Eco-Efficiency and Sustainable Product Development

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Abstract

Despite advances in environmental management in the recent past, businesses today need to take more action and responsibility in order to ensure for a healthy and sustainable future. In addition to taking more action, the type of action taken must also be carefully considered. In businesses today, environmental control usually entails 'end-of-the-pipe' solutions, which in fact do not produce environmental solutions, but rather forestall the problems. However, a few environmentally conscious businesses have developed new sustainable concepts and practices that have had a significant impact on the environment, emphasizing the principles of maximum value and minimum resources. Such concepts and practices include eco-efficiency, extended product responsibility, design for the environment, product stewardship, product services, and by-product synergy. Each of these concepts has developed into well-respected and successful programs in various businesses, and is influencing those businesses whose commitment simply involves complying with environmental regulations. In order to ensure for a more sustainable way of living, businesses must go above and beyond regulations in order to reduce the environmental impact of their products and services, for which they are responsible. Each member of the product chain must also share in this responsibility. Consumers' growing environmental awareness and concern are driving businesses to take action and include them into the responsibility of the product's life cycle. In order for all these efforts to be successful, the economic and regulatory systems surrounding the development of businesses today must also be considered. Only then can businesses operate at their highest environmental standards.

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Introduction

A growing concern in our world has been the impact of human activity on the environment. Our industrial society cannot function independently of the environment in which we live. Our decision making is the determining factor in the future impact of this planet. If we can reduce the impact of technology on the environment without compromising the standards of the technology, we can achieve a sustainable way of living.

Products can have a negative effect on the environment due to high levels of pollution emitted and both resources and energy consumed over the course of the manufacturing process. Most of what has been done to solve this problem focuses on controlling pollution at the 'end of the pipe.' When evaluating the sustainability of a product, however, factors must be considered over the entire life cycle of the product. The life cycle stages include extraction and processing of raw material, manufacturing, transportation, and distribution, maintenance, recycling/remanufacturing and final disposal (Figure 1).

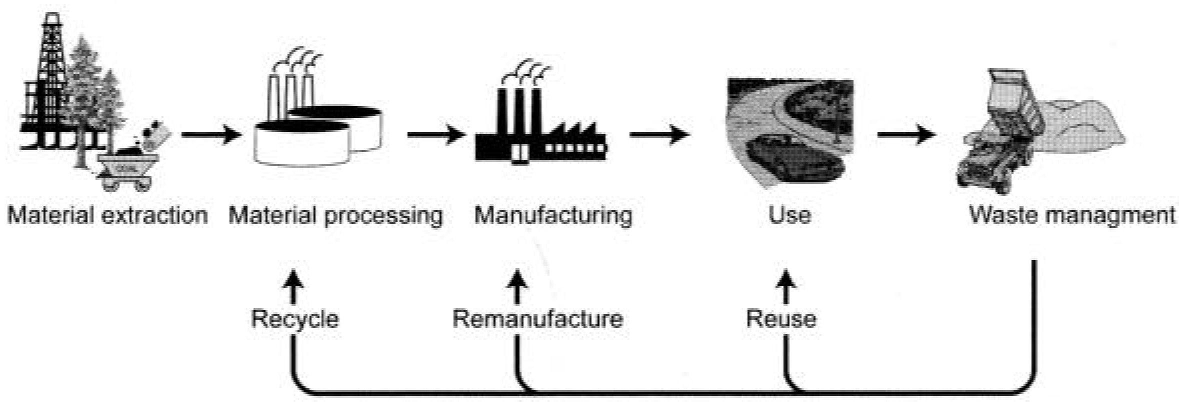

Figure 1: Stages of a product's life cycle [1]

Today, businesses operate much differently than they have in the past. Environmental management involves more than just controlling local pollution and recycling. More companies today are taking responsibility for the impact of all stages of a product's life cycle. In this environmental management of products, however, companies must not sacrifice the quality or function of the products themselves. The public today is concerned with environmental impacts, but not at the expense of quality. Customers are not willing to accept trade-offs. Environmental values in business play a great role in the marketplace today. A business that fulfills both criteria of environmental performance and product quality therefore holds an advantage over its competitors.

Businesses' environmental management practices can vary in levels of commitment. The first level of commitment simply involves complying with environmental regulations. The next level involves further reducing environmental impact beyond the required level. The final level embraces environmental, social and ethical concerns, improving environmental performance with sustainable objectives in mind. Less than 20% of North American and European companies are at this last level. [2] These companies have developed new sustainable concepts and practices that will hopefully influence other companies. Such concepts and practices include eco-efficiency, extended product responsibility, design for the environment, product stewardship, product services, and by-product synergy. These sustainable business principles and practices will be discussed in the following sections of this paper.

Eco-Efficiency

Eco-efficiency combines ecological and economic goals and was first addressed by *the World Business Council for Sustainable Development* (WBCSD). At the first Antwerp Workshop on Eco-efficiency held in November 1993, eco-efficiency was defined as being “reached by the delivery of competitively priced goods and services that satisfy human needs and bring quality of life while progressively reducing ecological impacts and resource intensity throughout the life cycle to a level at least in line with the earth’s estimated carrying capacity.” [3] The objective of eco-efficiency is to maximize value while minimizing resource use and adverse environmental impact. This concept of ‘producing more from less’ is very important for industrialized countries today, since they consume 80% of the world’s resources while accounting for only 20% of the world population. [4]

The WBCSD has identified seven success factors for eco-efficiency that a company should strive towards: [3]

- reduce the material intensity of goods and services
- reduce the energy intensity of goods and services
- reduce toxic dispersion
- enhance material recyclability
- maximize the sustainable use of renewable resources
- extend the durability of products
- increase the service intensity of goods and services

A company should therefore work towards making better products from the same amount of raw materials with less waste and fewer adverse environmental effects. There are a various number of ways that companies can go about implementing eco-efficiency. For example, in 1989, Proctor and Gamble introduced concentrated detergent powders that took up half the volume of traditional detergents. The same amount of clothes were cleaned while the product was easier to handle, used 30% fewer raw materials, required 30% less packaging, and cut the energy needed to transport them to the market. [2] In this example, the resource consumption and environmental impact of the product were reduced but the quality of the product was not compromised in the process. Reducing waste and pollution, and using less energy and fewer raw materials also reduce the company’s costs. Companies like Proctor and Gamble are going beyond environmental regulation requirements, by developing a “closed-loop” processing cycle in which wastes are completely recycled or reused and never enter the environment.

Extended Product Responsibility

Extended Product Responsibility (EPR) addresses the impact of the products themselves over their entire life cycle. It recognizes that long-term environmental improvements in product systems can only occur with the responsibility, commitment, and cooperation of all members of the product chain – from suppliers, designers, manufacturers, and distributors to retailers, customers, recyclers, remanufacturers, and disposers. EPR was originally adopted in the early 1990s by Thomas Lindhqvist, a Swedish researcher at Lund University, when he was studying a 1993 German packaging regulation that required manufacturers to take back product packaging. He developed a concept called Extended Producer Responsibility. In the US, the term was changed to Extended Product Responsibility to convey the idea that responsibility is shared by both producers and consumers. In its report released in February 1996, the *United States President's Council for Sustainable Development* identified EPR as a means to improve "the current fragmented approach to waste reduction, resource conservation and pollution prevention." [5] EPR is a way in which to make product systems sustainable. It extends the *Design for Environment* and *Product Stewardship* (described in the following sections) concepts beyond the producer, and to all participants in the process, conveying the principle that responsibility is "shared." Therefore, *Design for Environment* is one example of what a producer's responsibility would be in the overall EPR process; in fact, producers have the greatest responsibility in the chain of members because they have the most ability to reduce the adverse effects of their products on the environment. Some examples of EPR are variable rate pricing for garbage disposal, deposit-refund systems and mandatory product return requirements (customer); the purchase of environmentally sound products, established subsidies and tax credits to promote products with low environmental impact, and taxes on specific materials or products (government); and mandatory disclosure of environmental information (producer). Some of these principles of EPR will be discussed in further detail.

