World Resources Institute

Sustainable Enterprise Program
A program of the World Resources Institute

ALPHA MOTORS, LTD.:

Integrating Life-Cycle Environmental Concerns into Product Design

We are continuing to adjust our environmental management systems to provide the proper tools and processes to ensure continuous improvement in our environmental performance. We are committed to a comprehensive system of environmental management in all of our business activities.

Dennis Minano
Vice President of Environment & Energy
General Motors

Mike Barns, environmental champion of Alpha Motors's product design group, was reading during lunch when a headline in *Automotive Weekly* jumped out at him: "A Volvo will be environmentally labeled before the year 2000." Volvo was using a new "life-cycle tool" to assess the impacts of its products on the natural environment and would produce its first 100 percent-analyzed car in only three years. Despite Alpha's environmental commitment, Barns expected that the automaker's progress would be incremental. His own decision to push Design for the Environment (DfE) had been timely: that day he would head up the first pilot project using life-cycle analysis in a product design decision. If the design team could demonstrate the benefits of DfE-oriented tools and procedures, management would likely make them a permanent aspect of the product development process. Barns felt confident that these tools would help justify environmentally preferable decisions.

For more than a decade, WRI's Sustainable Enterprise Program (SEP) has harnessed the power of business to create profitable solutions to environment and development challenges. BELL, a project of SEP, is focused on working with managers and academics to make companies more competitive by approaching social and environmental challenges as unmet market needs that provide business growth opportunities through entrepreneurship, innovation, and organizational change.

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This case was prepared by Sandra Rothenberg of MIT's Sloan School of Management, Michael Lenox of MIT's Technology Management and Policy Program, Benjamin Jordan of MIT's Department of Civil and Environmental Engineering, and Dr. Frank Field III of the MIT Material Science Laboratory. Special thanks to Professor Jake Jacoby for his comments and assistance and to members of the automobile community who provided information for this case and to Saturn staff for help in preparing the case. While inspired by experiences at Saturn, parts of this case have been significantly altered for educational purposes. This case is intended to serve as the basis of class discussion rather than as an illustration of either effective or ineffective handling of a product design decision.

Founded in the mid-1980s, Alpha Motors, Ltd. was conceived as a forward-looking, innovative company. Since its inception, Alpha had fostered a culture of concern for environmental issues. Although earlier efforts focused on local issues ---manufacturing emissions and facility siting impacts, for example --- the environmental impacts of the product itself were growing in strategic importance to the company. As one of the company's most active environmental champions, Barns observed a general shift in strategy in many leading companies toward managing the entire life cycle of processes and products and their environmental impacts. This shift was fueled by an increased awareness of the cost of poor environmental performance. Improved understanding of the environmental consequences of decisions was essential in avoiding liabilities throughout the product life cycle, reducing material and disposal costs, and improving product attractiveness to environmentally concerned customers. Associated with this shift was a need to reconsider environmental management practices. As a result, the incorporation of environmental concerns into the product development process, DfE, was being touted as critical to the firm's managing their environmental impacts.

Well aware of a shift in industry environmental practice, Barns believed that environmental issues were basic to Alpha's future competitiveness; the time had come to push for more systematic DfE efforts. He had convinced Alpha's president to support a pilot project to explore the use of life-cycle design tools in product design. Now he was working with Alpha's design team specializing in body panels to help it select the material for the hood assembly of the XL2000, a continuation of Alpha's small car line. The team would consider the entire life-cycle impacts of material choice on the natural environment along with traditional decision criteria.

Background of Alpha Motors, Ltd.

Alpha Motors, Ltd. was announced in late 1983 as a subsidiary of the U.S. automaker, Mobility Company. Alpha was to build a small, fuel-efficient car that would outdo Japanese imports and make money---two goals U.S. automakers had been unable to achieve simultaneously for decades. Starting production in 1990, Alpha's basic platform consisted of sedans, coupes, and station wagons.

As initially marketed, Alpha was able to attract former import owners and non-Mobility customers. It went head-to-head with Japanese automakers and built a loyal customer base among affluent baby boomers. More than 50 percent of Alpha buyers said they would otherwise have bought an import, and 75 percent---in California, 83 percent---said they would have bought a non-Mobility car. In addition, 61 percent of Alpha owners stated that they would buy another Alpha when they traded in their old ones. At that time, Alpha sold cars only in the United States, Japan, and Taiwan. There was discussion, however, of expanding to a broader Asian market and to Europe.

One reason for Alpha's success was its strong brand identity. Much of this identity stemmed from the fact that the company placed a high priority on pleasing buyers. "We try to help people buy a car, rather than sell them a car," explained marketing Vice President Dan Rogers. Even though Alpha had recalled vehicles several times, for example, it received high marks for addressing the problems directly and accommodating customers to get the repairs done. In one case, when more than 1,000 cars were inadvertently filled with a defective batch of antifreeze, the company replaced the vehicles rather than making minor repairs. Such treatment helped Alpha develop a cultish following among its buyers.

