Remanufacturing: the Experience of the United States and Implications for Developing Countries

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Integrated Resource Recovery

UNDP Project Management Report Number 2

INTEGRATED RESOURCE RECOVERY SERIES

GLO/80/004

Number 2

This is the second in a series of reports being prepared by the Resource Recovery Project as part of a global effort to realize the goal of the United Nations International Drinking Water Supply and Sanitation Decade, which is to extend domestic and community water supply and sanitation services throughout the developing world during 1981 to 1990. The project objective is to encourage resource recovery as a means of offsetting some of the costs of community sanitation.

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Series cover design (clockwise from top): Aquaculture using wastewater yields about 8 tons of fish per hectare per year in India. Biogas is produced from organic wastes in India. Sullage from a shower is used to irrigate a garden in the Sudan. The original value added to aluminum is captured by using waste oil to melt scrap and then pouring new ingots in Egypt. A "state-of-the-art" plant, built to demonstrate the pyrolysis of garbage to make fuel oil, has been shut down temporarily because of excessive operation and maintenance costs in the United States. Paper is recycled in a factory of the Shanghai Resource Recovery and Utilization Company in China.

This report is printed on recycled paper.

WORLD BANK TECHNICAL PAPER NUMBER 31

Remanufacturing

The Experience of the United States and Implications for Developing Countries

Robert T. Lund

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ABSTRACT

This paper discusses all phases of remanufacturing: the disassembly, inspection, refurbishing, reassembly, and final testing of worn durable products which are then rendered less costly but otherwise useable. The process is particularly applicable to developing countries because it requires less capital and fewer labor skills than that of the original equipment manufacturer. For those developing country locations having an assured supply of unserviceable products and meeting the minimum requirements for labor and investment, this report reveals that the financial and economic viability of remanufacturing can be assured.

CONDENSE

Le présent document examine toutes les phases de la réfection de matériel, à savoir le démontage, l'inspection, la remise en état, le remontage et les essais finals de produits durables, toutes ces opérations étant centralisées et moins coûteuses que le remplacement de ce matériel tou: en offrant un produit de qualité égale ou même supérieure à l'original. Cette technique est particulièrement indiquée pour les pays en développement car ses besoins en capitaux et en main-d'oeuvre spécialisée sont moindres que pour la fabrication de ce même matériel. Selon le rapport, la viabilité financière et économique de cette réfection est assurée quand cette activité se déroule dans des régions de pays en développement où les approvisionnements en matériel pour lequel il n'existe pas de service après-vente et qui répond aux critères minimums en matière de main-d'oeuvre et d'investissement sont assurés.

EXTRACTO

En este trabajo se analizan todas las fases de la remanufacturación, es decir, las actividades centralizadas de desmontaje, inspección, restauración, nuevo montaje y prueba final de bienes de consumo duraderos, que resultan luego menos costosos pero en los demás aspectos iguales o mejores que en su estado original. Esto es especialmente interesante para los países en desarrollo, debido a las menores necesidades de capital y mano de obra calificada que las del fabricante original del equipo. En el caso de aquellos países en desarrollo cuya ubicación les asegure el suministro de bienes que no pueden repararse y que cumplan con unos requisitos mínimos en cuanto a mano de obra e inversión, este informe revela que puede garantizarse la viabilidad financiera y económica de la remanufacturación.