Governments can help promote the concept of EPR through enforced regulations. However, the EPA is interested in encouraging other members of the product chain voluntarily toward EPR. They have learned that voluntary measures often achieve more environmental improvement at less cost than enforced regulations or mandates. [6] Voluntary measures toward EPR can have environmental and economic benefits for both business and society as a whole. Dow Chemical Company has found that voluntary projects to improve environmental performance are often more cost-effective over the long term than actions required by legislation and regulation. The company has achieved average returns of 55% from voluntary investments over the past ten years and expects to see continuing financial gains from its environmental improvements.

Design for Environment and Remanufacturing

Design for Environment (DfE) incorporates environmental improvements into products or services before they enter the production, delivery and consumption phase. When a dissembler is faced with certain technical problems, design engineers are informed to study how the product can be better designed to simplify and speed up disassembly. An example of such a study is shown in Figure 2 for the design of a piece of medical equipment. One major aspect of DfE, therefore, is to reuse components of a product, recapturing the value added during the original manufacturing process. This can be done by building products from both new and remanufactured parts that must meet the same strict standards. DfE and remanufacturing must compliment each other – the remanufacturing process provides valuable inputs to company on how to improve the design of their product to make it more recoverable. Remanufacturing is an important aspect of DfE, and it is important to understanding how the remanufacturing process is different from the recycling process.

Measure	*Consequence*
1. Use fewer fasteners.	Faster assembly and disassembly.
2. Use fewer fastener types.	Fewer tools in assembly or disassembly.
3. Substitute nuts and bolts by quick fasteners.	Lower direct costs, faster assembly and disassembly.
4. Select environmentally friendly materials, whenever possible.	Fewer hazardous waste to be handled. Lower disposal costs.
5. Adopt returnable and reusable dollies to package equipment	Reduced waste at the job site. Increased customer satisfaction.
6. Use returned package to pack old equipment.	Value still remaining in old equipment is preserved. Old equipment is easily handled. Lower labor cost.

Figure 2: DfE study for medical equipment [7]

The remanufacturing process is one in which large quantities of similar products are brought into a central facility and disassembled. Parts from a specific product separated, collected by part type, cleaned, and inspected for possible repair and reuse. Remanufactured products are then reassembled, usually on an assembly line using the necessary recovered parts and new parts. Remanufacturing requires a high volume process similar to new product manufacturing, except the parts on the assembly line are mostly reconditioned parts. A remanufactured product has to comply with the same manufacturer's specifications on quality, control and testing as a new product does. [8] Some companies specialize solely in remanufacturing and do not build new products.

Recycling is the final stage of remanufacturing. The recycling process, instead of reusing old parts, reprocesses them directly after disassembly and cleaning of the product to new raw materials and later rebuilds these materials into a new product. The products created from the recycling process are always new, while the products created from the remanufacturing process are second-hand products, even if they have the same quality as a new product (which they are usually required to). To further understand the difference between the two, Figure 3 shows the recycling and remanufacturing process of a computer screen. In the remanufacturing process, a system for identifying used products should exist, such as marking the product or using a color label to show the number of passes through the remanufacturing process. The purpose of this step is so that, when the product has reached its useful life, after a certain number of passes through remanufacturing (depending on the product), it can be sent for recycling.

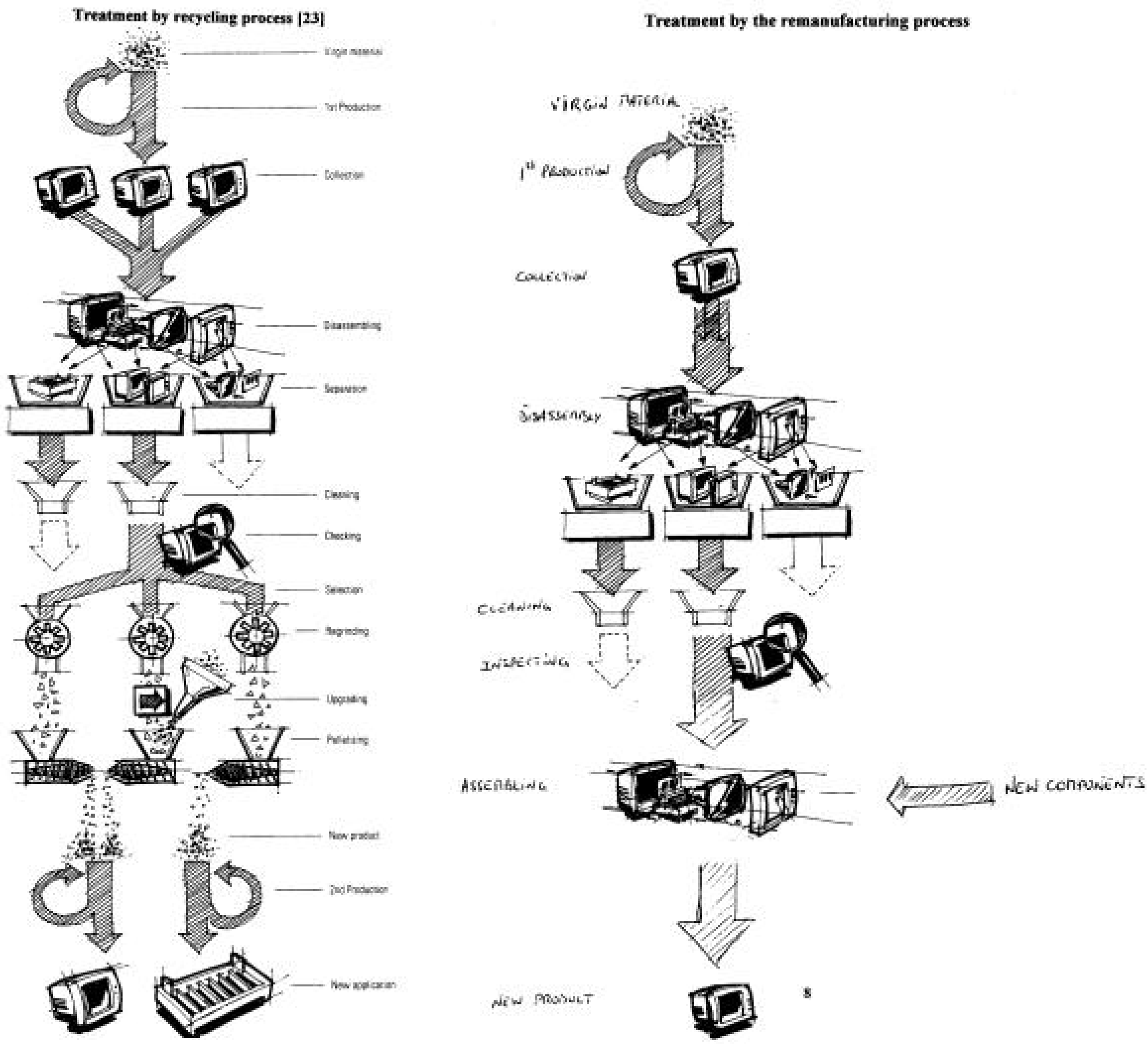

Figure 3: Recycling vs. Remanufacturing Process for a Computer Screen [8]

Economics of Remanufacturing

An important driving force behind remanufacturing is cost reduction. The cost of purchased parts and components as well as the cost of waste disposal are a very large percentage of manufacturing costs. For example, in Germany, disposal costs currently represent 2% of direct production costs of laser printers, 3% for cars, and 12.5% for refrigerators and freezers. [9] Remanufacturing has therefore become a potential incentive to reducing both the cost of purchased parts and waste disposal simultaneously. However, the economical viability of a remanufacturing process depends on the specific application.