Alpha's emphasis on personal attention was also reflected by the fact that for three years in a row it placed third on the J.D. Power Customer Satisfaction Index, behind Lexus and Infiniti. This success was undoubtedly due in part to the strong company culture, fostered through intensive training and directed employee selection, which focused on respect for the customer as well as the worker. Commented one industry analyst, "It's an incredible achievement that they have been able to build a strong culture in the company that is oriented toward the customer and quality."

Overall, using many product, process, marketing, and retailing innovations, Alpha met with relative success in its initial mission. However, it encountered problems meeting certain business goals. "It has a mixed record," explained one industry analyst, "The car has been an unquestionable sales, quality and marketing success. But the company has had significant problems with productivity, costs and profits." In response to these problems, Alpha undertook extensive cost-cutting measures, and in 1992 employee bonuses were tied to company profit.

In addition, some analysts worried that Alpha's four-year-old design was growing stale as the competition was strengthening. Alpha's main competitor had made some inroads with its sporty Neon, priced about $1,000 less than Alpha, which sold for about $14,000 well equipped. Alpha had just begun offering a passenger-side air bag to match Neon. Analysts noted that the subcompact market was extremely price sensitive and notoriously fickle; they questioned whether Alpha could survive without expanding its product lineup -- limited to a mix of coupes, sedans, and wagons built off a single chassis. Alpha officials insisted that they had no plans to offer a larger car.

Environmental Management at Alpha Motors

Since Alpha's inception, an important part of its customer and worker focus was a commitment to the environment. Alpha's initial operating philosophy -- outlined in a detailed mission, values, and philosophy statement -- contained promises to be "good citizens, protect the environment, and conserve natural resources." During and after construction of the assembly plant, Alpha's environmental efforts and organizational resources were focused primarily on minimizing waste through improved operational efficiency. One particular effort led to the development of water-based paints for plastics, which created significantly fewer emissions than traditional solvent-borne methods. When the water-based method produced greater-than-expected emissions, Alpha spent $25 million more on a carbon absorption system to capture them. Another ongoing effort was to reuse or recycle manufacturing wastes: in 1995, Alpha reprocessed approximately 59,000 tons.

More recently, Alpha started to focus on developing an environmental strategy for its product. Earlier product-oriented efforts had centered around the fuel efficiency of the vehicle. In addition to regulatory concerns under the federal Corporate Average Fuel Economy law (CAFE), fuel efficiency was an important consumer attribute in Alpha's target market. To develop and implement this strategy, the product development section established "environmental champions" in various areas (i.e., suppliers, marketing, product planning, and product design). To reduce vehicle weight and consequently to improve fuel efficiency, Alpha adopted thermoplastic body panels, which are lighter than traditional steel body panels. Unlike alternative polymer materials such as thermosets, thermoplastics are recyclable.

Mike Barns was the most active environmental champion in the firm. He led the effort to integrate environmental concerns into Alpha's design decisions and was the primary external spokesperson for Alpha's environmental efforts. Most of Barns's success could be attributed to his "can-do" attitude and genuine concern for the natural environment. His accomplishments were admirable given that he balanced his role as environmental champion with his many other traditional job responsibilities.

While Barns and other environmental champions strove to prioritize environmental issues in product development, Alpha's independent and decentralized structure complicated their efforts. Environmental champions could not mandate decisions based on environmental criteria. They created a list of environmental technical specifications for designers and placed recycling on the product designers' list of primary design criteria, but other design concerns typically dominated decision making. Cost-cutting pressures had also eroded environmental issues' importance in design processes.

Most employees understood that environmental performance was critical to Alpha's image. Care for the environment fit Alpha's image as a company that based its reputation on trust. Some product planners felt that Alpha customers brought environmental considerations into their purchasing decisions. As the environmental champion in product planning explained, "In the United States, customers have embraced environmental issues as part of their value system. While recycling may not outrank quality, safety, reliability, and durability when selecting a car, research indicates that it will grow in importance to tomorrow's customers." This belief formed the basis of some of Alpha's advertising campaigns. In one advertisement, Barns envisioned the day when cars would be 100 percent recyclable. As a result of these marketing efforts, Alpha won renown for its unique thermoplastic body panels as well as for its efforts to recycle them.

Barns's personal goal was for Alpha to recycle as much product material as possible. Although existing scrap markets recycled or reused upwards of 80 percent of used vehicle components, the remaining 20 percent was of great concern. In Germany, dwindling landfill space and opposition to incineration led to draft legislation that would require manufacturers to assume disposal responsibility for used vehicles. Despite the fact that such legislation appeared unlikely in the United States in the near term, Barns was still concerned with protecting Alpha's image as an environmental leader, and he pushed the company to explore the possibility of voluntarily taking back its product at the end of life to be disassembled and reused or recycled. He felt that if Alpha did not aim for 100 percent recyclability, it would not be living up to its responsibility to its customers. He explained: "It is very hard to create an image, but it is very easy to break one!" This concern related particularly to a pending decision to switch to body panels made of SMC-- a thermoset polymer that was difficult to recycle. Because of the lack of markets for it, SMC scrap was either sent to a landfill or incinerated.

