LCA was of more interest to academics and researchers than to decision makers. In recent years, the globalization of the economy, the recognition (primarily in Europe) of producer liability for products after their useful lives, and the emergence of sustainability issues have prompted increased use of LCA tools for environmental analysis. During the past decade, the military, industries, trade associations, and government organizations have used LCA to educate and to provide input to decisions on product/process design. Well-attended international LCA conferences have discussed methodologies, data collection, applications, and related topics.

U.S. Environmental Regulatory Structure

The process used to develop environmental regulations and policy in this country may not be conducive to the life-cycle approach. Many industrial, government, and public interest group representatives say that although environmental regulatory structure in the United States has enabled significant environmental improvements over the past 30 years, it is limited in its ability to produce additional improvements and to address new kinds of problems. The U.S. environmental regulatory system dates from the 1970s, when the public pressured Congress to take action to clean up water and air, and to more closely control solid and hazardous waste pollution. Congress responded by enacting laws to address each of these problems (e.g, the Clean Water Act in 1974, the Clean Air Act in 1977). Congress required the U.S. Environmental Protection Agency (EPA) to implement these laws, and EPA established separate offices to respond to each of them (e.g., the Office of Water, the Office of Air and Radiation). The types of regulations these offices promulgated (and continue to promulgate) generally pertain to a particular environmental medium and require the application of a specific technology to capture a pollutant just before it is released to the environment. However, pollutants removed from (or prevented from entering) one environmental medium often appear in another. These regulations neither require nor encourage industry to review its processes to determine the cause of pollutive emissions or to explore options for avoiding or reducing those emissions before they reach the environment. As such, the regulations limit incentives to meet environmental goals through pollution prevention, alternative resource use, or process redesign.

Recognizing these problems, EPA and others have been exploring "regulatory reinvention" options. These include Project XL, which encourages entities to apply for regulatory relief in exchange for superior environmental performance, and EPA's common sense initiative, which was designed to find "cleaner, cheaper, smarter" solutions to environmental problems using a multi-stakeholder process. But most of these efforts are short term and address specific environmental regulations. They do not foster a broader, life-cycle perspective.

Study Objective

Given the increased recognition and use of LCA, and the current concerns over U.S. environmental regulations and the processes used to develop those regulations, this study examined the relationships between LCA and environmental regulations and policy. The objective was to identify the extent to which LCA is used (or could be used) in the development of environmental regulations and policy, and the extent to which LCAs are conducted in response to specific environmental policies and regulations.

METHODOLOGY

The approach used for this study was to identify LCA applications and examine their linkages to environmental policies or regulations. Although various organizations conduct LCAs for different purposes, there are no LCA databases that could be tapped and sorted to provide a list of LCAs. Therefore, the LCAs for this study were identified through literature searches, reviews of recent LCA conference materials (e.g., EPA's April 25-27, 2000 *International Conference & Exhibition on Life Cycle Assessment: Tools for Sustainability;* Society of Automotive Engineers' April 26-28 2000 *Total Life Cycle Conference & Exposition*), Internet searches, discussions with colleagues specializing in the LCA field, and the author's own experiences with LCA.

The search identified several LCAs that were not included in the analysis because they did not contain sufficient information to answer the questions being asked. In addition, relatively few studies reviewed presented information on particular LCA applications; most studies describe data or more theoretical aspects of LCA, such as methodologies and analytical techniques. The case studies examined here may or may not represent the universe of LCAs that have been conducted, many of which may not have been published. However, the cases presented indicate the range of LCA applications. Future research in this area may identify additional cases to expand the coverage and enrich the results.

For each LCA identified for further analysis, the following information was collected:

- Purpose of the LCA—why the analyst(s) conducted the LCA;
- Link between the LCA and environmental policy/regulations—for each LCA, a determination of how (or if) the LCA was linked to environmental policy/regulations.

  Each LCA was placed into one of the following three categories:

  1. The LCA was conducted to help develop an environmental policy or regulation;
  2. The LCA was conducted to respond to an environmental policy or regulation; or

3. There was no direct link between the LCA and environmental policies/regulations. Where such links were not stated explicitly, the author inferred the linkage on the basis of the information presented in the report.

