ECO-EFFICIENCY, ASSET RECOVERY AND REMANUFACTURING

by

R. U. AYRES*
G. FERRER**
and
T. VAN LEYNSEELE†

97/35/EPS/TM

This working paper was published in the context of INSEAD's Centre for the Management of Environmental Resources, an R&D partnership sponsored by Ciba-Geigy, Danfoss, Otto Group and Royal Dutch/Shell and Sandoz AG.

* Sandoz Professor of Management and the Environment at INSEAD, Boulevard de Constance, 77305 Fontainebleau Cedex, France.

** Phd Candidate at INSEAD, Boulevard de Constance, 77305 Fontainebleau Cedex, France.

† Research Associate at INSEAD, Boulevard de Constance, 77305 Fontainebleau Cedex, France.

Eco-Efficiency, Asset Recovery and Remanufacturing

Robert U. Ayres, Geraldo Ferrer & Tania Van Leynseele

Center for the Management of Environmental Resources
INSEAD
Fontainebleau, France

March 1997

Abstract

In this article we consider the underlying imperatives driving the trend toward eco-efficiency and, especially, asset recovery, at the firm level. We show how the enormous potential for adding value while reducing material inputs can be realized in almost every sector of the economy. Many of these gains can be obtained by "internalizing" the product. In many cases there is a large scope for "double dividends", by which we mean increased profits for the firm combined with environmental improvement. We also discuss the role of government regulation as a driver of change. Finally, we review a number of specific cases from (mostly) European firms, with emphasis on the potential for internalizing the product by recovery, remanufacturing and materials recycling. We conclude with a discussion of the economics, the regulatory environment and the organizational and management aspects of the problem.

Cost as a Driver of Change

Cost reduction is always a driving force for change, in particular in those companies at the top of the value-added chain. The cost of purchased parts and components is a very large fraction of direct manufacturing costs for such firms. Waste disposal is another cost element that has been increasing very rapidly. Hence, for any manufacturing firm, the cost of disposal, by landfilling or otherwise, is an important variable. It becomes more so if the firm is forced to implement an end-of-life product take-back scheme for which it is unprepared. Thanks to a strong grass-roots environmental movement, together with high population density, Europe appears to be developing pro-active environmental legislation in this field. *Appendix A* provides a synopsis of the electronic take-back legislation that is currently under consideration in a few European countries.

One motivation is simple scarcity of landfill sites. Moreover, discarded electrical and electronic equipment contains hazardous materials, such as lead-based solder and a variety of toxic metals, ranging from arsenic to mercury to selenium. In some localities (including a number of U.S. states) electronic items such as circuit boards cannot be disposed of in landfills at all. Various studies show that manufacturing firms in Germany, the Netherlands and Scandinavia have become extremely sensitive to the disposal cost of production waste. For example, disposal costs now represent 2% of direct production costs of laser printers. For cars, it is 3% while for refrigerators and freezers, disposal costs amount to 12.5 % of direct production costs [Steinhilper 1995]. As European Union legislation evolves, one can reasonably expect that landfill costs will continue their steep upward path.

There is, luckily, a strategy for reducing both cost elements — purchased materials and waste disposal — simultaneously. Evidence is accumulating that there are many unexploited opportunities for manufacturing firms to reduce material costs through strategic recovery, renovation and remanufacturing of high value but unworn parts and subsystems. Used components can serve either in the manufacture of new products for maintenance purposes, or (in some cases) for manufacturing "equivalent to new" products. Hence, product (or asset) recovery and remanufacturing has become an attractive means to decrease overall production costs. We discuss this topic at greater length below.

Economics of Remanufacturing

In discussing the economics of remanufacturing, we are mainly referring to the recovery of durable goods (copiers, computers, cars). However, some of the issues discussed below can also apply to the recycling of intermediate products, such as solvents. To assess the feasibility of an economically viable remanufacturing operation in any given case, the following questions need to be addressed:

- Does the distribution system have sufficient "reverse flow" capacity to make it worthwhile to set up a remanufacturing operation? If not, is it possible to build up such a capacity? (NB the reverse flow problem is much easier to handle for a firm that distributes its own products than for one that operates through wholesalers. On the other hand it is much harder to achieve for a very long-lived product than for a relatively short-lived one.)
- Are there recoverable high-value parts and/or materials that require very little — if any — rework? An engine block, an electric motor or a microprocessor chip would be examples.

- What is the optimal level of disassembly to maximize recovery profits?
- Is there an existing demand (internal or external) for recovered parts and materials? If not, is it possible to generate such a demand?
- What are the labor costs? What level of skill is necessary to disassemble and select the subassemblies worth the recovery effort?

It is clear that without adequate arrangements to ensure return flows, it is not economically feasible to set-up an asset recovery operation. For some businesses that have already established materials recycling activities, inadequate return-flows continues to pose limitations to the efficiency of the recycling or recovery process. It is not simply the total volume of return flows but also the variety in product type and wear state at the time of return that matters. If a manufacturer has a diverse product line, the recovery operation is more complex due to the difficulty of achieving needed economies of scale. Any given operation must handle a return stream more diverse than the product line of that same firm, due to the fact that the return flows come from a range of different production year-models. The return flows will also reflect a range of degrees of wear due to the different usage patterns of individual customers.

For example, if a large manufacturers of electronic appliances were to introduce a take-back program, it would face an extremely diverse return stream, even if the products of competing manufacturers could realistically be excluded. The recovery value for each unit returned is an inverse function of the product line variety. Workers have to be trained on how to disassemble many more products and have to make many more decisions, selecting the destination of the several parts obtained in the disassembly process. In general, the objective is to have higher volumes and purer streams of end-of-life equipment to facilitate reaching economies of scale.

One advantage of a service-orientation, where leasing and renting dominate over direct sales, is that the logistics of the return flows can be easily established. The manufacturer is aware of how many machines (or other durable products) it has in the field, and where they are. Regular contact with customers through repair and maintenance operations facilitates the take back process. For instance, Rank Xerox, which leases a significant share of its copiers, has succeeded in its remanufacturing operations thanks partly to an efficient pre-existing logistic system.

In the computer industry, one of the constraints faced by recovery and recycling operations is the low rate of return of used equipment. For instance, IBM SEMEA (Italy) is mostly engaged in materials recovery and using recovered parts for maintenance purposes.[1] Up to now IBM (Italy) has been unable to develop a line of remanufactured computers because of the lack of adequate returns. In some cases, environmentally conscious consumers, as in Germany and Scandinavia, will voluntarily facilitate the returns process. But this behavior is not common everywhere.

Firms have to decide whether they should buy back the used equipment or should charge customers to get rid of it. Rank-Xerox pays to have the used equipment returned, recognizing the value still remaining in it. Siemens Nixdorf, on the other hand, has placed part of the burden on the customer. In summary, the issue of establishing sufficient reverse flows depends on a number of factors:

- The type of agreement between the customer and the manufacturer (lease or rent vs. direct sale; buying the product vs. buying an entire system; maintenance service included or not.)

- The environmental legislation influencing customers' and manufacturers' behavior as regards returning and taking back used equipment.
- Cultural factors that influence consumer behavior and environmental awareness.
- Manufacturer's incentives to increase return rates.

Assuming a logistic system to generate a sufficient return flow is established, or can be created, project viability depends on other criteria:

- Design choices (e.g. welds, rivets, adhesives, bolts or snap fasteners) affecting the product's suitability for disassembly and recovery.
- Type and variety of materials and parts used in the product's design.
- Logistics cost, including but not limited to organization, collection, consolidation and economies of scale.
- Recovery costs, as compared with the value of competing new components and materials.
- Component longevity, compared with the expected life of the whole unit.
- Rate of innovation (that might render used components obsolete).
- Market expectations regarding product performance.
- Legal requirements, including but not limited to patents, product liability and environmental regulations.

Any product recovery project needs to be analyzed with respect to each of the above factors. One criterion that we have found to be extremely important, and has been verified by a number of firms, is the existence of recoverable high-value components or materials (such as precious metals). If there are no such "nuggets" in the end-of-life equipment, the probability that the take-back scheme will be self-supporting is much lower. The firm will have to find other revenue sources to fund the program, at least for a number of years.

For example, in the copier industry, one of the high-value products that can be recovered and reused is electric motors. In the computer industry, the recovery and resale of memory components plays an important role. At IBM SEMEA, the sale of high-value ICs to other users is crucial for the financial viability of the operation. In the auto industry this feature is also evident.