Not all Alpha managers and designers believed that environmental issues were so important to consumers. Although market research indicated that consumers were most likely to show concern for fuel efficiency, alternative fuels, and automobile recycling, they were unlikely to pay more for these features. As a result, down in the product design "trenches," environment was still often the first criterion to be cut. Product design was market driven at Alpha and some felt that this attitude was unlikely to change until product planners outlined a clear market-driven environmental product strategy.

Barns realized that many Alpha employees did not share his zeal for improving Alpha's environmental performance. In addition, most employees did not understand how their decisions impacted the natural environment. Having closely followed the management initiatives of leading companies, however, Barns had begun to realize that if Alpha was going to remain an environmental leader, it needed more systematic incorporation of environmental concerns into the product development process. While Alpha had considered environmental issues in design decisions in the past, it had done so in an ad hoc fashion. Barns was aware of the so-called "Design for Environment" concept and felt that Alpha needed to establish its own formal DfE program. He was especially interested in the feasibility of using life-cycle analysis (LCA) methods in the design process. Barns felt that only through the consideration of its products' environmental impacts from "cradle to grave" could Alpha make good design decisions and prevent the deterioration of its environmental image.

Design for Environment and the Automotive Industry

Throughout much of the history of environmental management, industries pursued pollution control strategies by adding emissions control devices such as scrubbers and filters to manufacturing waste streams in compliance with various government regulations. Although pollution control devices allowed firms to preserve existing product characteristics and manufacturing processes, companies increasingly recognized that it was more efficient to prevent pollution at the source. By altering products and processes, industries could eliminate wastes---avoiding the escalating costs associated with pollution control equipment.

DfE arose out of pollution prevention efforts of the 1980s. A handful of companies began to explore ways to incorporate environmental concerns into the product development process. Despite the fact that notions of "green" design had been discussed for decades, the routinization of such practices among large multinational companies was new. Among the leaders were companies in the automotive industry, including BMW, Volkswagen, Volvo, and Ford.

Researchers at AT&T Bell Laboratories adopted the term "Design for Environment" to associate it with a set of concurrent product design practices referred to as "Design for X," where X represents a design characteristic such as manufacturability, service, or assembly. The motivation behind Design for X was to incorporate nontraditional criteria into the design process. To the researchers at Bell Labs, DfE was a logical extension to the Design for X concept.

From the outset, DfE was tightly coupled with LCA. LCA is a systematic process that characterizes the energy and resource use and the environmental impacts of a product, process, or operation from cradle to grave, i.e., from processing raw materials through manufacturing, use, and ultimately, disposal. LCA has been viewed as an effective analytical tool to inform DfE efforts.

LCA was first used in the late 1960s and early 1970s to quantify energy use associated with products. As early as 1969, The Coca-Cola Company conducted what it termed a "resource and environmental profile analysis" (REPA) to compare alternative beverage containers. Since the first REPAs, firms have come to use LCAs both internally and externally ---internally to help quantify the environmental impacts along the product life cycle and externally to compare two or more similar finished products (e.g., cloth diapers versus disposable diapers).

A wide range of potential users was interested in the application of this technique. Consumers and consumer interest groups saw LCA as a way to inform customers of the relative environmental impacts of alternative products, hoping to bring market pressures to bear upon producers. Regulators and policy makers saw LCA as a tool that could guide environmental policy development and assess the effectiveness of environmental laws and regulations. Further, industry focused on the internal use of LCAs to help study and analyze strategies to meet environmental challenges.

Process and product developers adopted LCA as a way to incorporate environmental considerations into their design processes, helping to anticipate and avoid potential pitfalls. LCA's strength derived from its roots in traditional engineering and process analysis and from the recognition, implicit in its formulation, that the consequences of technological undertakings are not limited to the performance of a single process or change. Rather, one must consider the entire range of precursors and consequences of that process or change.

The basic objective of LCA was to guide decision makers, whether consumers, industrialists, or government policy makers, in devising and selecting actions that would minimize environmental impacts while furthering other objectives. Thus this tool had to be used in concert with traditional motives for selecting one action over another, including economic, engineering, and social goals.

LCA was regularly presented as a five-step process:[1]

1. Goal recognition: The specific goals of the life-cycle analysis and needs of the users are clarified and then used to guide subsequent decisions in the analytic process. The goals of the LCA should be made clear from the beginning because as the depth and breadth of the information gathered and used in the analysis will be defined by the aim and scope of the study.

2. Inventory analysis: Data for the LCA are collected to quantify the inputs (energy and raw materials consumed) and outputs (pollutants and solid wastes produced) throughout the life cycle of the products and processes. To ensure transparency and reproducibility, data should be sourced from a specific time period and the technologies used or assumed should be clearly stated, as should any other assumptions. Inventory data are typically collected from cradle to grave.