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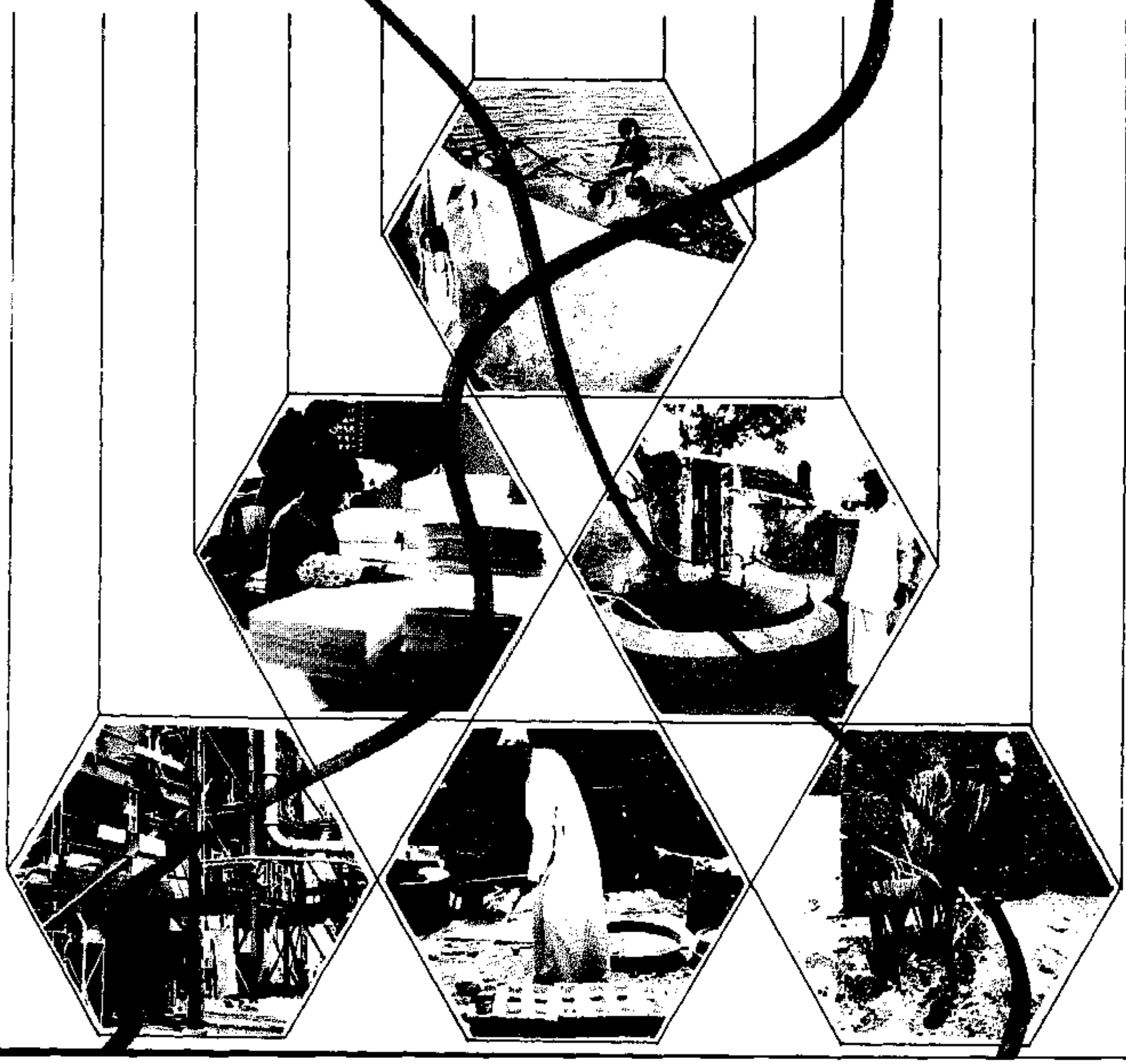

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FOREWORD

The dependence of economic growth upon domestic and environmental sanitation and upon sustainable use of human, natural and financial resources is revealed in ancient and modern systems for recycling wastes. Among those, remanufacturing is a recently rationalized technology for capturing energy, material, and labor value added in the original manufacturing of tools and machines. This report is one of a series being published by the World Bank as executing agency for the UNDP Resource Recovery Project (GLO/80/004). Other technologies are presented in companion reports.

We are soliciting comments and case study information from which future editions will benefit.

PREFACE

This report on remanufacturing is a summary of the major findings of a series of studies on the subject conducted at the MIT Center for Policy Alternatives beginning in 1978. This state-of-the-art overview is sponsored by the World Bank's Integrated Resource Recovery Project, a three-year program of research and development having the following goals:

- to achieve sustainable health, environmental employment, energy, economic and financial benefits through sustainable resource recovery and utilization projects in developing countries; and

- to assemble, assess, and disseminate technological, economic and financial information for resource recovery projects in developing countries.

We are pleased that remanufacturing has been included as a topic in the World Bank project, because it has a major role to play, not only in resource recovery but also in establishing an industrial base in developing countries. Remanufacturing is an appropriate technology for industrialized and industrializing countries alike and it provides an impressive list of benefits.