Simple logic suggests that disassembly will be profitable if (and only if) the reclamation value plus the savings attributable to non-disposal is greater than the disassembly costs [Johnson & Wang 1995]. A similar study proposed a model to determine the economically optimal level of disassembly. The authors propose that proceeding with disassembly is justified if the revenues from disassembly are greater than the disassembly costs and the costs for disposal after disassembly [Penev & Ron 1996].

To what extent are such theoretical models used by firms? This is debatable. However, they are useful in pin-pointing the crucial variables that needs to be analyzed by managers trying to determine the optimal level of disassembly. *Tables I-III*, developed by the recovery operation of IBM SEMEA, show the materials recovery at different stages of disassembly of an IBM PS/2 computer. The economic values (reclamation value in comparison to costs) are also presented.[2]

Table 1: Economic value of different materials in the IBM P/S2 computer

	US$/kg
Cables	$0.25
Iron	$0.40
Aluminum	$1.10
Copper	$1.60
Glass	$0.002
Plastic	$0.13
Cards	$0.004
Connectors	$0.005
Motors	$0.25
Compressor	$0.20

Table II: Outcomes of different disassembly strategies for the IBM P/S2 computer

	Total (grams)	*Iron (grams)*	*Aluminum (grams)*	*Copper (grams)*	*Glass (grams)*	*Plastic (grams)*	*Card (grams)*	*Connectors (grams)*	*Waste (grams)*
A. Shredding									
Whole PC	**11439**	**7572**							**3867**
%	*100%*	*66.2%*							*33.8%*
B. Partial Disassembly									
Keyboards	1375	765				270			340
Base	7230	5820				460			950
Cards	1360						1360		
Connectors	80							80	
Fans	110	30		20		50			10
Batteries	19								19
Hard disks	620	59	540						21
Flexible disk drives	645	435							210
Whole PC	**11439**	**7109**	**540**	**20**	**0**	**780**	**1.360**	**80**	**1550**
%	*100%*	*62.1%*	*4.7%*	*0.2%*	*0.0%*	*6.8%*	*11.9%*	*0.7%*	*13.6%*
C. Further Disassembly									
HDD	550	30	510						10
HDD motor	70	40	9	10					11
Floppy drive	475	260	155			40			20
Cables	10			3					7
Cards	160						160		
Whole PC	**11439**	**6945**	**674**	**33**	**0**	**820**	**1520**	**80**	**1367**
%	*100%*	*60.7%*	*5.9%*	*0.3%*	*0.0%*	*7.2%*	*13.3%*	*0.7%*	*12.0%*

Table III: Profit and loss of IBM P/S2 recovery operations

A. Shredding	**US$/Kg**	**US$**
Revenues from sales	$0.10	$0.78
General expenses	($0.023)	($0.26)
Profit/loss		$0.52
B. Partial disassembly	**US$/kg**	**US$**
Revenues from sales	$0.68	$6.70
Logistics	($0.065)	($0.74)
Transportation to landfill	($0.065)	($0.10)
Landfill costs	($0.097)	($0.15)
Labor costs (working time 11.5 minutes)	($0.43)	($4.95)
General expenses	($0.023)	($0.26)
Profit/loss		$0.51
C. Further disassembly of disk drives	**US$/kg**	**US$**
Revenues from sales	$0.74	$7.42
Logistics	($0.065)	($0.74)
Transportation to landfill	($0.065)	($0.088)
Landfill costs	($0.097)	($0.13)
Working costs (working time 16 minutes)	($0.43)	($6.87)
General expenses	($0.023)	($0.26)
Profit/loss		($0.67)

It should be noted that the profit/loss statement for the P/S2 model are not very representative of the actual situation because the values include just materials recovery. They do not include the recovery of high value components that are sold as such. Parts recovery has not been included here because in terms of weight it represents only 5% of all returned equipment. However, its economic value represents a much higher fraction of the turnover.

Recovery of high-value parts and materials is not very useful if there is no market for recovered and/or manufactured items. Product obsolescence plays an important role in this respect. For example, in the computer industry it is difficult to use remanufactured components such as memory chips, microprocessors or hard disks in new product lines, given the high rate of product change. There is limited demand for computer models of previous generations. The remanufacturer has to identify and reach a class of customers — such as schools — willing to purchase and operate machines using not-so-recent technology.

The issue of perceived quality also plays an important role. Firms marketing remanufactured products have employed different marketing tactics to convince customers that they are not purchasing a product that is inferior in quality. The most effective tactic appears to be a lower price combined with an "as if new" warranty. Another challenge, in the case of longer-lived durables, arises from industry dynamics. By the time the older product is returned to the manufacturer the demand for recovered parts for maintenance and replacement purposes for that model may be too low to justify the cost of recovery.

Hence the parameters governing a successful program for recovery and renovation of durable equipment (and materials) include the following:

- For certain products, customers are more willing to lease or purchase remanufactured models (copiers vs. computers). The dynamism of the industry plays a significant role. Industries where the models are changing rapidly, there is less opportunity to use recovered parts in new models.
- Pricing plays an important role in offering an incentive to customers to buy a remanufactured model. This concept also applies to recovered parts that are resold as spare. Pricing also plays an important role where a closed-loop system is offered to customers instead of simply the product. In this case the impact may be the opposite because the closed-loop system might look more expensive than the virgin product because it includes the take-back and recovery costs.
- Customers have to believe that they are not sacrificing quality by buying a remanufactured model. Offering the same warranty as a new machine shows to the consumers that remanufactured models are not inferior in this respect. It also shows that the firm is committed to delivering a quality product. An educational campaign may be necessary to clarify the issue.

Disassembly is essentially a labor-intensive task. Generally, it cannot be automated (although specialized tools can help, of course). The level of skill varies with the task. Typically, a combination of both skilled and unskilled labor is necessary. Skilled workers are necessary to recover the most valuable parts. Even higher levels of skill and knowledge are necessary to differentiate among the various models and the wear states of valuable components. Different models incorporate a different variety of subassemblies. Therefore, the supervisory operator, at least, has to have an in-depth understanding — comparable to that of a maintenance technician — of the design features of the different models and their respective disassembly and recovery sequences.

A disassembly operation usually employs a flexible workforce that varies with the flow of returned equipment. This characteristic is common to most disassembly operations where the return flow is not predictable or changes frequently. Overall, disassembly has the potential to create employment. But, the longer it takes to disassemble a returned product, the higher the labor costs. Thus, reducing the time spent on disassembly improves the operation's viability. Design plays an important role by making products easier (or less easy) to disassemble.

Designing a certain type of packaging or system to encourage recovery is also vital for non-durable products. In the case of Alpha Metals (below) the tin packaging for solder paste was specifically designed for recycling purposes. At Dow/SafeChem (below) the special containers ('Safe-Tainers') have an air tight pumping system which ensures that zero emissions occur during the transportation phase and when solvents are transferred from the containers into the distillation equipment.

The designer can improve the product's suitability for remanufacturing or recycling by maximizing recovery opportunities in all dimensions of product design. This includes appropriate selection of materials and auxiliary substances and designing new connectors that ensure the structural strength but can be easily undone with simple tools. The evidences from the firms we have studied indicate how input from disassemblers to design engineers has resulted in improving different aspects of product design to facilitate recycling and disposal.

At Rank Xerox, certain equipment and components are marked with recycling symbols and remanufacturing codes which detail the recycling potential and strategy for certain parts. Some parts have been redesigned to reduce the number of different plastics they contain. Components are standardized to facilitate the replacement of parts and repairing of copiers. At Siemens Nixdorf, new computer housings are no longer painted because paint renders the plastic non recyclable. Assemblers do not rivet fans into the UNIX systems, instead they clip the fans in for easier disassembly. Each of the computer's plastic components are identified by type and additive.

Most manufacturers have adopted strict toxic use reduction and toxic use elimination criteria as a way to facilitate end-of-life disposal. Typical is the case of refrigerators such as CFCs. This is implemented in the following manner. Component suppliers receive lists of substances either to be banned or reduced (within acceptance limits) or to be declared. This is normally done in anticipation of legislation.

Case Histories of Remanufacturing

We now consider some recent case histories in greater detail, beginning with the "modern classic" Rank-Xerox. Both Xerox and Rank-Xerox originally rented their copiers, and though some customers preferred to purchase outright, the end-of-life "take-back" was a traditional part of doing business. However, while some parts were recovered, they were normally sold to independent contractors and used for maintenance and repair of machines owned by customers and not maintained directly by Rank-Xerox. Some of these local firms began to recondition old equipment taken in trade. In effect, Rank-Xerox gradually found itself in competition with some of these reconditioners, while customers still blamed Rank-Xerox if maintenance services or parts were substandard. The company's reputation for quality began to suffer.