3. Classification: The inventory data are grouped, or classified, by type or particular impact on the environment made by each of the input/output components quantified in the inventory.

4. Valuation and impact assessment: The broad impacts on the physical, chemical, and biotic environment and on the health of the living organisms need to be assessed for all the resources consumed and the outputs released throughout the life cycles of the system(s) under review. This stage is one of the most contentious in the LCA process because much divergence and disagreement can occur. Issues of concern include the definition of environmental processes and effects, aggregation of the impacts, and the normative weighting in the different categories.

5. Improvement: The results of the LCA are used within a larger decision-making framework. Environmental and other important criteria are used to make a decision regarding the system under consideration. Recommendations for action are based on this final evaluation.

Much of the focus on LCA was upon the how and the what of its undertaking. Organizations such as SETAC (Society of Environmental Toxicology and Chemistry) and the EPA worked to develop a complete set of procedures for collecting and organizing the information developed in the course of an LCA. However, determining what to do with this information, once collected, left many observers at a loss. Expressed simply, the objective of employing LCA was to reduce environmental impacts.

Unfortunately, for all but the simplest situations, determining how this general objective informed specific problems was extremely difficult --- a fact recognized by increasing numbers of LCA practitioners.

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[1] The five-step process described is taken from Guinee, J.B., H.A. Udo de Haes, and G. Huppes, "Quantitative Life Cycle Analysis of Products," *Journal of Cleaner Production* 1(1993):1. Although this was the first well-known framework for LCA, a newer technical framework for LCA developed by the Society of Environmental Toxicology and Chemistry (SETAC) was recognized perhaps even more. SETAC identified three major phases: inventory analysis, impact assessment, and improvement, which incorporated elements of the process presented above.

This difficulty arose from several sources. Most apparent was the fact that understanding the relationship between releases to the environment and environmental damage was still in its earliest stages, particularly when many such releases had to be considered together. However, this difficulty apparently did not limit the development and application of LCA methodology.

What proved to be the most complicated aspect of LCA was the final improvement analysis component. Improvement analysis implicitly assumed that it was possible to discern the "best" action from a menu of options. Aside from simple cases in which it was possible to find an action that reduced all impacts on the environment, the "best" choice depended upon the relative importance placed on each of the possible consequences indicated by the analysis. This relative importance was a reflection of the strategic objectives underlying the problem under consideration rather than the result of any purely analytical evaluation. Because of this distinction, substantial hurdles were to be overcome before LCA could be applied to broad questions of industrial and social policy.

Selection of a Hood Assembly

Mike Barns had to establish basic design decisions, such as panel material, early in the design process. His supervisor had asked him to submit his design team's hood assembly material recommendation by the following week's XL2000 planning meeting. Prior research indicated that the only technologically feasible choices for the hood assembly were steel, aluminum, and SMC plastic. The choice would initially be made independent of the choices for other body panels.

With consideration of the impacts material choice has on the natural environment, added to other traditional decision criteria, this decision would differ from Barns's previous product decisions. He had decided that the most advanced method for evaluating the environmental life-cycle impacts was the EPS Method (Environmental Product Strategies in product design), developed by the Swedish-based Product Ecology Project. He chose this system because (1) it simplified environmental impacts in one single number for designers, (2) it moved beyond an emissions inventory to explore the actual environmental impacts of materials choices, and (3) it allowed for alteration of basic assumptions and sensitivity analysis (see Appendix A).

At this stage, however, Alpha was not ready to commit to a life-cycle tool. The president had agreed to try a spreadsheet tool that was developed by a local university and was based on the EPS system for material choice for the XL2000.[2] This experiment would then be used to decide if Alpha should adopt the system. Barns had been given the responsibility to work with EPS when choosing the material for the hood and to help the president understand its strengths and problems.

The challenge to Barns and the rest of the design team was to select the hood assembly that best met various criteria. These included the technical performance of the hood assembly, manufacturing and other costs, as well as environmental concerns ---recyclability, manufacturing emissions, and fuel efficiency. No specific constraints had been given, just the general edict to select the hood assembly that best minimized costs and environmental impacts, and maximized performance. Any decision had to be backed up with sufficient analysis to be acceptable to management. Barns had compiled technical data on each of the criteria.

The university's spreadsheet, based on the EPS system, included five tables: materials, manufacturing costs, end-of-life recovery operations, disposal rates, and environmental impacts:

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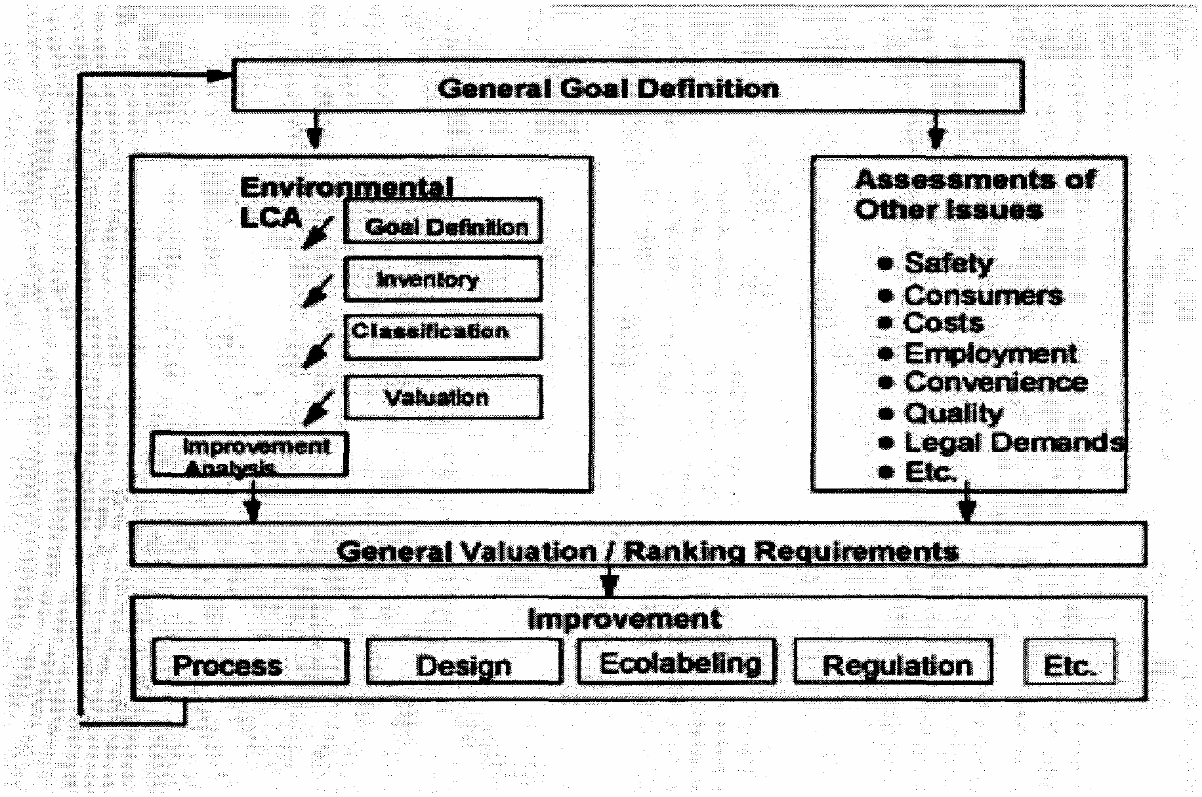
[2] The spreadsheet used in this case, although based on the EPS system, was not developed by the Swedish Product Ecology Project. The spreadsheet was developed solely for this case.

- The materials table contained information concerning the raw material needed for producing the hood and the amount of scrap produced during manufacturing.
- The manufacturing costs table contained the costs for raw materials, manufacturing, and disposal. The total cost to produce one hood was calculated.
- The end-of-life table allowed Barnes to explore the (possible) returns from recovering the XL2000 at the end of life. The product recovery rate reflected the percent age of manufactured vehicles recovered at the end of life.
- The disposal rates tables contained information about the deposition of both the manufacturing scrap and the end of life waste.
- The environmental impacts table used data from the EPS system (included on the same worksheet) to assess environmental impacts. Barns could play around with the EPS portion of the spreadsheet to understand how it weighted different impacts.

Barns also wanted to test various scenarios using data from the case and altering parameter values in the spreadsheet.