In order for remanufacturing to be economically worthwhile, sufficient "reverse flow" or take back of a product is required. Without this, the remanufacturing process will not be beneficial to the manufacturer. For example, remanufacturing is much harder to achieve for a long-lived product than a short-lived one. Sufficient "reverse flow" of a product depends not only on volume, but also on variety and quality. A return stream will typically consist of a larger variety of products than the forward product design stream due to (1) the range of models being returned from different years, and (2) the range of degrees of wear and tear on the returned product. A range of old and new models can make remanufacturing difficult when the return flow consists of high-valued parts. This situation can be seen specifically in the computer industry, where it is difficult to use remanufactured components due to the fast rate of product change. There is a limited demand for older models in the computer industry, making the recovery of high-valued parts not economically feasible. There is less potential for the remanufacturing process in industries where the models are changing rapidly.

The remanufacturing process within a company usually involves some type of take-back policy for its customers. Companies in this case need to decide whether they should buy back the used product or charge the customer to get rid of it. Rank-Xerox understands that there is a significant value still remaining in their used products and therefore pays to have their used products returned. Remanufacturing becomes profitable only if the value reclaimed from both the remanufactured product and the displaced disposal costs are greater than the remanufacturing costs.

Customer reactions to particular remanufacturing programs have a major impact on the economic viability of the process. An apparent concern of customers in the case of remanufacturing is that they are not purchasing a product that is inferior in quality. Customers have to believe that they are not sacrificing quality by buying a remanufactured model. By offering the same warranty as a new product, a company can show its customers that their remanufactured products are not inferior to their new products.

Case Study I: Rank-Xerox Corporation

Rank-Xerox, a UK based joint venture between the Rank Organization and Xerox Corporation, manufactures and sells plain paper copiers in Europe. In 1987, the company set up a remanufacturing take back program to maximize the rate of return on used machines - an asset recovery program. In the Rank-Xerox manufacturing plant in the Netherlands, take-back incentives have increased return rates to over 70% and the company now offers remanufactured equipment with full warranty, but at reduced prices. Although the remanufactured copiers compete with new machines, reduced manufacturing costs from the asset recovery program has proven the remanufacturing process to be profitable. Rising raw materials savings totaled about $69.4 million in 1995 (see Figure 4) and the demand for remanufactured copiers exceeded supply by 50% in 1997. [7]

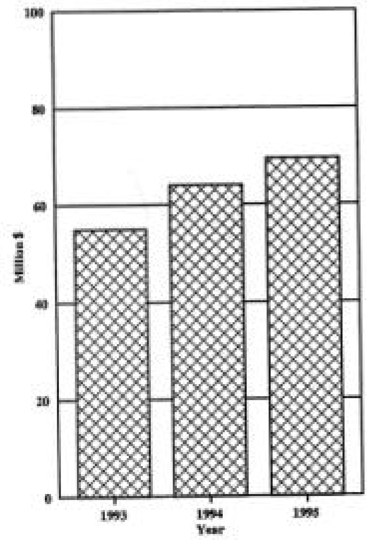

Figure 4: Raw material savings through remanufacturing at Rank Xerox [7]

Asset Recovery Operation (ARO) was started by Rank-Xerox in 1987 to acquire or take back used machines for profitable utilization. When a used machine is acquired, Xerox classifies it by age and condition. There are four categories used: [7]

(1) Excellent quality – mostly demonstration models that usually just need a clean up.

(2) Good quality – machines that have been used for about one year under moderate conditions. Remanufacturing, in this case, entails replacement of the parts most vital to the performance and life of the machine.

(3) Machines that have been used for the equivalent of two years under moderate to full load conditions. Subassemblies within these machines are recovered and reconditioned for re-use in newer machines as spare parts.

(4) Obsolete machines that have been used for more than the equivalent of two years under full load conditions. These machines are only suitable for recycling.

Components reprocessed through ARO at Rank-Xerox have increased from 250,000 in 1989 to 3.5 million in 1995, as shown in Figure 5. Statistics from 1997 show that about 75% of the copiers returned are in category 2 – suitable for remanufacturing. Approximately 20% of the returned copiers are in category 3 and 4, and are therefore disassembled into subassemblies. [7]

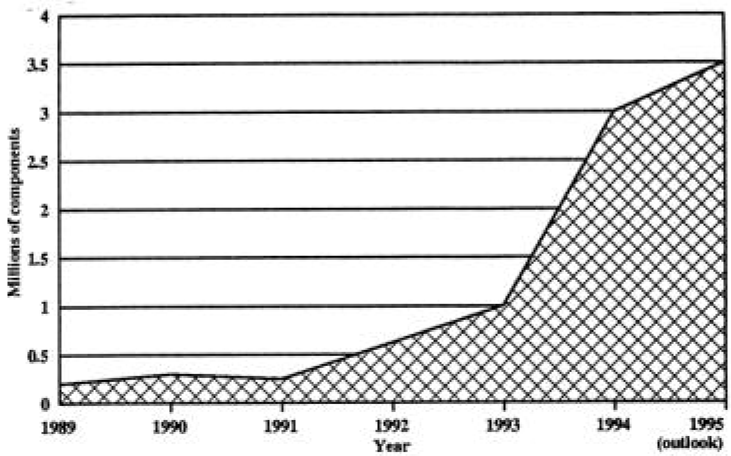

Figure 5: Components reprocessed through asset recovery operations at Rank Xerox [7]

Subassemblies in good condition (category 3) are cleaned, tested and reconditioned by replacing the worn parts. Those parts that cannot be reconditioned by Rank-Xerox are sent back to their supplier to compensate for its lost sales of new subassemblies. The reconditioned subassemblies are sold back to the parent company to be reassembled into remanufactured copier machines, which are labeled as such and sold to the distributor. These remanufactured copiers compete with new copiers, carry the same warranty, but cost less.

Subassemblies in less-than-acceptable conditions (category 4) are further disassembled to individual components, cleaned, reconditioned and tested. If these components do in fact meet specification requirements, they are sold back to the parent company for manufacturing. Substandard components are usually recycled and sent to the component manufacturer. The remaining materials that cannot be recycled are sent to landfills. The percentage of total manufacturing waste that has been sent to landfill has decreased from 41% in 1993 to 21% in 1995, as shown in Figure 6. [7]

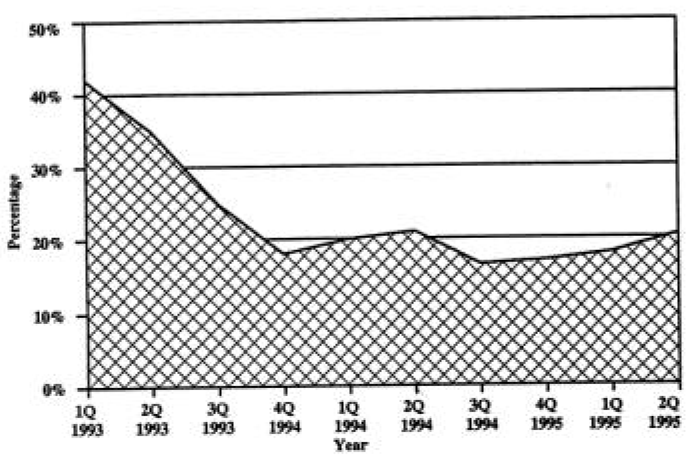

Figure 6: Percentage of total manufacturing waste that has been sent to landfill at Rank Xerox [7]

At Rank Xerox, the life cycle of its components is usually characterized by at least four “lives”: (1) part of a subassembly in a new machine, (2) part of the same subassembly in a remanufactured machine, (3) part of a remanufactured subassembly in a remanufactured machine, and (4) recycled material.