Starting in 1987, Rank-Xerox embarked on a bold strategy to protect its market position against this new threat and, at the same time, increase profitability. The new program was dubbed "asset recovery". Rank-Xerox created a new, wholly owned subsidiary with a facility adjacent to it's manufacturing plant in Venray, Netherlands. The new subsidiary was to acquire old copying machines from local distributors, removing them from the local waste disposal stream.

The second step in this process was to develop a profitable utilization for the used machines that the firm was acquiring. This was achieved with the creation of the Asset Recovery Operation (ARO) to process the returned machines. Today, when the used machine arrives at Xerox it is classified by age and condition, in order to proceed to the most appropriate recovery path. There are four categories, as follows:

(i) Excellent quality. Mainly demonstration models, needing little more than a clean up.

(ii) Good quality. Machines that have been used for about one year under a moderate load. They are suitable for remanufacturing with replacement of those parts that define the performance and the expected life of the complete machine.

(iii) Machines that have worked the equivalent of a moderate to full load for two years. They are suitable for the recovery of subassemblies with longer expected life that can be reconditioned and re-used in newer machines as spare parts.

(iv) Machines of obsolete design or that have been operating for more than the equivalent to two years under full load. Suitable only for materials recycling.

Machines reprocessed through the ARO have increased from 5% of those scrapped in 1989 to 50% in 1995. Components reprocessed have increased from 250,000 in 1989 to 3.5 million in 1995 (*Figure 1*). Presently, about 75% of the 80,000 copiers returned each year to Venray are in category (ii), suitable for remanufacturing.

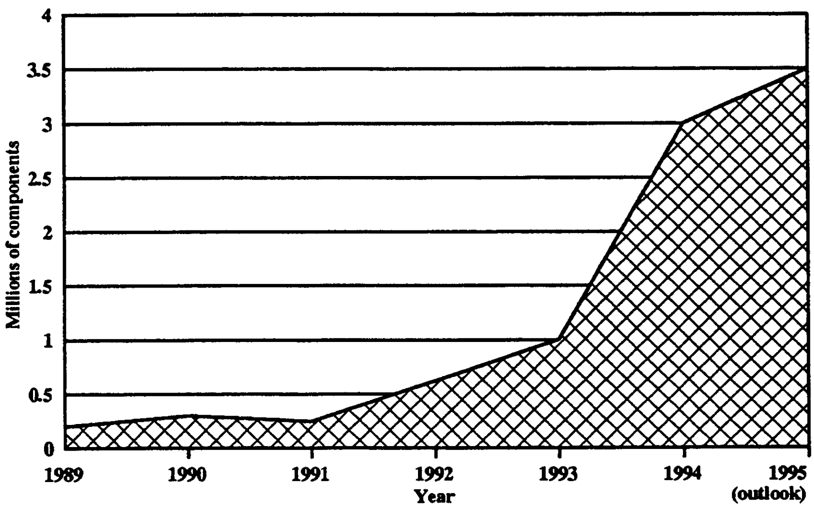

Figure 1: Components reprocessed through asset recovery operations at Rank Xerox

Categories (iii) and (iv) account for 20,000 machines, which are disassembled into subassemblies. Subassemblies in good condition are cleaned, tested and reconditioned by replacement of worn parts. Visible parts are repainted and re-coated. Parts that can be reconditioned are sent to the original supplier who remains in partnership with Xerox, as compensation for lost sales of new subassemblies. The reconditioned subassemblies are then sold back to the parent company for reassembly into remanufactured machines, which are labeled and sold to distributors as such. They compete with new equipment and carry the same warranties, but bear a lower price tag.

Subassemblies in lesser conditions are further disassembled to the component level, cleaned, reconditioned and tested. Components that meet the standard specifications are sold back to the parent company, also for remanufacturing. Substandard components may be sold to others, whenever there is a suitable application. (For instance, substandard ball bearings are sold to small shipyards for use in applications where some "play" is actually desirable). Most substandard components follow the materials recycling path. Recycled materials, such as aluminum alloys with exact composition specifications, can go directly to component manufacturers. Plastics are mostly recycled within the company. Only materials that cannot be recycled are now sent to landfills.

At the beginning of 1993 landfill accounted for 41 percent of total manufacturing waste at Rank Xerox. During the second quarter of 1995, it was only 21 percent. Landfill in terms of absolute weight was 2500 tons in 1992 (3rd quarter). By the second quarter of 1995 this figure had dropped to 1000 tons. See *Figure 2.*

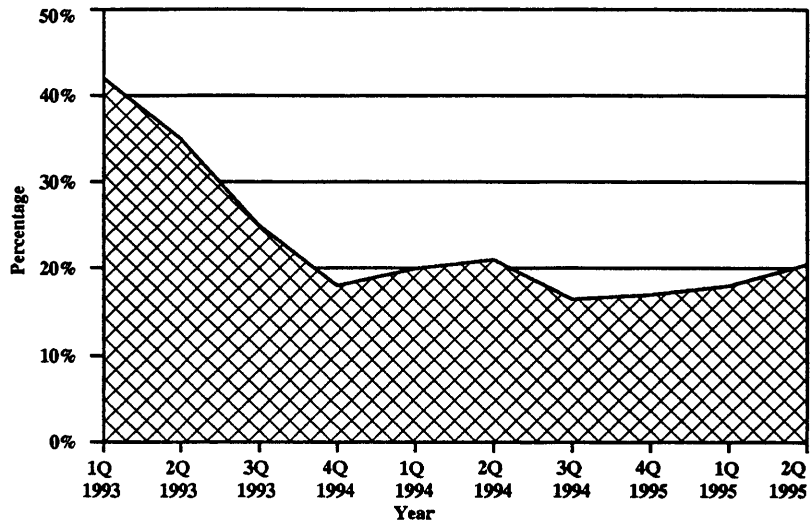

Figure 2: Landfill as percentage of total waste produced during manufacturing at Rank Xerox

A typical structural or optical component has at least four "lives", first as part of a subassembly in a new machine, second in the same subassembly in a remanufactured machine, third, in a remanufactured subassembly in a remanufactured machine, and fourth, as recycled material. Some subassemblies (such as electric motors) can be reconditioned and reused several times.

Demand for the remanufactured copiers is now strong. According to one source, it now exceeds supply by 50%. While these remanufactured machines compete to some extent with sales of new machines, they also capture some sales from lower priced competitors. The main effect is that Xerox was able to expand its customer base and ensure brand loyalty. The customer of a remanufacturer machine today could well be the customer of an all-new machine tomorrow, or vice-versa.

The ARO operation in Venray started with 10 employees. It now employs 400 people at several locations. It has an annual turnover of $200 million. Two thirds of the 120,000 Xerox copiers retired in Europe each year are now returned to Venray for reprocessing. After eight years in operation, ARO has proven to be quite profitable. The recovery operation itself is a financial break-even by design. However the parent company saves considerably on purchased materials and components. These savings were estimated at $69.4 million in 1995 *(Figure 3)*. Moreover, new jobs have actually been created in the asset recovery operation. Some of these new jobs could be at the expense of jobs with its suppliers, but it is evident that expenditures with materials is being substituted for human labor in this case. Xerox cuts its materials costs sharply, at no reduction in quality, by clever use of labor. This is a good omen for the future.

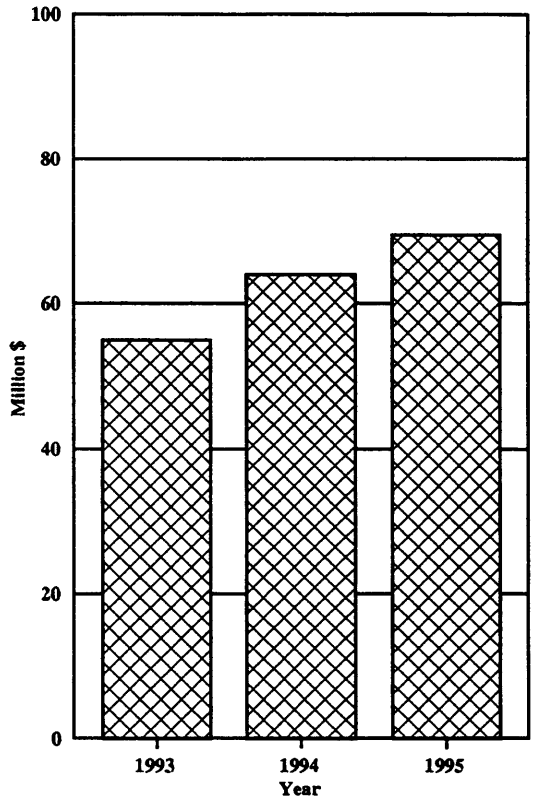

Figure 3: Raw material savings through remanufacturing at Rank Xerox

The asset recovery scheme described above is truly radical in an unexpected sense. Although Rank-Xerox does not retain ownership of its products over their lifetime, it effectively "internalizes" the product. This means that, despite appearances, Rank-Xerox is no longer really selling hardware at all. Rather, it is selling the services of hardware products. Having largely internalized its manufactured product in this way, Rank-Xerox now has all the incentives to maximize profits by minimizing new materials used i.e. keeping existing parts and materials in service as long as possible, improving the longevity of these parts, while still allowing for constant upgrading and improvement of the original product. It also has incentives to redesign the product to make asset recovery easier. For example, a toner cartridge that formerly used 17 different plastics has been redesigned to use only 6.