- Where appropriate, observations on the relationship between the LCA and environmental policy/regulations—sometimes, the case studies implied why LCAs were or were not used for environmental regulatory purposes.

The analysis of this information and consideration of the characteristics of the U.S. environmental regulatory system yielded conclusions regarding the current use of LCA in environmental regulations and policy. To project the future use of LCA in the context of environmental policy and regulations, U.S. and international regulatory drivers for LCA were identified.

A note on terminology: many terms denote life-cycle thinking. These apply to specific techniques and include life-cycle assessment, life-cycle impact assessment, life-cycle inventory analysis, and others. Variations on the life-cycle approach include life-cycle costing, life-cycle engineering, life-cycle design, and life-cycle management. Indeed, many practitioners view life-cycle assessment as consisting of four steps: goal scope and definition, life-cycle inventory, life-cycle impact analysis, and interpretation. Others use the term life-cycle assessment to mean life-cycle inventory. No standard, universally accepted definitions for life-cycle assessment exist, and as a result, observers can become confused over the use of these terms. In this study, unless otherwise noted, the term LCA is used in the broad sense, i.e., to connote life-cycle, or cradle-to-grave, thinking, rather than a specific technique.

FINDINGS

The nine individual LCA cases examined in this study are listed below:

- Generic automobile,
- Electric vehicle,
- Manure management,
- Interstate transport of municipal solid waste,
- Sustainable waste management systems,
- Taj Mahal discoloration,
- Military vehicle coatings,
- Milk production, and
- Beer production.

Summary findings from each case study are presented below. Table 1 shows the linkages between the individual LCAs and environmental regulations/policies.

Generic Automobile LCA

In 1993, the big three U.S. automakers, which were then General Motors, Ford, and Chrysler, the Aluminum Association, the American Iron and Steel Institute, and the American Plastics Council agreed to begin conducting a life-cycle inventory (LCI) of the resources used to make, operate, and ultimately dispose of a generic, 3,200-pound vehicle. These resources included the energy used to extract raw materials, plant and vehicle emissions, fuel consumption, and end-of-life recycling and disposal. The purpose of the study was to provide a foundation for optimizing the life-cycle environmental performance of future vehicles. The product of the study is a database containing information on 644 parts comprising 73 materials, 31 raw materials, and 27 environmental data categories. Project participants said that the LCI approach was limited by the high costs and time-consuming, intensive data collection efforts. The project took several years to complete and required the cooperation of the otherwise competitive automobile manufacturers and material supplier industries (USCAR 1999).

The project, a voluntary undertaking by the private-sector, was not used to develop environmental policies or regulations, nor was it conducted as a direct response to environmental policies or regulations. However, automobile manufacturer and supplier recognition that environmental aspects associated with automobile manufacture, use, and disposal can be important factors for design and marketing, may have helped motivate the study. This recognition may be heightened when considered in the context of global markets, where end-of-life vehicle concerns are taken seriously.[2]

Electric Vehicle LCA

Total-energy-cycle assessments (TECAs) are used to compare the energy used and emissions generated during a transportation energy cycle, which includes raw material extraction, conversion to an energy product, transportation, and end use. For each stage of the energy cycle, emissions and energy use are estimated for construction, use, and disposal. TECAs help decision makers select optimal means for reducing oil use, greenhouse gas emissions, and air pollutants from the transportation sector (DOE 1999).

The U.S. Department of Energy (DOE) sponsored a TECA for electric vehicles (EVTECA) (Argonne 1999) and for conventional vehicles so that the emissions and energy use for the two could be compared. The inventories provided information to address the assumption that EVs are environmentally preferable to conventional gasoline engines, and to identify any "hot spots" in the life cycle that should be addressed when designing future EVs.

[2]The European Commission and the European Parliament recently agreed on an end-of-life vehicles directive that requires car manufacturers to cover the costs of take-back and recycling of automobiles.