Exhibit 1: The LCA Process



Source: Guinee et al., 1992

Exhibit 2: Recycled Material Prices

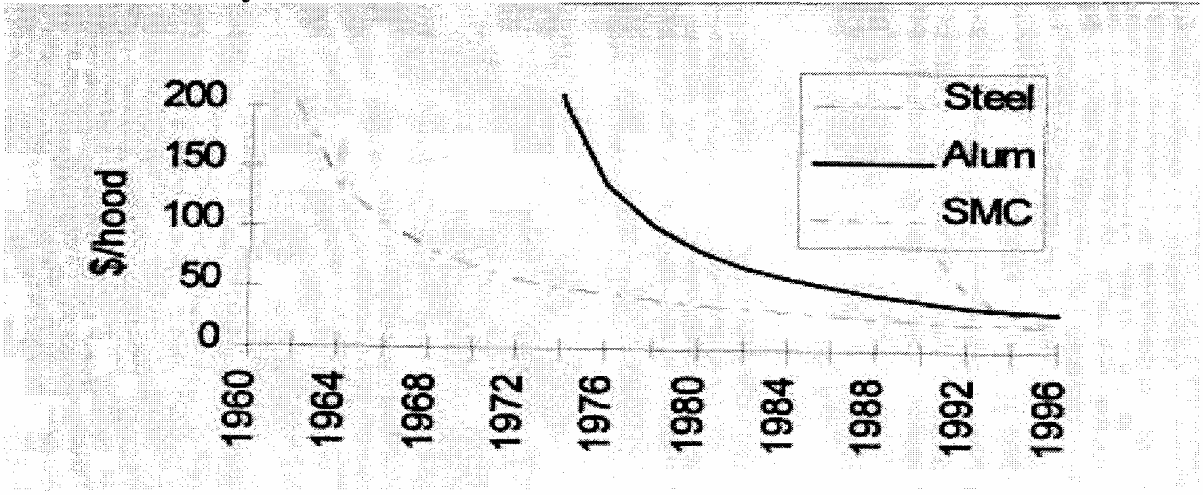


Exhibit 3: Raw Material Prices

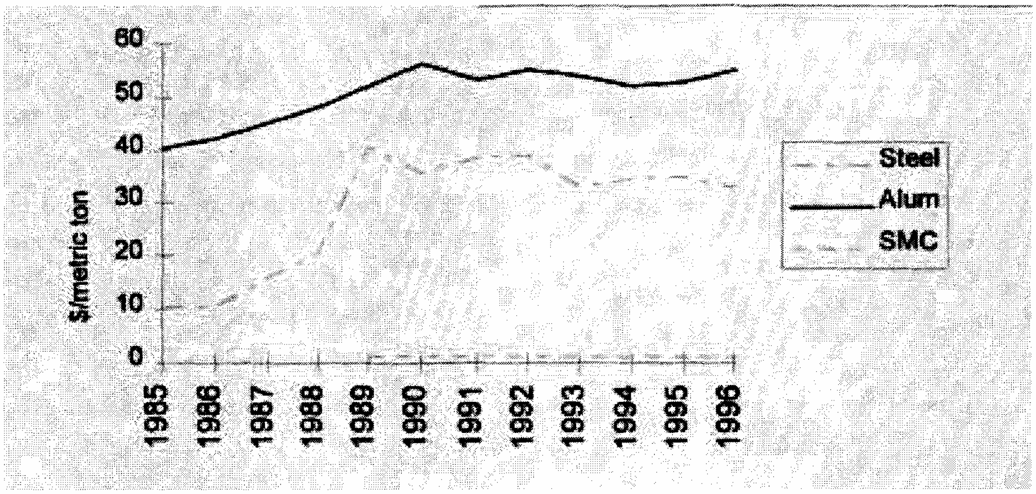


Exhibit 4: Manufacturing Costs

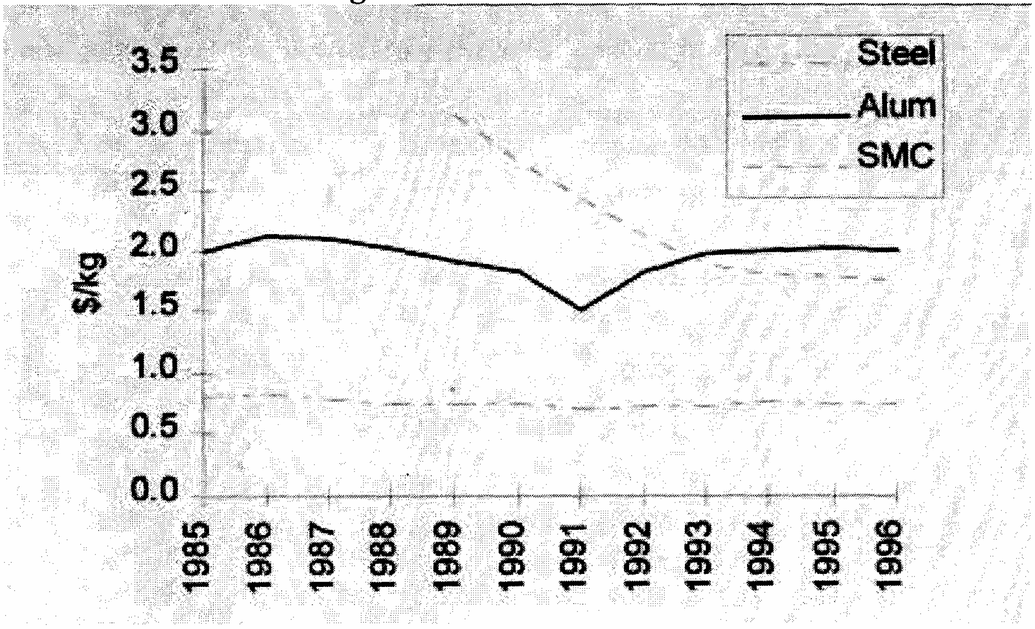


Exhibit 5: Automotive Hood Assembly Technical Performance Summary

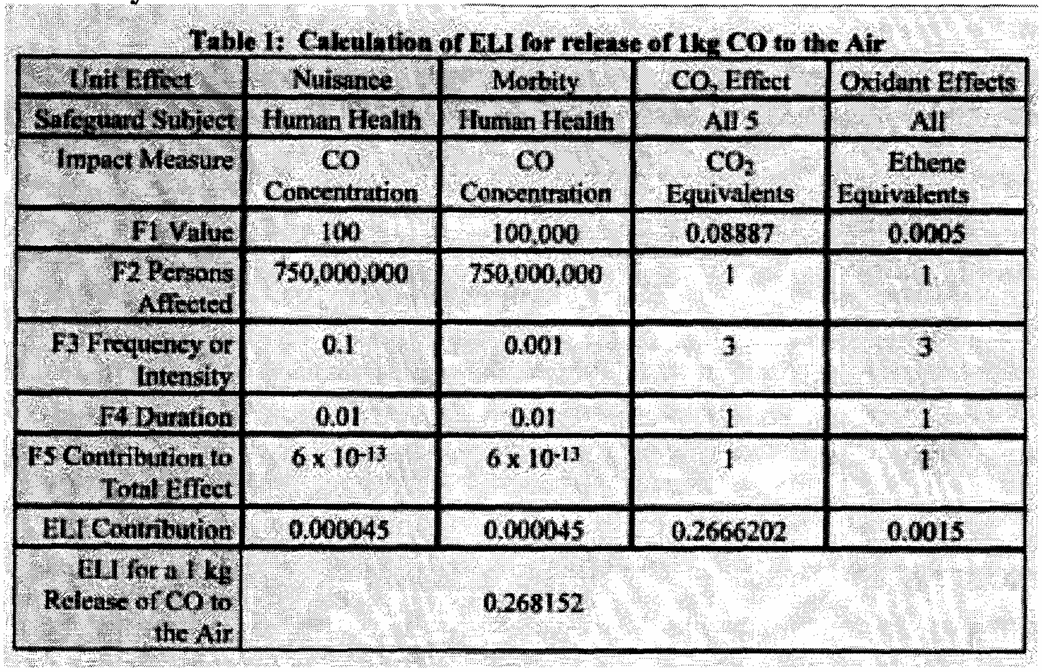


Table 1: Calculation of ELI for release of 1kg CO to the Air

Unit Effect	Nuisance	Morbity	CO_2 Effect	Oxidant Effects
Safeguard Subject	Human Health	Human Health	All 5	All
Impact Measure	CO Concentration	CO Concentration	CO_2 Equivalents	Ethene Equivalents
F1 Value	100	100,000	0.08887	0.0005
F2 Persons Affected	750,000,000	750,000,000	1	1
F3 Frequency or Intensity	0.1	0.001	3	3
F4 Duration	0.01	0.01	1	1
F5 Contribution to Total Effect	6×10^{-13}	6×10^{-13}	1	1
ELI Contribution	0.000045	0.000045	0.2666202	0.0015
ELI for a 1 kg Release of CO to the Air	0.268152			

Exhibit 6: Material, Disposal, and Recovery Data

The following was reported from the Environmental Affairs office. The numbers represent its best estimates based on today's infrastructure. Costs and disposal percentages will likely change in the future.

	Steel	**Aluminum**	**SMC Plastic**
Material per Hood	11.92 ± 1 kg	8.25 ± 1 kg	9.30 ± 1 kg
Manufacturing Scrap Rates[1]	40%	40%	10%
Landfill Disposal Costs	$15/metric ton	$15/metric ton	$15/metric ton
Incineration Costs[2]	n/a	n/a	$10/metric ton
Manufacturing Scrap Landfilled	0%	0%	60%
Manufacturing Scrap Incinerated	0%	0%	40%
Manufacturing Scrap Recycled[3]	100%	100%	0%
End-of-life Scrap Landfilled	0%	0%	60%