The environmental benefits are already significant. The asset recovery program has reduced landfill requirements by 7000 tons per year (at an annual savings of $200,000 in disposal costs). This finished materials savings (the same 7000 tons per year) translates into much larger reductions in the quantities of metal ores, coal, petroleum and other materials that would otherwise be extracted from the earth to produce them. Much of it would be aluminum, copper and other non-ferrous metals.

To take an extreme example, 1 ton of recycled copper avoids the mining of at least 200 tons of copper ore and at least twice as much overburden. All of this mining and ore concentration requires about one ton of nitrate explosives for removing the material from the ground, and half a ton of chemicals used in the flotation process. (These are disposed of in ponds). Moreover, there is a need for roughly one ton of coke or other hydrocarbon fuel for smelting. The successive processes of raw material concentration, smelting and refining generate solid process wastes, such as slag of the same order of magnitude. These wastes incorporate significant quantities of toxic contaminants like arsenic, silver and lead. These may or may not be recovered for use; if they are recovered, they become waste pollutants later. Last, but certainly not least, the smelting and refining process releases 3 tons or so of carbon dioxide and 2 tons of sulfur dioxide (recoverable in principle, but not always in practice), not to mention dust and smoke, into the atmosphere.

Given this combination of savings and environmental benefits, it is clear that Rank-Xerox has achieved a *very significant* double dividend: profits for the firm and environmental benefits for society. See Box below.

Rank Xerox, is the UK based joint venture between the Rank Organization and Xerox Corporation. manufactures and sells plain paper copiers in Europe. The company employs 24,000 people and has a turnover of £3.3 billion (roughly $5 billion). When the firm started operations in the 1950s, it leased most of its copiers. In recent years, most copiers were sold outright, but the lease option remained. Thus a certain percentage of used copiers was normally returned each year. Since 1987 the company has gone several steps further. While it still sells copiers outright, it has implemented specific programs to maximize the rate of return of used machines for purposes of asset recovery. In the Netherlands a concessionaires' incentive scheme has increased return rates to over 70%, and the firm now offers a line of remanufactured equipment with full warranty, but at reduced prices. Although the remanufactured copiers compete with the new machines, the asset recovery system has reduced manufacturing costs and proven profitable. Savings in 1996 amounted to about $65 million.

Rank-Xerox is not alone in actively encouraging parts recovery and recycling. IBM has recently announced a new line of low priced computers in the US, using recovered and remanufactured parts, called ETN, standing for "equivalent to new". Siemens-Nixdorf seems to be following the same lead. In 1988, 65% of its end-of-life products were sent to landfill. Seven years later, the breakdown of the 5400 tons of returned used equipment was dramatically changed. Only 14% was sent to landfill 17% was reused by the maintenance services and 69% was recycled (see Box below). The firm has a policy of no incineration, in agreement with the preferences of the German environmental lobby.

Siemens Nixdorf is a subsidiary of Siemens, created in 1990. It is based on a combination of the former Nixdorf computer firm, together with former Siemens information technology activities. The subsidiary now has offices in over 50 countries with 37,200 employees based worldwide. In 1996, the companies total sales were 12.1 billion DM (roughly $8 billion) and it made a loss of 785,096 DM.

Siemens Nixdorf Informationssysteme AG, has a recovery plant located in Paderborn, Germany. The recovery plant reconditions and recycles used computers. The firm has decided that the customer should bear a part of the burden of the disposal cost. It charges it's customers on a sliding scale based on the product type and the disassembly and recycling costs. The fee to return a notebook computer is DM 25 ($17) while the charge for a large mainframe can cost a customer up to DM 970 ($650). The company is aware that when the electronic waste legislation is implemented in Germany it will be obliged to take back its product free-of-charge. For this reason, the firm has already started to institute point-of-sale recycling fees on some of its products, thus increasing the total sales price of the item (passing at least a part of the cost of disposal onto the client).

Other major computer and peripheral companies in Europe have also initiated recycling programs. The list includes IBM (through its recovery operation in Italy), DEC, Hewlett-Packard, Apple, 3M (Germany) and Sony. Brief descriptions of some of these programs are provided elsewhere in this article. In brief, the recovery operation of IBM SEMEA supplies parts from returned used computers to the parent company, usually discounted to 30 percent of the price of new parts (see Box). IBM saves in the cost of purchased parts: they are used by the maintenance services in many European subsidiaries or sold to other industries (such as toy and video game manufacturers).

The recovery operation of IBM SEMEA (Italy) has an annual turnover of 100 billion lira, or about $65 million. The recovery unit has 180 employees based at the two plants in Busnago and Basiano. It is responsible for IBM's Italian logistics operations, including the take-back, dismantling and disposal of used IBM equipment. Recovered and reconditioned parts are sold for maintenance purposes at 30% of the price of new parts. The operation made a profit of 120 million Lira (approximately $800,000) in 1995. From an operational perspective, the recovery operation is a separate entity, and it was a legally distinct subsidiary (DST Logistica) from 1992 to 1996, although it has been reabsorbed into the parent company. One argument for in-house take-back and disassembly is security. IBM tightened requirements for the management of its end-of-life products in 1993, and as a result brought more of its disassembly and disposal operations in-house.

There is a trend in several industries to use more recovered computer chips. This has created a significant secondary market for integrated circuits (ICs) that have become obsolete by the standards of the computer industry, but are still usable [Davis 1996]. However, chip recycling is still a relatively new activity (see Box).

Aurora Electronics, based in Irvine California, is one of the world's largest recyclers of integrated circuits (ICs). The company had a 1996 turnover of $120 million and has 415 employees. Aurora electronics employs its state-of-the-art technology to recover and renovate the chips from obsolete equipment. Aurora Electronics sells recovered and remanufactured computer chips to brokers, both in the US and overseas.

In general, most of the companies that have initiated in-house recycling or remanufacturing programs are responding to proposed German take-back legislation, which is thought likely to spread eventually to other European countries. See *Appendix A*. For the most part, they work with existing service companies or recyclers with the primary objective of reducing the cost of disposal in landfills. It is only in the few cases where manufacturers have found opportunities to reduce their own manufacturing costs by utilizing recovered materials or components internally, or selling them at a profit, that a double dividend can be claimed. But such opportunities may be much more widespread than now appears. Most firms have not looked for these opportunities, because they do not expect to find them.

General Electric Medical Systems (GEMS), headquartered in Wisconsin, is the GE subsidiary specialized in the manufacture of medical diagnostic equipment. Its product line includes scanners, mobile X-ray equipment, magnetic resonance imaging systems, ultrasound equipment and positron emission tomography equipment. Several GE plants in the US are responsible for the manufacture or service of different components. Most of these products undergo final assembly at one of GE's plants in the Milwaukee area.

In 1988, GEMS established a voluntary take-back program for old medical diagnostic equipment. Upon the purchase of a GEMS product, the customer can return any diagnostic equipment to the firm's recycling center in Milwaukee. There, the equipment is inspected, disassembled, and individual components are sent any of three possible streams. One stream consists of components to be recovered, reconditioned and reused, one stream consists of components to be shredded for material recycling, and the third stream consists of unrecyclable wastes destined for a landfill.

The recycling center helps analyzing the used equipment in the development of disassembly and recycling routines. Initially, the disassembly and sorting process would generate a container of mixed metals. This had to be disposed of at a cost of $8/ton. The introduction of a magnetic separation procedure to separate the ferrous and non-ferrous components generated an annual profit of $100,000. Further analysis suggested that further separation would enable the recovery of valuable components that, until then, had been disposed at a cost. Several side benefits emerged, for example:

- Generation of a specialized personnel who developed and introduced new salvage methods that increased the profitability of the operation (learning curve effect).