As with the generic automobile life-cycle inventory, the EVTECA was not used to develop, nor did it respond to a particular, environmental policy or regulation. It did, however, provide decision makers with information to assist in design, and it does respond to policies advocated by EPA and DOE to develop and provide vehicles that are environmentally preferable to those with conventional gasoline combustion engines.

Manure Management

The United Kingdom (UK) is using LCA in a systematic analysis to help policy makers, the scientific community, and farmers compare various slurry and solid livestock manure management techniques. The premise of this case study is that "if UK policy makers legislate to control the UK's global and domestic environmental burdens, then it is in the farming industry's interests that it is only done so in the soundest scientific manner possible" (Sanders and Audsley 2000).

This case provides an example of LCA use as an input to environmental policy development. The LCA authors suggest that because the UK farming industry is becoming burdened with environmental constraints that limit the industry's ability to compete on price, it is important to compare manure management alternatives in a consistent manner that accounts for environmental effects of production systems that include both the upstream and downstream effects that occur beyond individual farm boundaries. For example, the authors explain that LCA can show that reducing ammonia and methane emissions from on-farm manure management, by trucking the manure over long distances to energy-intensive industrial processes that convert the manure to a clean organic fertilizer soil, can result in massive increases in fossil fuel emissions from the transportation and industrial processes. The study also notes that site-specific LCAs can show how measures taken to prevent the loss of nitrogen as ammonia from within farm buildings can be offset if the manure is applied inappropriately to the land. A more generic LCA would need to account for variabilities in actual operational practices; farmers operate at different efficiencies, and the impacts of these differences are difficult to incorporate in a non site-specific LCA.

Interstate Transport of Municipal Solid Waste

Throughout the 1990s, the U.S. Congress debated issues surrounding interstate transportation of municipal solid waste (MSW). Midwestern states had more landfill space and hence lower disposal costs than the more densely populated eastern states. Midwestern representatives said that their states were being used as dumping grounds, and eastern states should be responsible for their own wastes. Eastern representatives explained that they could not afford the high costs of in-state disposal. Although the Interstate Commerce Clause of the U.S. Constitution generally protects interstate waste shipments, many receiving areas lobbied their representatives to find constitutional ways to ban out-of-state waste. Representatives introduced legislation that would alter the Commerce Clause or otherwise allow states to impose restrictions on the importation of waste. The hearings were highly charged, and witnesses reported midnight dumping, increased accidents, and other anecdotes as arguments against interstate shipments. Emotional debates continued with little quantitative or analytical input.

The DOE became interested in the issue because of the potential impact of interstate bans on the waste-to-energy industry, which, in order to be assured of a dependable fuel supply, often contracts with municipalities outside their state boundaries to supply a minimum amount of waste each year. The DOE sponsored a study to compare the life-cycle emissions, energy use, and employment of various MSW disposal scenarios (Elcock 1992). These scenarios included long-haul transport to out-of-state landfills, landfilling locally, and burning as fuel in waste-to-energy plants both near and far from the area that generated the waste. The study results were mixed — it could not be concluded that interstate transportation was necessarily better or worse than the alternatives. Some scenarios had high emissions but low energy costs; some had low emissions but high energy costs. Decision makers would also need to determine if they wanted increased employment, or if they viewed high employment (and its associated costs) as a negative. Nonetheless, the study produced data on a per-ton of trash basis that could help decision makers compare alternatives.

As with the manure management case, the intent of this interstate waste transport study was to provide objective input to environmental policy making. Although the study did provide useful quantitative results, there is no evidence that they influenced the debate.

Sustainable Waste Management Systems

Many Canadian municipalities have implemented "waste diversion" strategies into their waste management systems. These strategies are based on the generally accepted (and in some countries mandated) hierarchy that encourages pollution prevention or source reduction over reuse and recycling, reuse and recycling over treatment (e.g., energy recovery), and treatment over disposal. Taking this approach a step further, some Canadian municipalities have established greenhouse gas emission reduction targets. (Presumably, more greenhouse gases result from treatment and disposal than from source reduction and recycling.) LCAs are being developed for these municipalities to establish baselines of environmental performance against which reductions in greenhouse gases can be measured, and to help evaluate the environmental performance of proposed changes to waste management systems using the best information currently available (Mirza 1998).