End-of-life Scrap Incinerated	0%	0%	40%
End-of-life Scrap Recycled[3]	100%	100%	0%
Disassembly Costs	$10/metric ton	$10/metric ton	$10/metric ton
Recovery Transportation Costs	$10/metric ton	$10/metric ton	$10/metric ton

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1. The scrap rate for SMC is considerably lower because SMC parts are injection-molded – little scrap results and the rejection rate is a low. Stamping metal has an unusually high scrap/rejection rate.
2. Steel and aluminum may not be incinerated.
3. Steel and aluminum are both easily recyclable. SMC is currently not recyclable.

Appendix A: The Environmental Product Strategies (EPS) System

The Environmental Product Strategies (EPS) system is a life-cycle tool developed by the Swedish Federation of Industries. EPS offers a single all-encompassing measure of environmental impacts for a specific material or product choice. The basic calculation principle of the EPS system is

Environmental load unit (ELU) = environmental load index (ELI) x product quantity

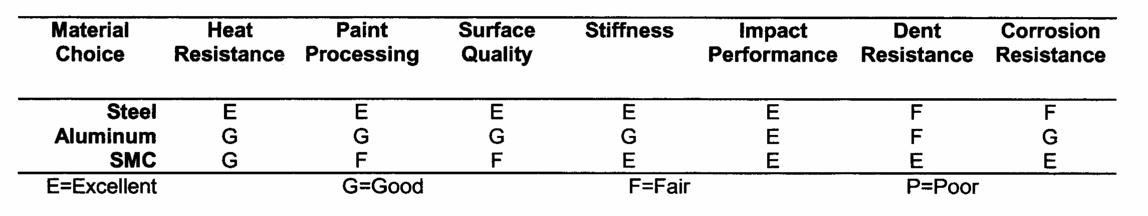
where the ELIs are the key indices that indicate the relative environmental impacts associated with the production, use, and disposal of a particular product or material. The various weighting factors are based on the environmental objectives of the Swedish Parliament. As an intermediary step, EPS relates all the physical consequences of the production, use, and disposal of a material to its impact on five environmental "safeguard subjects": biodiversity, human health, biological production, resources, and aesthetic values.