Through their asset recovery operation, Rank Xerox is selling a service of their product more so than the product itself. This results in a driving incentive to maximize profits by minimizing new materials used, keeping existing parts in service as long as possible. In addition, Rank Xerox has redesigned their product to make asset recovery easier – the main principle behind DfE. A Design for Environment action that has been taken by Rank Xerox is the reduction of 27 different plastics in their toner cartridge to a redesign with only 6. This enables them to create a take back system in which cartridges are disassembled more easily and components are recycled.

The environmental benefits of Rank Xerox’s asset recovery program are apparent. One benefit is the large reduction in total waste being sent to landfills (see Figure 6). This translates into even larger reductions in the displaced quantities of metal ores, coal, petroleum and other materials that, without remanufacturing, would be extracted from the earth to create new products. An extreme example of the reduction in environmental impact occurring as a result of reduced raw materials and remanufacturing can be seen in the following example, given a ton of recycled copper. This ton of recycled copper avoids the mining of at least 200 tons of copper ore. This mining requires about one ton of nitrate explosives to remove the materials from the ground, and half a ton of chemicals used in the flotation process. There is then a need for about one ton of coke or other hydrocarbon fuel for smelting. Solid process wastes, such as slag are produced from the smelting and refining process, and contain large amounts of toxic contaminants, which may or may not be recovered. The most significant environmental impact, however, is the 3 tons of carbon dioxide and 2 tons of sulfur dioxide released from the smelting and refining process. [7] Although this example may be extreme, it conveys the message that Rank Xerox has achieved significant environmental benefits in its asset recovery program. In addition to achieving this accomplishment voluntarily, the program has also proven to be profitable without having to compromise the quality of its products, offering its customers with zero trade-offs.

Product Stewardship

Product stewardship is a part of EPR and involves promoting the safe use of products by providing information and technical assistance. Table 1 shows an example of a product stewardship checklist that was developed by DuPont that the company distributes freely.

Table 1: Product Stewardship checklist developed by DuPont [10]

What are the principal safety, health, and environmental (SHE) hazards?
What competitive products may be substituted for ours? What are their SHE hazards? What advantages do we have?
Does the customer have our MSDS and product information?
Product and Packaging Use
How does the customer use the product? For what purpose? Are there unique or new users?
Do any uses or handling raise potential SHE concerns?
Do the customer's employees have access to product information?
Are the customer's employees using recommended personal protective equipment?
Are recommended protective systems, including local ventilation, in place?
Has the customer done workplace monitoring? Should this be done?
Is the product stored properly? Storage tanks labeled? Spill containment facilities, e.g., dikes?
Does the customer have emergency response procedures in place?
What happens to product packaging? Is it reduced, reused, recycled?
Product Issues
Have there been any incidents involving our product? What was learned?
Have allegations been made regarding health effects of the product? Environmental effects?
Any other issues associated with the product?
Product Emissions and Disposal
Does any of the product become waste? Regulated hazardous waste? How is it disposed?
Is any of the product discharged to a wastewater treatment system? What is its fate?
Are there any air emissions from the product's use or disposal? What is their fate?
How do the discharges/emissions affect customer permits, compliance?
How can we continuously reduce all emissions and waste?
Distributor Questions
Does the distributor open and repackage or blend our product? If so, answer all questions above for the distributor.
Does the distributor provide product information to all customers? How do we know this?
Does the distributor visit customers to confirm proper use and disposal?
Other
Can we help in SHE? (waste management and minimization; SHE training)
Does the potential exist for exposure to downstream users of our product? If so, answer first 20 questions in checklist for downstream users.

Case Study II: Dow Chemical/Responsible Care® Program

In the late 1980's, Dow Chemical was facing serious regulatory problems with its vinyl ester resin and styrene monomer products. The Occupational Safety and Health Administration (OSHA) had adopted new regulations for acceptable exposure to these chemicals and had decreased the allowable exposure level (PEL) from 100 ppm to 50 ppm. [11] At the same time, California started to regulate emissions of Styrene through it's own environmental protection laws.

The problems that Dow faced were large. In 1988, the EPA estimated that 20 million pounds of styrene were emitted into the air. In response, Dow decided to take action. Under their "Product

Stewardship Program," Dow created a system of communication to voluntarily give its customers advise on how to deal with the new regulations, on what equipment to purchase in order to minimize styrene emissions, and about the risks of particular chemicals. Dow also allowed public access to its Emergency Planning and Community Right-to-Know Act (EPCRA) filings for toxic releases by setting up user-friendly computer systems in public libraries. [11] Finally, the company began to expand its research on methods to remove styrene from its vinyl ester resins.

Dow's program proved to be extremely successful for their resin products and, in 1991, they adopted the product-stewardship program throughout the company. While Dow started to apply this approach to its entire product line, the Chemical Manufacturers Association (CMA) began to take a great interest in Dow's stewardship approach. Confronted with increasing levels of regulation and public anger at the chemical industry, the CMA was also looking for ways to improve its image and its environmental responsibility. As a result, the CMA created a program called Responsible Care® in 1992, which called for a "cradle to grave" extended product responsibility approach to the products the industry was producing. [11]

Responsible Care®, a program under the Chemical Manufacturers Association (CMA), includes six codes that govern company conduct — Community Awareness and Emergency Response (CAER); Pollution Prevention; Process Safety; Distribution; Employee Health and Safety; and Product Stewardship. [11] The code establishes an ethical sense of responsibility in a sustainable world. Responsible Care® Program is responsible for making health, safety, and environmental protection a major part of a product's life cycle – from manufacture, marketing, and distribution, to use, recycling, and disposal. This responsibility is shared by all that are involved with the product, addressing the concept of EPR. The product stewardship code of the Responsible Care® program is the foundation of its program. Product stewardship is acknowledged to be one of the toughest aspects of Responsible Care® to implement.

Services vs. Products

One way in which to optimize the performance of a product is to replace the good by a service, resulting in a significant decrease in material consumption and economic gain. There has been an increasing trend among companies to replace products by services, creating increased customer loyalty and reduced marketing costs. This concept has the potential to shift our way of living from having to being. Customers are now having their needs satisfied for functions related to copiers and carpeting without owning anything – perhaps they will start to look for similar options in other aspects of their daily living.

In most product service cases, the product used to perform the service remains the property of the service company. The function of the product is delivered directly to the customer, rather than the product itself. The product is taken back after use and cleaned or remanufactured prior to reuse. This creates a financial incentive for the company to decrease the environmental impact and increase the lifetime of the product delivering the service. A primary example of these service company-customer relationships is a case involving Ford Motor Company and DuPont.

Other product service cases involve the leasing of a company's product to the customer, thereby maintaining ownership of its product over its entire lifetime. By doing this, a company extends their responsibility for the product over its entire life cycle. This new form of responsibility for the product providing the service exemplifies the principles of sustainability. One particular case of great interest is Interface Carpet's Evergreen Program.

Case Study III: Ford Motor Company/DuPont

In the United Kingdom, Ford Motor Company hired DuPont to manage its entire paint shop operation, rather than simply to supply paint. Ford pays DuPont not for the amount of paint is applies, but for the number of vehicles painted. DuPont's incentive now is to use its chemical expertise to minimize the paint used per vehicle and to develop a more durable finish, rather than simply increasing the volume of paint it sells. In this case, DuPont's success is defined in terms of their services or benefits provided rather than the quantity of products sold. [2]

Case Study IV: The Evergreen Program, Interface

The Evergreen Program, developed by Interface Flooring Systems, Inc., devised a new approach to carpet sales, by providing this traditional product as part of a customer service package. This leasing program exemplifies an innovative materials management concept known as "product of service." Instead of simply selling carpets, Interface leases long-term carpet services: the company designs and installs section of carpet based on an analysis of traffic patterns in customers' facilities, replaces worn sections as needed (recycling these sections), and periodically re-carpets the entire space using both new and existing carpet. [12] Instead of buying and replacing entire flooring systems every few years, customers prolong the life of the flooring by replacing individual tiles as needed. Interface assumes responsibility for the on-site condition of the carpet and for its eventual disposal and re-use in ways that do not harm the environment. (e.g., old carpet tiles can be ground into a powder that can then be molded into new products or used as backing materials). [12] Therefore, the responsibility is being extended over the entire life cycle of the carpet. This creation of responsibility for the product and service is a radical form of sustainability, even though the idea of service itself is not new. Through the Evergreen Program, Interface is drastically de-materializing its industrial process, while also saving customers money and protecting the environment.