- Increased customer satisfaction; the opportunity to dispose of obsolete equipment at no cost that, otherwise, would have to be landfilled at a cost (helping customers meet regulations).

- Opportunity to learn and develop new design approaches that will facilitate recycling and recovery of disposed equipment (design for the environment, or DFE).

- Improved control of the handling and servicing of GEMS equipment (lower product liability).

- Development of a recovery stream for components rejected during the original manufacturing process (reduced rework cost).

The adoption of a formal design for the environment (DFE) program at GEMS included the following measures (*Table IV*):

Table IV: Outcomes of DFE program at GEMS

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.

The first three measures are typical "design for assembly" measures. They should be adopted even if the firm were not interested in product recovery. However, the recovery process was the catalyst that allowed the firm to identify new opportunities for improving product design.

The adoption of the last three measures, by themselves, would be a burden insofar as they increase production cost without additional direct profit. However, the firm judged that it would eventually have to adopt them in order to comply with new or potential environmental regulation, in the domestic and in the international markets. Thanks to the recovery process, instead of a burden, they become recovery facilitators, improving the profitability of the recovery process. *Figure 4* shows the amount of total material processed in the GEMS recycling plant, in Milwaukee.

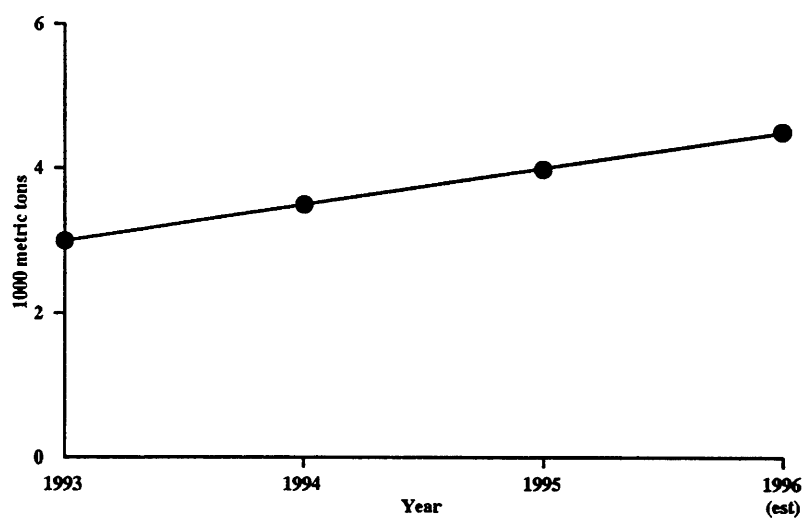

Figure 4: Material processed at GEMS recycling plant

In contrast to an earlier stance, when standard production control methods were in use and the firm reacted to pollution events only as they occurred, GEMS introduced a more proactive position to reduce waste and prevent pollution. It included the following three elements:

- Substitute hazardous with non-hazardous materials.
- Adopt less toxic or less dangerous materials to reduce the severity of pollution incidents.
- Increase recycling efforts to maximize the life-span of raw materials.

As a result of these efforts, GEMS has exceeded the regulatory requirements and improved its image with all constituencies: customers, employees and regulatory agencies. By 1994, it had reduced the consumption of major pollutants in its process by 60%. It has consolidated its market leadership with the recovery of used products of competing brands, and it has avoided considerable landfill expense. The program has also generated about $5 million in direct profits from the resale of recovered materials.

One other example worth describing is the new automobile recycling program in the Netherlands. The program started in January 1995 with the creation of a "solidarity fee" contributed by buyers of new cars to help fund the disposal of the 5 million private cars in that country. The fee, currently $150, has been used to help consolidate and expand the private sector dismantling and recycling activities, thus increasing economies of scale that formerly did not exist. It is expected that the fee will help pay for the development of new processes and help facilitate learning.

Auto Recycling Nederland (ARN) is the independent foundation that manages the fund, selects authorized recyclers, and promotes the development of new uses for post-consumer automobile material. The success achieved so far is quite remarkable. The number of authorized dismantlers was reduced from over 1500 in 1994 to about 250 in mid-1996. This reflects the much harder environmental standards that these plants have to adopt, and the technical skills required to achieve the minimum recycling targets imposed by ARN. Typical automobile shredding and recycling processes currently recover little more than the ferrous metal content in the car. The intervention of ARN has increased the recovery and recycling by an additional 122 kg (approx. 268 lbs.), mostly of plastics and fluids. This is important, given the long term trend toward the substitution of plastics for metals in the automobile.

The $150 deposit fee is expected to be progressively reduced in the coming years, as the ARN revenues enable the process to be more and more self-sufficient. By the year 2000, ARN expects to increase material recycling per car by 218 kg (approximately 480 lbs). This will effectively solve the end-of-life disposal problem for automobiles in the Netherlands. The program exploits the absence of similar initiatives in neighboring countries, by finding new markets for the used materials obtained at the Dutch dismantling sites.

BMW AG the German automobile manufacturer, is based in Munich Germany. Recycling at BMW started in the mid 1980's with the first studies and projects in the area of plastics recovery and recycling. After the close-down of the first pilot dismantling plant, in April 1994, the company built a recycling and dismantling center (RDC) in Loffof, Germany. The objective was to disassemble prototype cars and give feedback to design engineers. In 1991, BMW teamed up with Renault, Fiat and Rover to set up an international recycling network based on a principle of reciprocity. Each firm, is responsible for the network in its own country.

From the mid 1960's BMW initiated a program to recondition and remanufacture high-value used components for resale as used parts. The resale of these remanufactured parts are at 50-80% the price of new parts, includes a notable profit margin for the company (taking into account the costs of labor, logistics, disassembly and purchase of the used car).

To be sure, the Dutch program, so far, does not involve and significant remanufacturing component. Thus it is unclear whether the Dutch program is the first step towards internalizing the automobile, or whether it is a dead end. While initial results are promising, it is unclear whether the scheme would work as well if it were extended to the whole of Europe. It does not yet qualify. in our view, as a true double dividend. Recovered auto parts are used for maintenance and repair purposes, as has always been the case. (This is also true of comparable programs operated by automobile manufacturers, such as BMW and Renault).

However, while truck engines (especially diesels) and transmissions are remanufactured to some extent by independent firms, the original equipment manufacturers in the automobile industry have not yet shown themselves ready to undertake any significant remanufacturing activities. BMW is a partial exception. At BMW's recycling facility all materials and components are classified according to 3 criteria: R1 for good, R2 for adequate after some reconditioning, and R3 for non-recoverable except as materials. BMW reconditions approximately 2000 different high-value parts such as engines, transmissions, water pumps, and electrical systems [Cummings & den Hond 1993]. These recovered parts are usually sold for spare parts at 50-70 percent of the value of comparable new parts.

Neglected Opportunity: Tire Retreading

Tires are still another example of products that can and should be recovered and remanufactured to a much greater extent than is now the case. Apart from other reasons for doing so, old tires cannot be landfilled (they tend to work their way back to the surface), and they cannot be burned in the open without producing tremendous amounts of air pollution. They can be safely burned as fuel only in large, specially designed power plants or cement kilns. But even this solution usually generates strong local opposition. Large stockpiles of worn-out tires are therefore accumulating in many countries, where they constitute both health[3] and fire hazards. It appears that most old tires are finding their way to rural areas where they are used for a variety of purposes — mostly inappropriate — and often end up being burned as "smudge pots" to protect vineyards or orange groves from frost damage.

The automobile tire is one of the most durable products that is produced in high volumes. It results from a complex production process that starts when crude oil is pumped out of the oil-well, it passes by several refining and petrochemical stages to produce synthetic rubber until its main components tread and casing, are assembled.

Figure 5 shows how value is added in the several stages in tire production. From the picture, we notice that the final step in the production, here called final assembly, is responsible for adding about 55% of the value of the finished tire. The production of tread and casing from high grade rubber (SBR, BR and IIR) is responsible for 25% of the total value in a tire, leaving just 20% for the production of the raw materials, rubber, steel cord and chemical additives.

It is striking that the very first stage in the process – where petroleum is refined to obtain the derivatives that will be used in the production of elastomer – is responsible for a minimal fraction of the final value in the finished tire. When a tire is incinerated for heat generation, it is treated as fuel oil. Consequently, the only value that is recovered is the oil refining value, worth about 1.5% of the total value in the tire. (This assertion is not totally correct, since rubber has higher energy content than fuel oil. However, since it is obtained from successive transformation of petroleum derivatives, it can be taken as a reasonable approximation.)