Because the impacts on any one safeguard subject may take several forms, EPS allows for individual consideration of each of these consequences, called "unit effects." Two criteria are applied when establishing which impacts will become unit effects: the importance of the impact on the sustainability of the environment and the existence of an ability to establish a quantitative value for that impact within traditional economic grounds. Examples of unit effects for human health include: mortality owing to increased frequency of cancer, mortality owing to increased maximum temperatures, and food production decreases (and, hence, increased incidence of starvation) owing to global warming.

Once the individual unit effects are established, their relative value must be determined. This valuation is accomplished by expressing each unit effect in terms of its economic worth and associated risk factors. Formally, the value of each unit effect is set equal to the product of five factors, Fl through F5. Fl is a monetary measure of the total cost of avoiding the unit effect. The extent of affected area (F2), the frequency of unit effect in the affected area (F3), and the duration of the unit effect (F4) represent "risk factors" similar to those employed in toxicological risk evaluations. F5 is a normalizing factor, constructed so that the product Fl-F5 is equal to the cost of avoiding the unit effect that would arise through the use or production of one kilogram of material. The product of all five factors yields the contribution of a particular unit effect to environmental load. Summing the value of each unit effect yields the environmental load index (ELI) in units of environmental load per unit of material consumed or processed (ELU/kg). Because these unit effects were specified according to their relevance to the five safeguard subjects, the ELI represents the total environmental load (or impact) of the process.

Consider the data in Table 1, for example which illustrates how the ELI for the release of carbon monoxide to the air is estimated. The first two columns of data demonstrate how the impact of two specific unit effects, nuisance and morbidity, are incorporated into the overall ELI for a CO release to air. Based upon a variety of studies, the value of excess nuisance and morbidity are estimated at 102 and 105 ELU/man-year, respectively. (Note that, according to the definition of F1, these values are the estimated costs, in ECUs, of avoiding these unit effects). Further, the incidence of these impacts is estimated for the world urban population, assuming that hazardous levels of CO occur only 10 percent of the time and that 0.1 percent and 10 percent, respectively, of the population succumb to this effect when exposed. Further, given that 1,600 million metric tons of CO are already being released, the incremental effect of one additional kilogram released is 1/1,600,000,000,000, the F5 term. These terms, F1-F5, are multiplied together and then summed over all unit effects to develop the ELI for CO release to the atmosphere in ELU/kilogram released. With this number, any life-cycle data that reveal the release of some amount of CO can be valued by multiplying that release by the ELI. The EPS system is designed to develop these ELIs for all release, as well as for all human activities that consume resources; thus the relative ELUs for any two life-cycle inventories can be computed and compared.

Table 1: Calculation of ELI for release of 1 kg CO to the air



Material Choice	Heat Resistance	Paint Processing	Surface Quality	Stiffness	Impact Performance	Dent Resistance	Corrosion Resistance
Steel	E	E	E	E	E	F	F
Aluminum	G	G	G	G	E	F	G
SMC	G	F	F	E	E	E	E

E=Excellent G=Good F=Fair P=Poor

The safeguard subjects represent the sustainability of the environment in terms of the environmental "capital" (biodiversity, resources, and aesthetic values) and production capacity (production and human health). A value is set to a change in the environment for each of the safeguard subjects. The valuation is traditionally based on economical grounds and is expressed in monetary terms (an ELU, therefore, is equal to 1 ECU or approximately $0.80). The notion of willingness to pay (i.e., to pay for saving a species, avoiding a decrease in production, avoiding a death or nuisance, or maintaining a given level of aesthetics) is used to assign values to a particular effect of a change in the environment. As a result, the elements of the valuation process for a change in the environment are both subjective and objective in character.

Based on the calculated ELIs, ELUs are then calculated for a material choice for three main phases: production, product use, and caretaking. The example below illustrates how an ELU is calculated for the production phase of a polypropene bucket. The environmental load related to various subprocesses is calculated following an inventory of multiplication of indices with quantities. Summing up the environmental load indices from the subprocesses results in a total index, indicating the overall environmental load associated with the production of 1 kilogram of a material.

Exhibit 1: Example of ELU calculation

To what extent has a newly produced bucket made of polypropene affected the environment?

Weight: 0.7 kg
Material: polypropene, environmental load index (ELI) = 68 ELU/kg
Process: injection molding, environmental load index = 0.08 ELU/kg
Total ELU = 0.7(0.68) + 0.7(0.08) = 0.54 ELU