These LCAs are based on the hierarchy's premise that certain waste management practices are always environmentally preferable to others. Therefore, this type of LCA can be considered to respond to an environmental policy or regulation.

The study notes that of the four assessment stages (goal scope and definition, life-cycle inventory, life-cycle impact assessment, and interpretation), this particular LCA remained focused on the first two primarily because of the lack of consensus on impact assessment methodologies. Potentially, though, the LCA approach will help ensure that a reduction in an impact at one stage of a product's life cycle (e.g., disposal) is not outweighed by an increased cost at another stage (e.g., production). Also, the LCA can allow waste managers to consider how various factors affect environmental releases and impacts associated with different waste management techniques. Factors such as waste characteristics, required waste system efficiency, end use of materials recovered from the waste stream, availability of markets for recovered materials, and emission standards to which waste management systems are designed and operated can even challenge the hierarchy's assumptions (e.g., that recycling and reuse are always preferable to disposal).

Taj Mahal Discoloration

The famous Taj Mahal in India had begun to turn yellow, and observers believed that the discoloration had something to do with nearby foundries. Analysts used LCA to find "hot spots" in the foundry furnace technology that could identify the source of the discoloration. The LCA indicated that the source was the coke used to fuel the foundries. Before changing the fuel type, however, other factors had to be considered, such as technical performance and cost control. Using these constraints, designers were asked to develop a "cost-effective, indigenous, eco-friendly melting furnace technology." The results were a new natural-gas fueled technology, which met the environmental constraints, and had lower operating costs than the coke fueled technology. Although there is no clear linkage between using the LCA and environmental regulations or polices, this case shows another application of LCA for environmental decision making. The authors note that LCA can be used again to identify and quantify further improvements.

In this case, decision makers used LCA to help develop and assess a new technology. They found that when the newer technologies have higher capital costs than the older technologies, rigorous life-cycle analyses can help justify such investments over the long term (Wadhwa 2000).

Military Vehicle Coatings

The U.S. EPA and Department of Defense (DOD) conducted an LCA for a new coating for military vehicles known as chemical agent resistant coating (CARC) (Stone 1997). CARC substitutes for paint, which, once contaminated by chemical warfare agents, releases toxins that can endanger personnel, particularly during decontamination operations when the paint must be stripped and treated as hazardous waste. CARC (comprised of pigments, solvents, and heavy metals) produces a hard coating that resists penetration by chemical warfare agents.

The LCA provided a baseline of life-cycle data for use in identifying and evaluating environmentally preferable improvements to the manufacture and use of CARC. In addition, the impact assessment phase identified three key areas of concern over the CARC life cycle: ozone depletion, acid rain potential, and human inhalation toxicity. The improvement assessment phase determined alternatives that had the greatest potential for reducing these impacts. (The alternatives were substitution of a water-thinnable primer, and use of turbine-powered painting equipment instead of spraying technology, which uses more solvent.) A technical evaluation to test these conclusions supported the LCA findings and, further, showed that use of the turbine-powered painting equipment would eliminate the environmental impacts of the solvent. The LCA helped to identify several upstream and downstream impacts and field problems not previously known to the designers. The data collection phase showed that, despite technical instructions and written operating procedures, field application techniques varied, resulting in differential environmental impacts depending on site-specific conditions. The LCA, which was used to compare alternatives to the baseline on a site-specific basis, was able to capture these differences.

This LCA was not conducted to help develop environmental regulations or policy, nor was it conducted to comply with an environmental regulation or policy. However, it is related to life-cycle costing, an approach that DOD requires for purchases of new equipment. (DOD's life-cycle costing requirements evolved with the development of increasingly sophisticated weapons systems that had significant post-acquisition costs (e.g., maintenance) and provided a means to identify costs both before and after a system is deployed.)