By-Product Synergy

By-product synergy, also referred to as industrial ecology, is an aspect of eco-efficiency in which the by-products and waste of one industry are used as the raw materials and resources for another. [13] By-product synergy thereby draws a system boundary around not one product or one organization, but a group of organizations or systems, in an attempt to optimize the inputs and outputs between the collective group. The formal definition of by-product synergy is: "the synergy among diverse industries, agriculture, and communities resulting in profitable conversion of by-products and wastes to resources promoting sustainability." [13] The primary idea behind by-product synergy is that one business' waste may potentially be another business' raw material. Once companies have reduced wastes and conserved energy, they can begin to look at the valued remaining wastes and unused energy streams. In order for this concept to be effective, businesses must work together to determine what waste exists and who the potential users of this waste are.

Case V: Chaparral Steel

Chaparral Steel Company owns and operates a steel mill that produces bar and structural steel products by recycling scrap steel. Their facilities reflect recent advances in electric arc steel making. Wastes and by-products from Chaparral's steel making process include slag from the electric arc furnaces (EAF), automobile shredder residue (ASR), and baghouse dust. Chaparral has found synergies for all of these main by-products. [14]

Baghouse dust is a by-product of the steel process and contains heavy metals. In its synergy process, Chaparral removes and sells the heavy metals, while the remaining dust is then supplied to the cement industry, where it is added to cement mixtures.

EAF slag is more of a problematic by-product. After 18 months of theoretical studies, practical test, and economic evaluations, a solution was found. This solution, patented "ChemStar," added slag to the cement raw material mix, producing larger quantities of high-quality cement without compromising its characteristics.

Finding a use for ASR was the most difficult problem for Chaparrel to solve. Of the approximate 700,000 obsolete cars that are shredded every year, about 180,000 tons of residue are generated. [14] ASR is a random mixture of aluminum, magnesium, glass, PVC, and rubber, as well as non-chlorinated plastics and other non-ferrous metals. Since this poses the problem of finding a way to separate resources, these potentially valuable materials have been simply dumped into landfills. However, Chaparral has in fact found a way to separate these resources, completing its by-product synergy process.

In 1996, Chaparral purchased exclusive rights to an innovative flotation separation technology for separating ASR into mostly pure components. Although the process is still in the research and development stage, it has been economically producing pure, separated by-products. Chaparrel will easily be able to sell the metals that are produced. The next step in this separation process will be to find a way to separate chlorinated and non-chlorinated plastics. Non-chlorinated plastics could either be remolded or used as a clean fuel. Through Chaparral's efforts, a large quantity of waste has been kept from landfills. [14]

Life-Cycle Analysis

Life-Cycle analysis (LCA) is a technique used to determine the environmental impact of a product. LCA is described by the Society of Environmental Toxicology and Chemistry (SETAC) as

> An objective process to evaluate the environmental burdens associated with a product, process, or activity by identifying and quantifying energy and materials used and wastes released to the environment, to assess the impact of those energy and material uses and releases on the environment, and to evaluate and implement opportunities to affect environmental improvements. [15]

The product life cycle has been represented in various ways, but the most well-known and respected life cycle representation is that of SETAC, shown in Figure 7. The life cycle of a product consists of the stages that the product goes through from conception, through use and operation, to final disposal ('from cradle to grave'). Much research over the past decade has focused on developing a product and process in which the product life-cycle is re-iterated as many times as possible, transforming the phrase, 'cradle to grave' into 'cradle to cradle.' The different life cycle stages are: [16]

- *Raw material extraction and processing*

  This stage consists of all processes from extraction of raw materials to the production of useful materials
- *Material and product manufacturing*

  This stage consists of all processes that are necessary toward the creation of the final product. Product preparation (packaging) is also included in this stage.
- *Transportation and distribution*

  This stage consists of all processes between the factory gate and the consumer.
- *Product use, re-use, and maintenance*

  This stage consists of all activities related to the use of the product. This includes operation and maintenance. For products that can be re-used in a different function at the end of its life, these processes are also considered.

- *End of life*

  This stage consists of different situations depending on the type of product. Some products are directly disposed of, using various disposal methods, while others are partially recycled.

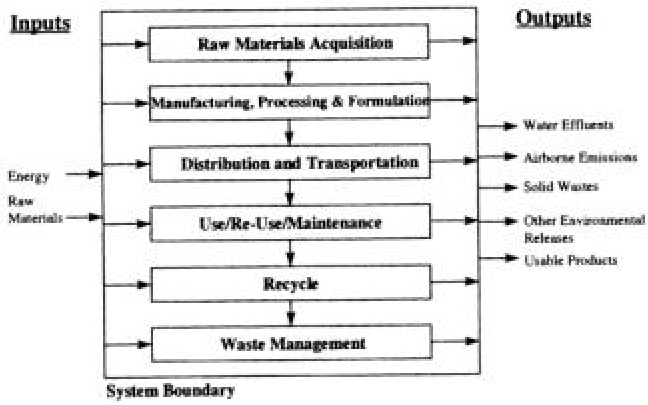

Figure 7: Product life-cycle according to SETAC [15]

LCA considers the environmental impact over the entire life cycle of the product. It considers the air, water, and solid waste pollution generated when raw materials are extracted. It includes the energy used in the extraction of raw materials and the pollution resulting from manufacturing the product. It also accounts for any negative environmental effects that might occur during the distribution and use of the product. Finally, it includes the solid and liquid wastes that are added to the environment after the final use of the product. After an LCA is complete, a company can reevaluate all aspects of their operations and incorporate the LCA findings into their decision-making process.

The goal of LCA is to evaluate environmental emissions, raw materials, and energy requirements for a product system, measured at the boundaries of that system. [16] According to the standards of SETAC, an LCA consists of the following four stages (the framework of which is shown in Figure 8): [16]

(1) Goal and scope definition

This step identifies the purpose for the LCA and its intended application. It presents reasons why the study is being conducted and how the results will be used.

(2) Life cycle inventory

This step identifies each life cycle step and each material input traced back to raw materials. After that, data is gathered on upstream production of raw materials, transportation of products to be sold, energy data pertaining to product use, and data pertaining to disposal of used products.

(3) Impact assessment

During this step, particular inventory data from the previous step is associated with specific environmental impacts. There are various methods of impact assessment, with one of them being eco-efficiency indicators.

(4) Improvement assessment

This step identifies and evaluates needs and opportunities for reducing the environmental impacts of the product system. During this step, the results of the entire LCA are interpreted in order to come to conclusions and recommendations regarding improvements to the product system.