We are grateful for the encouragement given to this project by S. Arlosoroff and Charles G. Gunnerson of the World Bank. This report also owes much of its existence to the continuing interest and support of the U.S. Department of Energy, and more specifically to Dr. Jerome F. Collins and Mr. Stuart Natof of that agency.

The contents of this report are a synthesis of sixteen reports prepared at the Center on various aspects of remanufacturing. The process of selecting what topics should be discussed and the level of detail to be provided necessarily has involved substantial condensation, and the reader is referred to the original documents for elaboration.

While recognizing the contributions of many researchers that have made this report possible, I accept responsibility for what is written herein. The opinions, findings, conclusions and recommendations are mine and do not necessarily reflect the view of the Center for Policy Alternatives, Massachusetts Institute of Technology or the World Bank.

Robert T. Lund
Principal Investigator

1 REMANUFACTURING DEFINED

1.1 Introduction

When a durable product (machine, vehicle, appliance, tool, or other mechanical system) reaches the end of its normal life, it is typically disposed of landfill or it is scrapped for recovery of its material. In either of these actions the costs associated with collection and operation of a landfill or the costs of shredding, sorting and melting down the reclaimable materials exceed the direct economic benefits of these operations.

Remanufacturing is often an economically advantageous alternative that can significantly extend the lifetime of a product and thereby reduce the amount of material that must be treated by recycling or as landfill. Remanufacturing is the restoration of used products to a like-new condition, providing them with performance characteristics and durability at least as good as those of the original product. Through a series of industrial processes, worn-out or discarded products are completely disassembled, their useable component parts are cleaned and refurbished, new parts are provided where necessary, and the parts are reassembled and tested to produce units meeting new product performance standards. These operations are performed in a factory environment and the assembly processes are usually very similar to those employed in making the product originally.

Because remanufacturing recovers a substantial fraction of the materials and the value added to a product in its first manufacture, and because it can do this at low additional cost, the resulting products can be offered on the market at substantial savings to the user.

Although it has had a very low visibility in all world economies, remanufacturing has been a viable economic activity (at least in the United States) for three or four decades. Very little has been written and virtually no research has been conducted on the subject outside of a series of studies launched by MIT's Center for Policy Alternatives in late 1978. Through these studies the Center for Policy Alternatives has been able to:

- o define the nature of remanufacturing[1*]
- o study the characteristics of specific U.S. remanufacturing operations[2]
- o determine some of the major operating characteristics of known American remanufacturers[3]
- o establish criteria for selecting product candidates for remanufacturing[2]

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* References are found at the end of each chapter.

- o perform a screening of currently made durable products to recommend products for remanufacture[4, 5]
- o provide guidelines for individuals and firms considering establishing remanufacturing operations[6, 7]
- o identify the social and economic benefits of remanufacturing in the United States
- o suggest possible public and private policy issues relating to the activity.

All of these studies have been sponsored by the Waste Products Utilization Branch of the Office of Industrial Programs of the U.S. Department of Energy. Because the sponsor was an agency of the U.S. Government, the principal focus of the studies was domestic remanufacturing. In addition to the Center's sponsored research, five theses by Favreau,[12] Gonzalez,[13] Holzwasser,[14] Kutta,[15] and Skeels[16] further expanded our understanding of remanufacturing, particularly in the automotive (car, truck and motorcycle) components and chain saw sectors.

Shortly after the U.S. studies began, however, it became apparent that certain aspects of remanufacturing should make this an advantageous activity for developing countries. In particular, the opportunity to develop industrial skills within the indigenous workforce, to transfer technology at an operating level and to obtain capital equipment at low foreign exchange cost were appealing features.

As a consequence, the Center began a low level effort to examine some of the possibilities for remanufacturing in other countries. This effort has been carried on primarily by students who conducted the research for their bachelors or masters degree theses. Their reports provide some insights into the applicability of remanufacturing in a variety of countries: the Andean region of South America,[8] India,[9] Nigeria,[10] Turkey and Pakistan.[11] These studies generally support our early hypothesis that remanufacturing should be attractive to a country that is trying to enlarge its industrial base.