Milk Production

This LCA was conducted to identify "hot spots" in organic and conventional milk production systems, and to test the hypothesis that milk production systems with large inputs of feed and fertilizer have greater impacts than those that are more self-supporting (Cederberg and Mattsson 2000). The LCA compared organic and conventional milk production at the farm level in Sweden.

It was found that the importation of feed by conventional farms often results in substantial inputs of phosphorus and nitrogen. Phosphorus is a limited resource used for fertilizer and fodder. Phosphorus use per functional unit (1,000 kilograms of milk leaving the farm gate that has been corrected for fat and protein content) was higher in the conventional system than in the organic system.

While organic milk production can reduce pesticide use and mineral surplus, the LCA found that the leaching rate for nitrate per functional unit was greater for the organic system than for conventional farming. More land is used for the former, and there is always "base leaching" from agricultural land. Thus, land use is a hot spot for organic farming (even though there is enough excess arable land in Europe today to warrant a set-aside program). The LCA study authors note that the conclusion that land use is a hot spot should be evaluated qualitatively as well as quantitatively to consider factors such as soil erosion, soil compaction, and aesthetics (land use for grassland promotes Swedish environmental goals). Nonetheless, these findings indicate that the low-input approach does not always lead to lower environmental impact.

The LCA also identified a number of improvements that can be made to both the organic and conventional systems. For example, the study showed that farmyard manure handling releases much more ammonia than other activities, such as fossil fuel use. As a result, measures to decrease ammonia emissions from farming have been developed.

This LCA was conducted in response to both an environmental law and an environmental policy. In 1994, the Swedish Parliament established an environmental target of organic production on 10 percent of arable land by the year 2000. In 1997, the Swedish Environmental Protection Agency evaluated future scenarios where as much as 75 percent of Swedish milk should be organically produced by 2021. In Sweden, more milk is produced organically than any other food product. Organic milk production in 1998 (3 percent of total sales) was expected to double by 2000. The policy that encourages this production is the European Union's Common Agriculture policy, which gives financial support to environmentally sound agriculture. By examining total LCA impacts, a better understanding of the environmental impacts of different farming methods can be assessed. The LCA can be used to examine the assumption that organic farming is more environmentally sound than conventional farming and to justify financial support for less environmentally destructive farming methods.

Beer Production

This study documented the materials and energy associated with the beer production process at a specific brewery in Germany. The study's goal was to help identify ways to avoid environmental pollution from the brewery's activities (Faustmann et al. 2000). A comprehensive inventory was developed by identifying and analyzing relevant input and output flows of the production system, evaluating potential environmental effects of the inputs and outputs, and interpreting the results. Although the study considered all of the inputs and outputs of the processing system, the system was the facility per se; pre- or post-production activities were not considered. Even at this level, the data collection required more than a year. A future study will identify the environmental impacts associated with the inventory.

This assessment was conducted in response to an environmental regulation. The comprehensive environmental inventory was the first of many steps necessary for the brewery to obtain certification in accordance with the European Eco Management and Audit Scheme (EMAS) regulation. EMAS is a voluntary, site-based registration system that officially recognizes a company's environmental management system. Companies seek EMAS certification to gain credibility and market advantages. To be certified, a company must have an environmental management system that contains several components (e.g., policy statement, provision of environmental performance to the public) and that is approved by an external accredited verifier every three years. It is similar to other voluntary environmental management systems, such as the International Organization for Standardization (ISO) 14001 system. However, EMAS is more stringent than the ISO system, and applies only to European companies or companies doing business in Europe, whereas ISO 14001 applies worldwide. The other steps required for EMAS certification (after the inventory) are evaluation of the environmentally relevant activities, derivation of environmental protection targets, and development of the environmental management system, which provides the basis for the EMAS certification.

DISCUSSION

LCAs to develop environmental regulation/policy

Of the nine LCAs reviewed in this study, two can be considered to have been conducted to help develop or influence environmental policy or regulation. Although neither case seems to have had a direct effect on policy, both provided information that could have helped with decision making. The reasons for the lack of impact on policy/regulatory development might include the following: the limited scope of LCA results (few go beyond the inventory stage); the challenges of linking LCA to temporal or geographic impacts and risks; the large resource requirements; and the difficulty of incorporating site-specific variations into more generic LCAs.