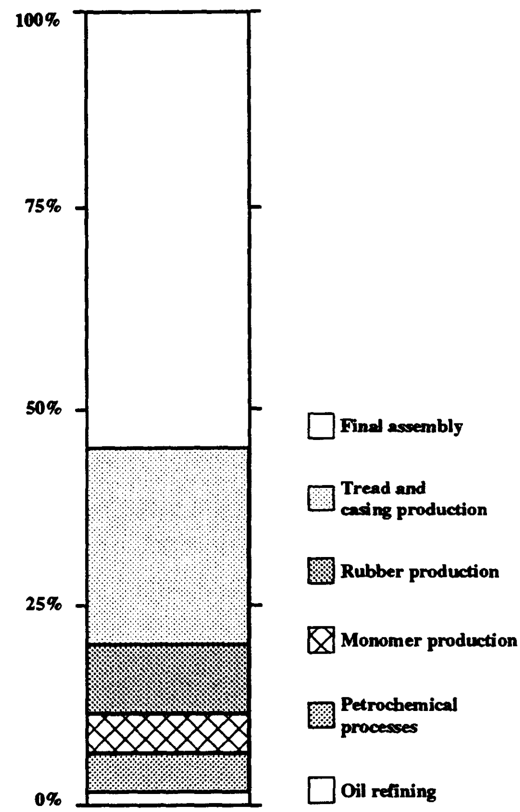

Figure 5: Value-added by each step in tire retreading

The single best recovery process for used tires, both from an environmental and an economical viewpoint, is retreading. There are two competing technologies in tire retreading: the *mold cure process* and the *pre-cure process*. They differ in the sequence of operations, whether the tread application occurs before or after its curing. One advantage of the pre-cure process is that the vulcanization is outsourced, allowing the development of specialized small shops retreading a limited variety of tread types. In contrast, in the mold cure process, the whole tire is placed in a heated chamber to vulcanize the tread design. This process mimics the new tire production process.

Tires can be remanufactured (retreaded) quite safely, and profitably, if they are recovered before becoming too worn. When a tire is used, the tread is the only part of the tire that is actually lost: wear accounts for about 10% of the total weight. A used tire has lost the value that was added in tread production and final assembly. But wear does not destroy the value added in casing fabrication or rubber production.

During retreading, additional material is removed by buffing. Also, a few tires are rejected in the pre-inspection and in the final inspection. Still, a retreading process can recover 85%-90% of the original material in the form of finished retreaded tires. Despite its complexity, it is clear that the retreading process consumes much less energy or material than original tire production. Hence, retreading can potentially recover up to 1/3 of the original tire value. The casing suffers minimal wear and can be used much longer than the original tire is typically used. The retreading process takes six steps, as follows [Ferrer 1997]. The procedure is outlined schematically in *Figure 6.* The six steps are:

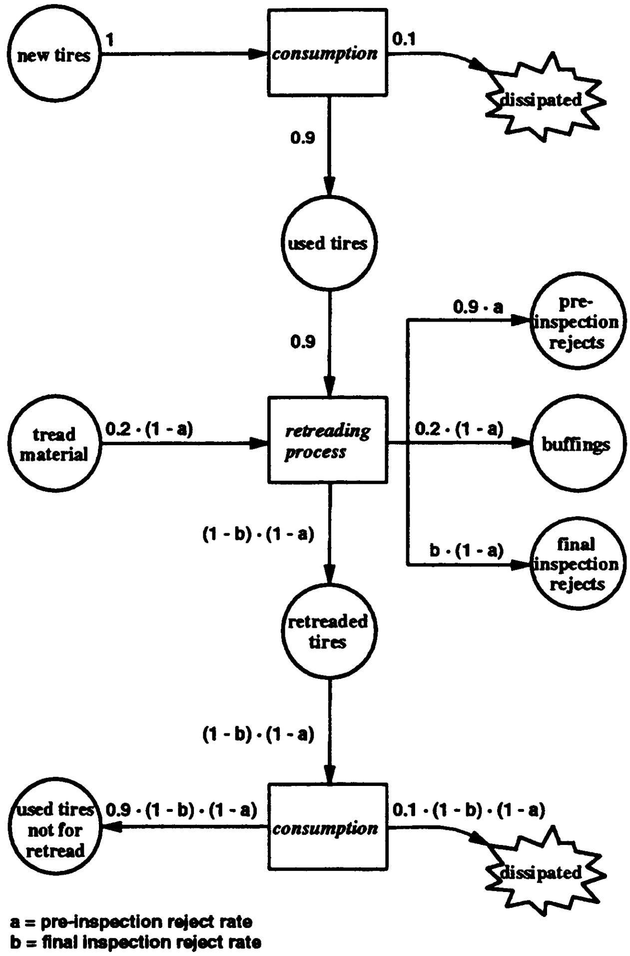

Figure 6: Process-product flows in tire retreading

- Pre-inspection: The used tires enter the process with an initial inspection that selects the ones with retreading potential. (In terms of *Figure 6* the rejection rate at this stage is **a**.) Inspection is a labor intensive task, where the inspector uses his experience selecting the tires that demand the simplest repair process.

- Buffing (or shaving): Here, the tread is removed from the worn tire in a lathe-like machine, the *buffer.* It is a batch process requiring the predetermination of the buffer settings for each tire model and size, removing the correct amount of rubber from the casing without compromising its resistance.

- Casing preparation: The casing is repaired from all injuries remaining after buffing. An operator may reject a tire because its structure has been severely degraded and repairing it would be too costly.

- Tread application: This is where the two processes differ. In the *mold cure process,* the tread is applied to the tire in the same way as in the primary tire manufacture. Uncured tread rubber is applied on the buffed casing up to the correct tire diameter. In the *pre-cure process,* the tread is molded and cured before it is applied to the tire. A layer of cushion gum is applied on the casing's outer surface to bond the pre-cured tread.

- Curing: The curing – or vulcanization – is the process that ensures the bonding between the case and the new tread. It gives the hardness and abrasion resistance required in the tread. In the *mold cure process,* this stage is responsible for forming the tread design and vulcanizing the rubber tread. The prepared casing is placed into a full-circle mold where it is inflated. Swelling the tire against the mold's inner wall conforms the uncured rubber to the tread design in the mold. Then, the mold is heated to the temperature and time for ideal curing. In the *pre-cure process*, the cured tread is applied with its final design. Instead of a whole mold, a simple ring is assembled onto the tire casing to receive the curing pressure. Then, the assembly enters a chamber for a certain time and temperature for vulcanization.

- Inspection and finishing: The inspector in this station is looking for defects occurred in the retread process, because the casing itself has already been inspected. (In terms of *Figure 6*, the rejection rate at this stage is **b**.) If the tire meets the safety requirements, it may go on to the finishing process. The excess rubber is trimmed and the sidewall is painted and labeled for a like-new appearance. Now, the retreaded tire is ready to return to market for a new life.

Retreading is already standard procedure for large truck tires, off-road vehicle tires and aircraft tires, which are normally leased and replaced on a regular cycle by a specialized service organization. The replacement market accounts for 85% of the demand for truck and bus tires; new tires account for only 15% of this market.

The problem for private automobiles is that owners tend to keep tires until the treads are too thin for remanufacturing. A large percentage of old automobile tires are literally useless, having been worn beyond the point of no return. The high cost of sorting out the remanufacturable ones from the rest (Step 1 above), and disposing of them safely, makes the whole process uneconomic.

However, a technical fix for this problem may be on the way. Goodyear, the American rubber and tire manufacturer, received a $2 million US federal grant for pursuing the development of "smart" tires. These tires contain a microchip embedded in the carcass which can identify critical operating parameters, and transmit them upon the trucks arrival in the garage. Beside the tire identification number, it provides information about the pressure, heat and number of revolutions (or distance driven).

Bridgestone/Firestone Inc., the American subsidiary of Japan-based Bridgestone Corp. has also developed a prototype smart tire which can provide real time information on tire temperature and pressure, besides identification. The smart tires designed by Bridgestone include a battery with projected life-span of 10 years to power the microchip and sensors. The advantage of having this autonomy is that it ensures that the chip will remain operational for as long as the tire is used, even considering the multiple retreading events.