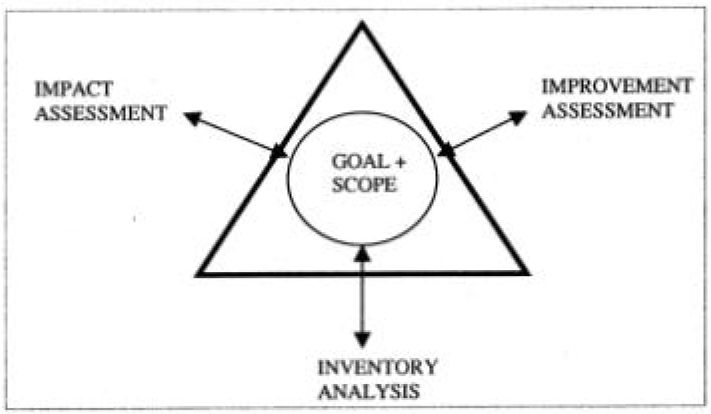

Figure 8: SETAC technical LCA framework [16]

Full-scale LCA has encountered various problems when used. One main problem is the difficulty in comparing results between organizations. Since organizations define their systems differently, many inconsistencies have been found. Some examples of such inconsistencies are the prioritization of environmental issues and different system boundaries for similar products. In the 1990s, SETAC and the EPA sponsored workshops and other projects designed to develop and promote consensus on a framework for conducting life-cycle analysis. [16] As a result of these efforts, a consensus has been reached on an overall LCA framework and a well-defined inventory methodology.

Another major problem encountered with LCA is the cost and time required to implement this technique. Many times, the potential user of LCA does not require the full complexity of the standard LCA technique and is therefore less likely to use it. Abridged tools have been provided which "streamline" LCA to make it more feasible and more immediately relevant for most users while still maintaining the main features of LCA. This method is discussed in the following section.

Streamlined LCA

Streamlining can be thought of as "What can be eliminated from a full-scale LCA design and still meet the goals intended?" There are many different approaches to streamlining LCA since the objectives and goals vary from organization to organization. Approaches to streamlining can include elimination of certain life-cycle stages that are not necessary, or reducing the detail in the data that is required. SETAC identified some of the major streamlining approaches to be: [17]

- Limiting or eliminating all or some upstream stages
- Limiting or eliminating downstream stages
- Limiting or eliminating upstream and downstream stages
- Focusing on specific environmental impacts or issues
- Establishing criteria to be used as "showstoppers" or "knockouts"

These approaches will be further discussed in the following paragraphs.

All LCA's must establish upstream boundaries. If this is not done, tracing of a product's materials may go back through an infinite number of steps. Therefore, with streamlining, a certain limited number of stages prior to or upstream of the main manufacturing process are set as a boundary. In some cases, all upstream stages are eliminated, concentrating the study to just the manufacturing process and the use and disposal of the product (downstream). Some benefits of eliminating upstream stages are that definite boundaries are set, efforts are concentrated on the products and processes most under the manufacturer's control, and the issue of proprietary vendor data is eliminated.

While some organizations focus on the manufacturing and downstream stages, other organizations choose to neglect the downstream stage and focus on the upstream stage. Such an organization would most likely be looking into new materials or upstream processes that will have a positive environmental impact on their product. A major advantage to this approach is that it embodies the ideas behind Design for Environment, which is to incorporate environmental improvements into products or services before they enter the production. This approach can also encourage vendors and suppliers to provide materials that have a better environmental impact.

In some cases, streamlined LCA has been limited to the manufacturing operation only. The advantage of this approach is that the data can be collected and studied directly by the manufacturer. However, this approach actually eliminates the life-cycle aspect of the process, and is sometimes not considered to be a streamlined LCA.

Some organizations choose to focus their LCA study on a certain environmental issue that is significant to the particular product or process. Some examples of such issues are certain GHG emissions, depletion of a resource, or generation of highly toxic pollutants. Focusing on limited issues of importance can produce information that is helpful to the specific organization. Also, it is usually safe to say that no single product or process can or will be able to achieve superior positive impacts for all environmental issues. The major disadvantage to this approach is that certain environmental impacts are neglected in this streamlined LCA.

Streamlined LCA is sometimes approached by defining a certain criteria that, if met, could result in an immediate decision. This approach is usually taken when a certain issue is so important that other issues of LCA become irrelevant. Some of these criteria can include those mentioned in the previous approach, and the choice of criteria is based on a particular organization's values.

The above examples are just some of the many approaches to streamlined LCA. Each seeks less expensive methods that produce more timely information. Potential users of LCA are generally not interested in the detailed quantitative information, but rather in the comparison between various alternatives in a particular product design process. This concept is apparent in the recent case of AT&T's abridged life-cycle assessment.

Case Study VI: AT&T's Abridged Life-Cycle Assessment

An abridged life-cycle assessment adopted by AT&T enables them to perform LCA rapidly – in about 2 days for a product and about a week for a facility. Their streamlined approach is effective in producing improvement analyses that can be implemented immediately. This approach consists of a 5x5 assessment matrix (see Figure 9). For each cell in the matrix, a basic life-cycle stage and an environmental concern are evaluated on an integer scale from 0 (highest impact) to 4 (lowest impact). This evaluation is performed by an assessor with experience and access to design and manufacturing information. Although this streamlined LCA is very subjective and may seem imprecise, it was found that the results from different assessors differed by less than 15%. [17]

Figure 3-1 AT&T's Environmentally responsible product assessment matrix (Reprinted with permission from Graedel et al. 1995. Copyright 1995 American Chemical Society)

	Environmental Concern				
Life-cycle stage	Materials choice	Energy use	Solid residues	Liquid residues	Gaseous residues
Pre-manufacture	(1,1)	(1,2)	(1,3)	(1,4)	(1,5)
Product manufacture	(2,1)	(2,2)	(2,3)	(2,4)	(2,5)
Product packaging and transport	(3,1)	(3,2)	(3,3)	(3,4)	(3,5)
Product use	(4,1)	(4,2)	(4,3)	(4,4)	(4,5)
Refurbishment/ recycling/disposal	(5,1)	(5,2)	(5,3)	(5,4)	(5,5)

Figure 9: At&T's Environmentally responsible product assessment matrix [17]

Once the evaluation is performed, an overall environmentally responsible product rating can be calculated by totaling the matrix elements:

$$R_{erp} = \sum_i \sum_j M_{ij}$$

A maximum rating of 100 can be obtained from this 5x5 matrix. Although matrix scores are typically used without a relative weighting factor, it can easily be incorporated into the assessment. The results of this matrix analysis can also be more clearly viewed around the circumference of a circle, in a “target plot.” Points on the circumference represent a value of zero. A good product therefore has more points near the center of the circle. This arrangement allows for easier evaluation and comparison. This streamlined LCA approach was performed for generic 1950s and 1990s automobiles, as shown in Figure 10. The overall rating of the car improves from 46 in the 1950s car to 68 in the 1992 car. However, even with an improvement in environmental impact from the 1950s to the 1990s, there is still a need for further improvement. [17]

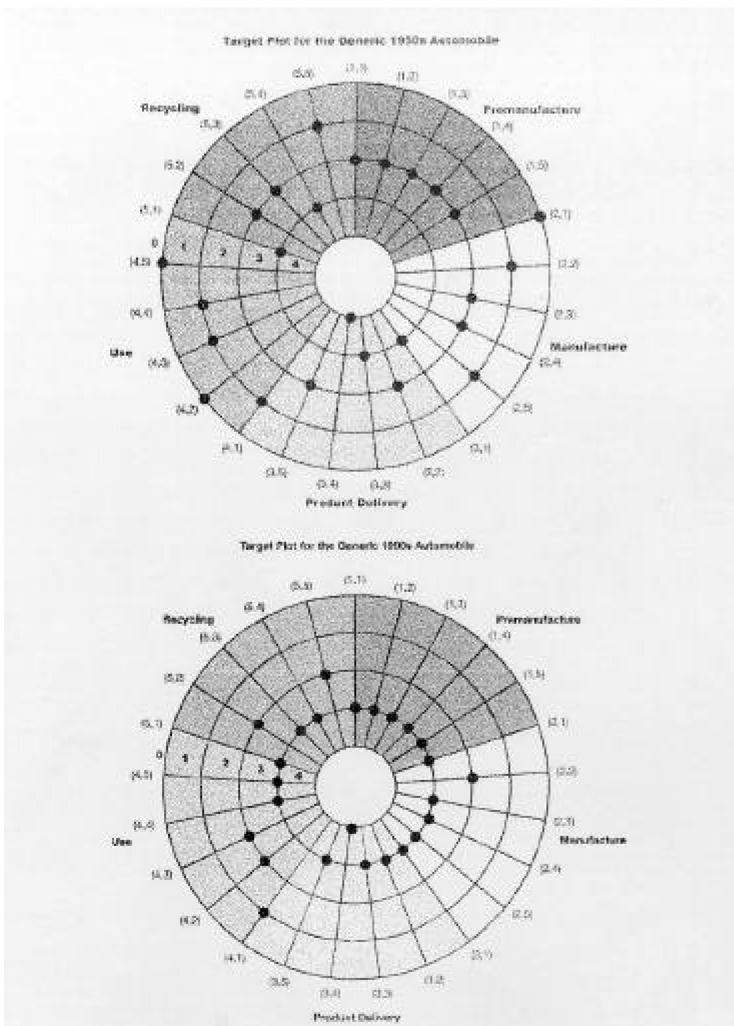

Figure 10: AT&T’s target plots for generic automobiles [17]