LCAs to respond to environmental regulation/policy

Three of the LCAs were conducted in response to environmental regulations or policies. None of these cases was in the United States. The sustainable waste management LCA responded to the implementation of greenhouse gas emission targets by many Canadian municipalities by providing these municipalities with a baseline of environmental performance against which reductions in greenhouse gases can be measured, and to help evaluate the environmental performance of changes to waste management systems.

An even greater link between environmental policy and LCA appears in the Swedish study of milk production, which was conducted to identify hot spots in organic and conventional processing systems, and to test the hypothesis that systems with large inputs of feed and fertilizer have greater impacts than those that are more self-supporting. This LCA relates to a Swedish statutory target for organic production, and more directly to a European Union policy that gives financial support for environmentally sound agriculture. Demonstrating that milk production techniques are environmentally sound on a life-cycle basis can support the allocation of funds to such practices. The German brewery assessment marked the first step toward developing an environmental management system, which, in turn, is required to obtain official EMAS certification. EMAS certification is highly regarded in Europe because it demonstrates a certain minimum amount of environmental commitment, and as such, facilitates trade and marketing.

The number of LCAs probably will increase in the next few years as a result of increasing regulations and policies that directly or indirectly call for such an assessment. European regulations, such as the recently enacted end-of-life vehicle directive, can be expected to stimulate LCA use in the

United States. Recently promulgated state regulations and recently issued federal executive orders will also contribute to its use.

European regulations and U.S. LCA: The European Union and individual countries are initiating policies and passing regulations pertaining to end-of-life product management. Earlier this year, the European Commission and the European Parliament passed the end-of-life vehicle initiative. As this requires auto makers to pay "all or a significant part" of the costs of taking back all cars sold after 2001, it is likely that not only automobile manufacturers, but also suppliers of components and materials, will be conducting LCAs to identify and correct hot spots in the life cycle to minimize environmental impacts and costs at disposal. In January 2000, the Netherlands instituted a take-back law for electronic and electric equipment. This law requires suppliers to take back used equipment from consumers, and requires manufacturers and importers to take back goods from the suppliers. It applies to large and small household appliances, audio equipment, video equipment, electronic tools, computers, printers, batteries and chargers, and office and telecommunications equipment. Manufacturers of all of these items will need to consider the environmental impacts and associated costs of disposing or recycling these items and the materials contained in them. LCA will be a useful tool in conducting those analyses.

The United States has enacted no end-of-life, take-back, or product responsibility laws at the federal level, although EPA and others have discussed such laws.[3] Individual states and municipalities have proposed and, in some cases, enacted such requirements. In April 2000, the state of Massachusetts banned the disposal of televisions and computer monitors. Other states are

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[3] In 1996, for example, the President's Council on Sustainable Development (PCSD) and EPA jointly sponsored a workshop on extended product liability. At the workshop, the PCSD endorsed the principle of extended product responsibility as a means for industry, government, and the environmental community to identify opportunities for resource conservation and pollution prevention throughout the life cycle of a product. However, no federal laws have been enacted, nor even bills proposed, to require such responsiblity.

considering similar bans. These restrictions will require greater consideration of life-cycle impacts by manufacturers.

Policies for U.S. government agencies and DOD, and LCA: Recently established policies for federal agencies in the United States may also lead to increased LCA use. In September 1998, President Clinton signed Executive Order 13101, *Greening the Government Through Waste Prevention, Recycling, and Federal Acquisition,* the goal of which is to improve the federal government's use of recycled products and environmentally preferable products and services (E.O. 13101, 1998). The order defines *environmentally preferable* to mean products that have a lesser effect on human health and the environment than competing products that serve the same purpose. "This comparison may consider raw materials acquisition, production, manufacturing, packaging, distribution, reuse, operation, maintenance, or disposal of the product or service." The order requires all federal agencies to comply with the executive branch policies for the acquisition and use of environmentally preferable products. The order also requires EPA to develop guidance to address environmentally preferable purchasing, and states that the guidance can consider "tools such as life-cycle assessment in decisions on environmentally preferable purchasing." Another executive order that may result in greater use of LCA is E.O. 12893, *Principles for Federal Infrastructure Investments*, which requires all federal agencies with infrastructure responsibilities to, among other things, make investments on systematic analyses of benefits and costs, "measured and appropriately discounted over the full life cycle of each project" (E.O. 12893, 1994).