Retreaded tires now account for 50% of the replacement market for commercial tires. Some tire manufacturers have established retreading plants to compete in this market by offering tire leasing contracts to large fleets. For them, the development of smart tires is an additional step into internalizing the product. It is expected that smart tires will facilitate the management of these contracts and provide useful information for the determination of the optimal retreading routine. Whether the tire is managed by the fleet manager as one of the many assets in the firm, or whether the tire is leased from the manufacturer, tire retreading is an efficient way to obtain double dividends: it requires much less materials and energy from the environment, and provides large savings to the fleet operator.

Some Miscellaneous Examples

Although the above examples focus attention on traditional durable goods like copiers, computers and cars, there are some lessons to be learned from non-traditional cases. For example, environmental legislation has encouraged the emergence of new and profitable services by facilitating the recovery of a formerly dissipated industrial material. Chlorinated solvents are quite durable in the sense that they could be used, in principle, many times. In practice, solvents have been sold for dissipative use. Dow/SafeChem clearly demonstrate this kind of situation. By using a closed loop system, approximately 65 percent of virgin solvent is recoverable in the metal-cleaning industry. In the dry cleaning industry, approximately 30 to 40 percent can be recovered. The recycling process does not compromise the chemical qualities of the solvent, and the product can be resold to customers at a lower price.

Dow/SafeChem accomplishes this by offering a returnable packaging system — itself a durable good — developed for this purpose. This allows the recovery of the original product, which had previously been released into the atmosphere. The service provided by the solvent is now profitably marketed independently of the product itself (see Box). In fact, a similar service based on Safe-Tainers has already been initiated in France by a joint venture between Dow France, a chemical distributor Lambert Riviere (subsidiary of a Dutch firm, Royal Packoed) and a waste treatment specialist Groupe Tredi (subsidiary of EMC). Similar joint ventures are being developed in the U.K. and Spain.

There are clear environmental benefits from pollution reduction. The joint ventures are profitable in themselves. Clearly the take-back service also adds customer value to the original products. This seems to be a marketing and cost-saving opportunity for the original solvent manufacturer (Dow). This idea qualifies as a double dividend.

SafeChem is a joint-venture between Dow Chemical Co. (Germany) and the German recycling company Westab. It is in the business of leasing chlorinated solvents in Germany and Switzerland and is planning to initiate operations in Austria. It represents a capital investment of US$2.3 million, employing 14 full-time workers. SafeChem offers a system to help customers to comply with the strict environmental legislation in Germany. The firm distributes chlorinated solvents in special containers ("Safe-Tainers") with an air tight seal and pumping system to eliminate transient losses and emissions during the transportation and transfer phases of the operation. The company also provides empty "Safe-Tainers" to store and transport spent solvent back to the firm, where it is sent on to a Dow plant for redistillation. With this closed-loop system, SafeChem includes the cost of take-back and recycling in the price of the virgin solvent. The idea to create SafeChem was a strategic move by Dow, in an attempt to increase its share of the declining chlorinated solvents market in Germany. In 1995 the company was operating at a profit and it's market share had increased to 20 percent of the total metal cleaning industry in Germany.

A creative marketing department may be able to convert a legal take-back requirement into a new service to customers. A good illustration is provided by the case of 3M Germany's "Data Care" program to recycle magnetic tapes and cartridges. Some large users of magnetic data storage tapes, especially banks, are naturally concerned about data security. For example, the account identification codes of the bank's clients must remain absolutely confidential, even when the account data itself is obsolete. Shredding and incineration are the classic methods of destroying such records. Yet incineration generates air pollution and, of course, the underlying physical material of the tapes is destroyed as well. The 3M company (Germany) has created a service for such clients (Box). Not only does it relieve the client of responsibility for destroying the electronic data on the magnetic tapes, it also preserves and recovers the physical substrate, which can then be recycled or remanufactured into new tapes. Thus not only does 3M gain a marketing advantage over its competitors, it also saves on material costs and reduces environmental pollution. This is a double dividend.

Another example of a durable material that can be recycled (but usually is not) is anti-freeze. Each year, in Germany alone, about 110,000 tons of radiator anti-freeze are sold —

mostly ethylene glycol. Of those, 90% is normally flushed into drains and the rest evaporates. In 1993 SafeChem adapted its safe-tainer system for recovering and recycling this coolant from service centers and garages where it can be collected. Dow took over the scheme in 1995 with agreements from several auto manufacturers, including BMW, Rover and Peugeot. The used anti-freeze is treated by filtration and distillation, then shipped to Dow's plant in the Netherlands to be repackaged as new.

Dow expected the operation to be profitable, but so far it has not been because of competition from used motor oil recyclers who have discovered the niche and are also collecting and recycling antifreeze. Since then, a new transport system (using plastic instead of metal drums) and a more efficient treatment process have cut costs, allowing the system to approach break-even. Now, Dow has 70% of this market. This operation would quickly become profitable if market conditions changed (perhaps with the help from legislation or public pressure) and garages were to save the used materials for collection, rather than dumping them. One-half of the double dividend, resource savings, is already perceived. Hopefully, the other half will soon be realized.

A similar example comes from Alpha Metals, a German manufacturer of solder bars, coils and paste for the electronics industry. In this case, the environmental regulation on toxic material disposal in landfills created an incentive to discover a double dividend opportunity. The cost of landfill implicitly required the firm to wash and reuse the partly used solder-paste jars that it received back from its customers. However, washing the jars merely created another environmental problem, and brought no advantages to the firm. The cost of treating the effluents is very high and the excess material is wasted. In this instance, a clever solution was found, by-passing the glass jars altogether. (See Box). Glass jars have been replaced by tin cans. In effect, the used and partly filled returned tin cans go directly into the solder melt and have a second (and durable) life as part of the solder itself. Again, strict environmental legislation has created an opportunity for a double dividend.

Alpha Metals is a subsidiary of the Alpha Fry Group, which is part of the Cookson Group's electronics division. Alpha Metals is based in Duisburg, Germany. The company employs 121 people and had a turnover of 40 million DM (about $25 million) in 1996. Its primary business activity is the production of solder paste and solder to the electronics industry. It has approximately 50% of the German market share, selling 40 tons per year. Major customers include Bosch, Sony and Siemens Nixdorf. The German packaging ordinance obliged Alpha Metals to take back the glass jars that once contained the solder paste that it sells to the electronic industry. The firm had to wash and reuse the glass jars to avoid the ever-rising landfill cost for hazardous wastes (300 DM per kilo in 1995). Although the washing process also generates wastes, the company calculated that it was cheaper to clean the jars (accounting for labor costs) and reuse them than to landfill the used jars. However, Alpha Metals developed an ingenious package for solder paste, made of pure tin. The tin can (still containing the remains of used solder paste) is now melted with the raw material to make solder bars, another of the company's products. Under German conditions, this innovation has proven profitable.

The German petrochemical giant, BASF, has just introduced a program for collection and recycling end-of-life carpets in the US market. The firm is one of the major manufacturers of nylon fibers for carpet manufacturing. It has developed a recycling process for its 6ix® fiber that results in fibers of the same quality as the virgin material. This achievement is particularly impressive, given that most plastic or rubber recycling processes result in lower-grade material which cannot be used in the production of the original product.

BASF collects used carpets made exclusively of the 6ix® fiber in seven locations in the US. In each of these locations, the used carpets are shredded, the nylon fibers are recovered and other non-nylon fibers are separated to be recycled by independent firms. The 6ix® fibers are compressed to obtain small nylon pellets. The polymer chains are broken and then re-polymerized into 6ix® fibers identical to the virgin material, ready to be woven into new carpets again.[4]

This re-polymerization technology is a closed-loop recycling process which can result in the elimination of most of the waste generated with the substitution of end-of-life carpets. Because of the usual incompatibility among polymers, BASF recycles carpets made exclusively of the 6ix® fiber (regardless of the brand of the new carpet that the customer is buying). The firm has decided to internalize its product, with the adoption of an efficient recycling technology for nylon 6. It has not disclosed the financial outcome of the operation, but the environmental impact can be significant. In exchange, BASF asks the customer (initially likely to be a commercial user, like a hotel) to pay the transport cost to the collection site. This cost is generally lower than the landfill fee charged by municipalities.

Discussion

Perhaps the most important question of all is the most basic: Under what circumstances can a firm expect to discover major opportunities for asset recovery through remanufacturing? Other important unanswered questions are: To what extent does the organizational structure of firms facilitate and encourage product recovery and remanufacturing? What are the relative advantages of a vertically integrated recovery operation in comparison to out-sourcing? A closed-loop system does not necessarily imply a vertically integrated operation. How does the organizational structure affect the efficacy of the remanufacturing operation? What are the advantages of vertical integration to the firm? to society? What are the benefits of out-sourcing?