In performing streamlined LCA, potential users must be aware of the benefits as well as the limits of such an "abridged" analysis. In order to assist the user through the process, Table 2 shows a profile summarizing the differences between typical streamlined and full-scale LCA techniques. It is necessary to understand the characteristics of streamlined LCA to prevent the misuse of this potentially valuable technique.

Table 2: Features of streamlined and full-scale LCA [17]

Study feature	More streamlined		Less streamlined
EXAMPLE	VERY STREAMLINED	✓	FULL-SCALE LCA
Completeness of life-cycle stages	One stage only		All stages
Breadth of impacts/pollutants	Single impacts/pollutants		All impacts/pollutants
Quantification of data	Qualitative data		Quantitative data
Specificity of data	Generic/averages		Product specific/actual
Data quality	Estimates/high uncertainty		Measured/low uncertainty

Environmental Policy

Achieving eco-efficiency is much easier when it is supported by, but not threatened by, governmental regulations. The traditional "command and control" regulation method of forcing businesses to take environmental action may be effective in preventing environmental "free-riders" who will not involve themselves in voluntary improvements. However, this regulation creates barriers to eco-efficiency by providing little incentive for companies to go beyond the minimum compliance requirements. "Command and control" regulations also impose strict deadlines on regulations, forcing companies to implement end-of-the-pipe improvements rather than life-cycle improvements due to insufficient time. Since there are significant penalties involved, the sustainable principles, such as Design for Environment and Extended Product Responsibility, no longer become an option for these companies, who may have otherwise committed to these improvements. Endorsed by its environmentalist members, the US President's Council on Sustainable Development came to a consensus view on traditional "command and control" regulation:

> There is no doubt that some regulations have encouraged innovation and compliance with environmental laws, resulting in substantial improvements in the protection of public health and the environment. But at other times, regulation has imposed unnecessary – and sometimes costly – administrative and technological burdens and discouraged technological innovations that can reduce costs while achieving

environmental benefits beyond those realized by compliance. Moreover, it has frequently focused attention on cleanup and control remedies rather than on product or process redesign to prevent pollution. [18]

There will always be a need for environmental policy and regulation. However, the limitations placed by current governmental regulations must be reduced. One possible regulation improvement would be to permit a company the flexibility to choose its own method of reducing pollution and environmental impact. Another improvement in regulations would be to allow for continuous improvement by maximizing economic benefit to companies that exceed the minimum compliance.

Governmental regulation is one type of environmental policy used for achieving eco-efficiency. However, there are currently other forms of environmental policies, which may sometimes be more effective in achieving eco-efficiency. Arthur D. Little identified the four main forms of environmental policy, based on the extent of government control and whether the relationship between business and government is confrontational or cooperative (see Figure 11). [18]

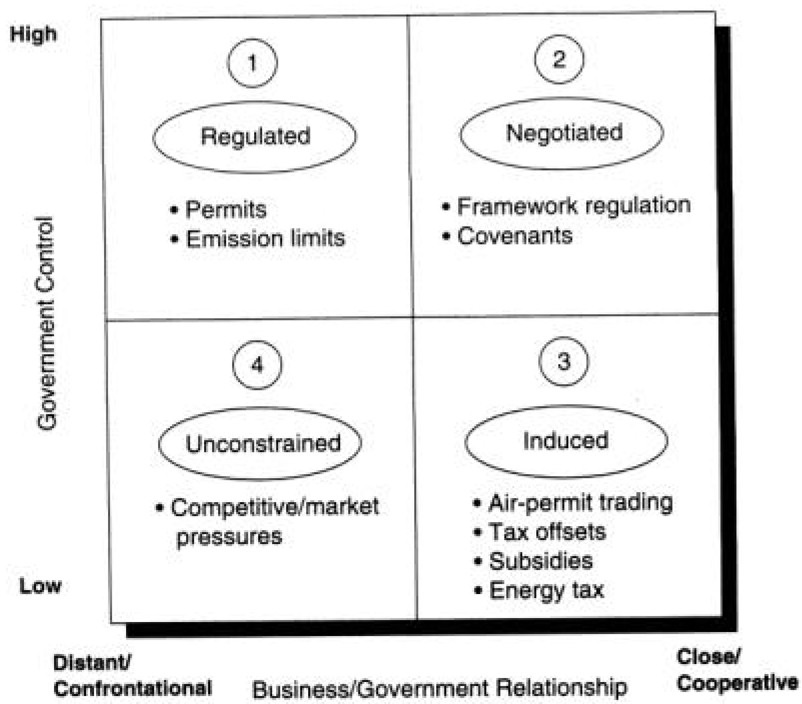

Figure 11: Four types of environmental policy for achieving eco-efficiency [18]

In Figure 11, unconstrained environmental policy (category 4) refers to the voluntary action taken by certain companies, driven by environmental ethics or under pressures from suppliers and customers. This is the action that is least taken by companies today, although it is an ideal one in which the company completely internalizes environmental policy into its decision-making process. Rank Xerox is an example of a company that adheres to this policy, with sustainable objectives, rather than regulations, in mind.

To move away from the negative impacts of regulation (category 1), which was discussed previously, a company's next step may be to incorporate negotiated environmental policies (category 2). These policies, set by agreements between governments and large industrial associations, regulate the ends but allow individual member companies to choose what means to implement in order to achieve these ends. In return, a covenant is required of each company to issue an annual report on their achievements and plans for future improvement. For example, the Dutch chemical industry commits its member to reduce their emissions of hazardous chemicals, increase energy efficiency, and cut emissions of nitrogen oxides and sulfur dioxide by specific amounts. [18] The benefit of this policy over regulations is that it gives companies the flexibility to incorporate environmental improvements into the design of their product rather than end-of-the-pipe improvements (DfE).

Another alternative to regulation is induced environmental policy (category 3). The idea behind this policy is to create disincentives and incentives for companies to take environmental action. One form of induced policy is environmental taxes and levies, such as carbon taxes and levies on product disposal. Another form of induced policy involves environmental impact trading. For example, the American Clean Air Act sets an upper limit on sulfur dioxide emissions from power plants. [18] This provides an incentive for aggressive companies to reduce their emissions below this requirement and then sell these reductions as "emissions credits" to others polluters that have not met their requirements. A third form of induced policy is mandatory disclosure of a company's environmental plan. The US Emergency Planning and Community Right-To-Know Act of 1986 requires the publication of an annual toxic release inventory (TRI) from most large companies, which forces them to report any significant quantities of listed substances that they store or use. [18] This has been a very successful program that has had a positive effect on the reduction of emissions.