The DOD has established similar policies. On March 15, 1996, DOD Directive 5000.1, *Defense Acquisition,* was issued. It contains policies and principles for DOD acquisition programs. The directive states that "it is DOD policy to prevent, mitigate, or remediate environmental damage caused by acquisition programs," and that acquisition programs must minimize the potential impact on the environment of the relevant total system. A "total systems approach" is part of this policy; it requires acquisition programs to be managed to optimize total system performance and minimize the cost of ownership. The total system includes equipment, implementation, operation, deployment, and the potential impact on the environment.

LCAs Not Linked to Environmental Regulation/Policy

The remaining LCAs reviewed were conducted neither to develop policy nor to respond to specific regulations or policy. Nonetheless they were or are used for environmental decision making, and could be used to respond to environmental regulations or policies such as the types mentioned above.

CONCLUSIONS

There is little evidence that LCAs are used to develop environmental regulations and policy in the United States or abroad. In the United States, this may be due to the environmental regulatory process, which is directed toward individual environmental media and generally requires the application of end-of-pipe pollution control technologies. Tools such as LCA, which consider resource use, cross-media impacts, and process changes, do not fit within this structure. Recalling the 1970s, when LCA was used as input to U.S. policy development during the energy crisis, one can envision such use in the future, but not without a similar crisis (e.g., an agricultural crisis). Such a crisis could result in the allocation of resources necessary to undertake a comprehensive nation-wide LCA for policy development.

LCAs are used to respond to policies, particularly those pertaining to product end-of-life. Designers and analysts recognize that designs and actions taken in earlier stages of a product's life cycle (the "cradle" and the use portions) can affect end-of-life (the "grave") impacts. These uses can be expected to continue both in the United States and abroad, although the United States appears to be lagging behind other countries. The global economy and European policies can be expected to pressure U.S. companies to follow suit, with or without specific U.S. regulations. In addition, implementation of state-level take-back rules in the United States can lead to increased LCA application.

Most of the LCAs that are not directly linked to environmental policies or regulations are nonetheless conducted to assist in environmental decision making. These LCAs provide information to identify potential hot spots and areas requiring additional research. While these roles are very important, few LCAs can satisfy them because most of the LCAs are really inventories or accountings of environmental releases or resource requirements; few LCAs actually identify impacts, and even fewer include interpretation. While the results of inventory analyses are certainly useful, the real power of LCA can be expected when these inventories are used to assess life-cycle impacts. Combining LCA results with risk assessment, cost-benefit analysis, and other tools may help to translate data into impacts that consider factors such as exposure and differential temporal and geographic impacts.

Today, LCA can help to inject science into decision making; in the future it may play a more significant role, especially if the regulatory development process can be modified to incorporate the full benefits of life-cycle thinking, which include consideration of multi-media and cross media impacts, process design impacts, and resource use throughout a product's or process's life cycle.

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Table 1. Linkages between LCA cases and environmental regulation/policy

LCA used to help develop environmental regulation/policy*	LCA used to respond to environmental regulation/policy	No direct link between LCA and environmental regulation/policy
• Manure management (UK) • Interstate MSW transport (US)	• Sustainable waste management (Canada) • Milk production (Sweden) • Beer production (Germany)	• Generic automobile (US) • Electric vehicle (US) • Taj Mahal discoloration (India) • Military vehicle coatings (US)

* Includes LCAs for which the intent, although not necessarily the result, was to help develop or influence environmental regulations or policies.