Most of the cases discussed above were either vertically integrated or involved cooperative agreements with a separate business unit or subsidiary. One benefit of vertical integration (verified by a number of cases) is the flow of information from the disassembler to design engineers. 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. Facilitating disassembly will encourage remanufacturing in the long run. Rank Xerox, IBM, Siemens Nixdorf and Digital Equipment have all observed that if the recovery operation is established internally, it may provide valuable inputs to design engineers on how to improve the design of their products to make them more 'recoverable'.

At Rank Xerox, the remanufacturing operation is integrated into the main production line. The Asset Recovery Organization (ARO) operates as an independent business unit. It is responsible for disassembly and recovery of components and subassemblies. Two factors that pushed Rank Xerox to vertically integrate are (1) the firm is already at the forefront of remanufacturing (so it is necessary do it themselves) and (2) there is a need to protect proprietary knowledge.

A major benefit for Rank Xerox of organizing the ARO as an independent, not-for-profit, but wholly owned subsidiary is accounting transparency and visibility. The reduction in landfill costs is one source of saving. But the major saving arises from reduced costs of parts and materials formerly purchased from outside suppliers. Rank Xerox has in effect developed an internal supplier to provide remanufactured parts and modules to the assembly line. Since then, it has become less dependent on external suppliers. The company is however trying to draw up agreements with several of them in order to subcontract the remanufacturing of some categories of used parts. Once these agreements are concluded the remanufacturing operation will be somewhat less vertically integrated than it is now. The suppliers will continue to be responsible for their respective parts and components, partly compensating for the reduction in the sales of new parts.

Some of the difficulties in developing an in-house operation include high start-up costs, the need to develop an effective network of recyclers, the proper analysis of the waste streams and handling the disposal liability. An official at Digital Equipment has estimated that it could cost a manufacturer up to $5 million to start up its own in-house take-back program. Japanese copier maker Fuji Xerox has invested 300 million yen (about $2.5 million) to build a disassembly line at one plant.

Theoretical advantages of out-sourcing the asset recovery activities include economies of scale or scope, specialization, and location factors. Logistical support is a major issue and one *a priori* disadvantage of out-sourcing is the increased difficulty of integrating the collection and return flows with distribution and maintenance. Yet, the potential for economies-of-scale is absolutely dependent on establishing reliable and adequate return flows. For precisely this reason, manufacturers of capital equipment that have limited volume and turnover may find it to be more economical to subcontract the entire recovery activity to a specialist. Economies-of-scale can arise from the consolidation of materials from several manufacturers, provided the diversity is not too great.

Table V: Motivations for asset recovery/remanufacturing activities

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.

Specialized recycling firms have their advantages. Typically, they can obtain a better market price for recycled materials. Overhead costs are usually lower, depending on the magnitude of the operation. For the same reason, they may be able to invest in more sophisticated equipment to assist in disassembly and parts sorting. In the event that subcontracting is the preferred choice, the greatest challenge is to select the right partner for the recovery process. The choice depends on several factors such as the type of end-of-life solution (refurbishing vs. recycling vs. disposal), product type and quality.

In conclusion, motivations for entering upon the asset recovery/remanufacturing approach to increasing eco-efficiency are varied. For some companies, environmental legislation, or expected legislation, is the crucial factor that prompted the firm to undertake an eco-efficiency initiative. Conversely, Rank-Xerox and GEMS are two examples where regulation was not a factor, at least in the direct sense. However, in the majority of instances that we have investigated the role of environmental regulation is evident. In some cases the regulation was already in place (e.g., Alpha Metals and Dow-Safe Chem response to regulations on hazardous waste disposal or toxic emissions.) For other firms, the anticipation of future legislation has prompted the company to develop internal recovery recycling options (e.g. Siemens Nixdorf, DEC). *Table V* presents a brief analysis of the main motivating factors for the cases described.

The impact of environmental regulation on firms' profitability and competitiveness has been a matter of controversy. There are two schools of thought on this issue. The traditional perspective is that environmental regulation simply imposes an additional burden on firms, by increasing total costs and thus adversely affect the company's competitiveness in the long-term as against competitors less burdened. A more heterodox viewpoint is that properly designed environmental legislation can actually encourage firms to innovate and discover unsuspected and profitable business opportunities [Porter 1991, Porter & van der Linde 1995]. Granted, the examples we have cited can be classified as preselected success stories. However, to say the least, our survey does not offer much support to the pessimistic view.

Appendix A: Status of Electronics Take Back Regulation in Selected European Countries

Country	*Proposed scheme and targeted products*	*Status of legislation*	*Status of other national take-back programs*
Austria	1994 draft regulation would mandate electronics take-back; Environment ministry now waiting for EU to make first move	Not clear, although the Umweltforum Haushalt (UFH) uses unique payment system	Industry cooperative. UFH handles take-back for refrigerators, air conditioners and freezers.
Denmark	Negotiated agreements expected between government and consumer electronics industry by May 1996 and IT industry by the end of 1996. EPA also wants agreements with manufacturers of automobiles and building materials	Legislation will cover any manufacturer not involved with voluntary agreements.	National take-back program for tires is funded by surcharges in new product prices.
France	Government favors idea of national scheme run by industry. Pilot projects underway.	National goal of 100% recovery or recycling for electronics by year 2002.	Not applicable.
Germany	Government and industry have negotiated three-step take-back decree for electronics. Industry group CYCLE has proposed its own plan for handling information technology equipment.	Eco-Cycle law to take effect in 7th October 1996. It allows government to impose take-back on industry in general	Packaging Ordinance of 1991 obliging manufacturers to take back their waste packaging or have someone else collect it for them.
The Netherlands	Several associations of Dutch electronics industry have proposed schemes.	Landfill ban on electronics is in effect; Government has threatened electronics industry with mandatory take-back legislation.	Not applicable
Norway	*Multistakeholder* working group proposed 80% collection rate for electronics by year 2000. Collection will be overseen by private organization.	Working group proposed regulation to allow customers to return electronics to retailers or other appropriate collection sites.	No applicable
United Kingdom	No proposed national scheme. Pilot projects by industry groups underway.	Government wants electronics industry to establish a voluntary approach.	Not applicable.

Source: [Davis 1996]

Endnotes

1. In 1992, IBM created a wholly owned subsidiary DST Logistica to engage in the recovery operation; very recently the subsidiary was absorbed back into the parent company as a division, IBM SEMEA..

2. Information provided by Giuseppe Franzosi, Manager DST Logistica during a site visit to the recovery plant in Busnago, Italy on April 5th, 1996. Italian Lira have been converted to US$ at the rate of 1550 Lira/$, a median rate for the 1st half of 1996.

3. Old tires are breeding grounds for mosquitos and rats.

4. Nylon 6 is a polymer of caprolactam, a nitrogenous chemical manufactured originally from ammonia, sulfuric acid and light hydrocarbons. Less than 20% of the nitrogen content of the ammonia feedstock is embodied in the nylon; the remainder ends up in a relatively low value fertilizer, ammonium sulfate. Thus nylon manufacture is extremely energy-intensive, and it is very beneficial from an energy standpoint (among others) to recover and recycle the monomer.

References

[Cummings & den Hond 1993] Cummings, Christopher and den Hond, *Bayerische Motoren Werke AG*, Management Institute for Environment and Business (MEB), 1993.

[Davis 1996] Davis, John Bremer, *Product Stewardship and the Coming Age of Take-back* Cutter Information Corporation. 1996.

[Ferrer 1997] Ferrer, Geraldo, "The Economics of Tire Remanufacturing", *Resources, Economics and Recycling*, forthcoming, 1997.

[Johnson & Wang 1995] Johnson, M. R and Wang, M. H, "Planning Product Disassembly for Material Recovery Opportunities", *International Journal of Production Research*, 1995, 33(11) :3119 -3142.

[Penev & Ron 1996] Penev, K. D. and de Ron, A. J, "Determination of a Disassembly Strategy" *International Journal of Production Research*, 1996, 34(2) :495-506.

[Porter 1991] Porter, Michael, "America's Competitiveness Strategy", *Scientific American*, April 1991.

[Porter & van der Linde 1995] Porter, Michael E. and Claas van der Linde, "Green and Competitive", *Harvard Business Review*, September-October 1995 :120-134.

[Steinhilper 1995] Steinhilper, Rolf, *Product Recycling and Eco-Design: Challenges, Solutions and Examples* Paper presented at the International Conference on Clean Electronics. October, 1995.