From the four categories of environmental policy shown in Figure 11, a combination of more than one is usually necessary in the progress toward sustainability. In an analysis performed by an MIT professor, Vicki Norberg-Bohm, she found that negotiated and induced policies demonstrate the most promise for achieving both environmental improvements and economic savings, involving the collective efforts of industry, regulators, and the environmental community. [18] Her analysis involved looking at various policies such as regulatory standards, emissions trading, mandatory information disclosure (e.g. TRI), and voluntary actions. She then evaluated how effective each policy was in producing information disclosure, creating incentives for investment in environmental improvements, and encouraging development of life-cycle management and other positive action. Her overall conclusion was that regulatory standards are least effective while induced policies, specifically mandatory information disclosure, are most effective.

However, the effectiveness of a particular regulation varies with application. Although many regulations and policies related to companies' environmental impact may be detrimental rather than beneficial, properly designed environmental policies can be effective in encouraging companies to take environmental action and produce profitable results.

Stemming from the many types of environmental policy currently in use, motivations for incorporating eco-efficiency into a company's manufacturing process are varied. For some companies, strict regulations are the driving factor, while for others, the anticipation of regulations in the future encourages early action to be taken. In rare cases, environmental ethics and the principles of sustainability drive companies such as Rank Xerox. These main motivations for environmental action are shown for a variety of cases in Table 3.

Table 3: Several companies' motivations for taking environmental action [7]

Company	*Motivating factor*	*Strategy*	*Result*
Rank Xerox Asset Recovery Operation	Competition from secondary suppliers and potential damage to Rank Xerox's reputation for quality.	Initiated an asset recovery operation at the manufacturing plants in Europe.	Raw materials savings through remanufacturing at Rank Xerox was estimated at $69.4 million in 1995.
DEC	Anticipation of regulation on take-back of electronic waste in Germany.	Started an internal remanufacturing/recycling operation for computers.	Not available
IBM SEMEA	Reduce waste disposal costs by increasing recycling. Provide parts for maintenance purposes.	Creation of a subsidiary to engage in recovery and logistics activities.	The dismantling and scrapping operation was profitable in 1995.
Dow SafeChem	Regulations regarding the use of CHC solvents. Maintain market share in a diminishing market.	Instead of selling virgin solvents, to sell an entire service package, where the cost of disposal and take back is included in the price.	After operating at a loss during the first 3 year, SafeChem made a profit of 0.25 million DM in 1995.
BASF Corp. (US subsidiary)	Internal culture of developing new processes or products that will keep the firm ahead of the competition.	Developed a program to collect and recycle end-of-life carpets in the US market. Developed a recycling process that results in fibers of the same quality as the virgin material.	Not available
Aurora Electronics	Saw a potential niche market for used integrated circuits (IC) that could be used in other industries (e.g. toy industry or home appliances)	Initiated an IC recycling operation using state of the art technology.	Profitable.
BMW	The motivation for BMW's recycling program is to minimize residues and waste from the reutilization of old cars to the largest possible extent. Anticipating legislation in Germany regarding the takeback of End of Life Vehicles (ELV's)	The strategy was to create a recycling network in Europe to find efficient dismantlers that would guarantee that the cars are dismantled according to BMW's standards. Components are also classified for recyclability to facilitate the dismantling operation.	The remanufacturing and reselling of high value parts (engines, water pumps transmissions), makes the operation financially viable.
Siemens Nixdorf (SIN)	Motivating factor was the increasing landfill costs in Germany. An appropriate solution needed to be found that would minimize disposal costs.	The strategy was to centralize the recycling facilities, create a liasion between the disassemblers and the design engineers, to build easier to recycle machines in the future.	In 1995, the recycling facility at Paderborn was operating at break-even. Overall the disassembly and recycling facility is a cost center for SIN, while the remarketing and reuse of components brings in some revenue SIN
Alpha Metals	German Packaging Ordinance obliging the firm to take back used packaging. High cost of landfill of hazardous waste.	Packaging of solder paste in tin cans (which can be recycled) instead of the traditional glass jars (or plastic syringes).	Despite the higher price of the tin jars, this solution is more profitable for the company.

Industrial vs. sustainable economy

Sustainable development has to start with a considerable reduction of the consumption of resources. Therefore, economic success can no longer be measured by resource consumption and production, which is representative of an industrial economy. An industrial economy focuses on production as a means of creating wealth. This industrial economy must be replaced with a sustainable economy, which would allow for the maintaining of profits with a considerable reduction in resource consumption. A 'service economy' is an example of such a sustainable economy in that it creates the highest possible utilization value for the longest possible period of time while consuming as few material resources and energy as possible. Therefore, the service industry is one example of a solution that has a major impact on the future of sustainability.

Linear economy vs. cyclic economy

A linear industrial economy is one in which the responsibility for goods stops at the factory doors, and where 'waste' – everything that the leaves the factory – is somebody else's problem (and cost). This linear-structured economy can be seen in Figure 12. A cyclic economy, however, is based on a value concept that never stops – an 'economy in loops.' Society's present economy system tends to side towards linear. The fact that waste management, car accidents and de-pollution costs all count as positive contributions to Gross National Product (GNP) reflects that the GNP is an indictor or our economic activity rather than our wealth and well-being. [4] By using this as a gage, waste prevention corresponds to a 'loss of income' and is therefore deemed economically undesirable. In a sustainable service economy, waste prevention is a cost reduction, and is therefore an economic saving. In order to achieve these goals of sustainable economic activity, a change in economic thinking and organization is therefore required.

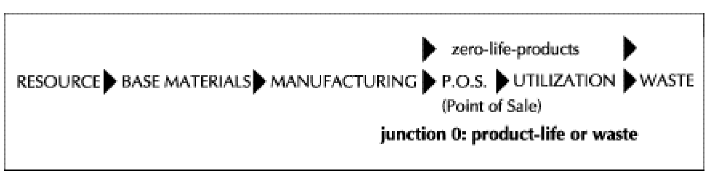

Figure 12: Linear industrial economy [4]

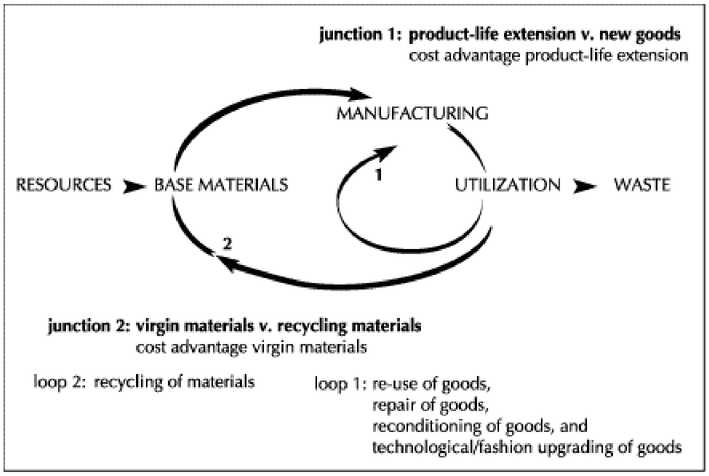

Figure 13: Cyclic sustainable economy [4]

Conclusions

Companies have become motivated to consider the environmental implications of their actions for various reasons (e.g. legislation, competition, and consumer response). For whatever reason specific to each company, they are operating to higher environmental standards than ever before. Environmental issues are becoming an area where companies see opportunities to compete with each other. A few environmentally conscious companies have gone beyond regulations and requirements in their actions, while other companies have developed a wait-and-see attitude. Environmental trends, such as product stewardship and by-product synergy, are just some of the ways companies are distinguishing themselves from others in the field. Consumer pressures are developing from growing environmental awareness and concern, driving companies to improve the environmental impact of the products they manufacture. This consumer awareness is at the point now where environmental superiority is expected in products, without compromising performance or cost. This will prove to be a continuing challenge for companies throughout the world who strive to work towards a more sustainable existence.

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