When the MIT studies came to the attention of members of the World Bank's Integrated Resource Recovery Project, it commissioned this report, a state-of-the-art paper on remanufacturing, as the initial step in what is expected to become one or more remanufacturing demonstration projects in developing countries.

This report is a survey of available information on remanufacturing. In the chapters that follow we will discuss remanufacturing in the United States, the economics of remanufacturing, what constitutes a favorable environment for remanufacturing, selection criteria for products that can be successfully remanufactured, preliminary findings from studies related to other countries, and benefits of remanufacturing in the United States and in other countries. We conclude with recommendations for a program to apply remanufacturing concepts in developing countries.

In the balance of this chapter we examine the kinds of products that are remanufactured, describe the process steps involved, explain terminology, give perspective to remanufacturing in its relationship to resource utilization and recovery, and, finally, summarize the societal benefits of remanufacturing.

1.2 Process Stages and Terminology

There are three types of remanufacturers:

- The OEM (original equipment manufacturer) remanufacturer, who makes and sells both new and remanufactured versions of its product. Some OEM firms lease, rather than sell, their products; for them, remanufacturing becomes a means of rehabilitating their own equipment.

- The independent remanufacturer, who buys non-functioning products and remanufactures them for resale.

- The contract remanufacturer, who rehabilitates a product under contract from a customer who retains title to the product. This latter category of firm can be either an independent or an OEM. The essential characteristic of this category is that the remanufacturing is performed as a service to some other person or firm that owns the product.

The remanufacturing cycle begins at the point where a user relinquishes a product (through trade-in, sale, abandonment or contract) to the system that collects and forwards these items, called "cores", to a remanufacturer. Because of the trade-in aspect of cores, dealers tend to be the initial collection points. If the product is one being remanufactured by an OEM, the collection system is likely to be just the reverse of the firm's distribution channels for its new products. Dealers supplying cores to independent remanufacturers may sell both new and remanufactured products, accepting non-functioning units as trade-ins when customers buy replacement units.

Further consolidation of cores may occur at intermediate points such as warehouse distributors or regional warehouses before they are forwarded to the remanufacturer. Payment for cores is by a series of credits that can be applied to the purchase of remanufactured units for resale. Additional cores may be obtained from scrap dealers or independent collectors, called core brokers. An objective for a domestic remanufacturer is to get back a core for each remanufactured unit sold, thus assuring a continuous supply. There are losses in the system, however, and the core brokers and scrap dealers help to augment the stream.

Core collection, pricing, evaluation and inventory levels are all important facets of remanufactuaring and will be discussed in greater detail later in the report.

When cores are received by the remanufacturer, they pass through three processing stages:

- o Disassembly and cleaning
- o Refurbishing of component parts
- o Reassembly and testing

After initial cleaning and examination of each core to determine its condition and to identify it by model and year of manufacture, the core is disassembled. This may be done in stages, first by subassembly and then into individual parts. Each part is thoroughly cleaned. Parts that are corroded, painted or discolored are blasted by or rolled in abrasives to restore the surface in preparation for refinishing. Throughout disassembly and cleaning all parts are inspected for damage or flaws that would require repair or rejection. Parts are sorted by part number and, where volume permits, are handled in batches through the balance of the operations.

Component refurbishing may take several forms. In addition to surface cleaning and preparation, worn areas may be built up by welding and machined to original dimensions, out-of-round holes may be bored to a larger size to accept an insert having the correct internal diameter. bent shafts may be straightened, electrical wiring cleaned and re-insulated, and precision surfaces re-ground and scraped. In each instance, the objective is to restore a part to its original condition, or, in instances where the original design has proved to cause premature failure, to rebuild or replace the part in a way that eliminates the weakness. Measurement, testing and quality control methods used during refurbishing are similar to those used in original manufacture. The one important exception is that inspection must be made on a 100% basis. When all parts must be presumed faulty until proved otherwise, sampling plans are inappropriate.

Good refurbished parts are put into a parts inventory awaiting assembly. Replacements for items that must be discarded (seals, washers, bearings, gaskets, pins, etc.) are ordered from suppliers or made by the remanufacturer, and these are also put into stock.

When the schedule calls for production of a quantity of a given product, the parts for that product are issued to the assembly floor, where subassemblies and final assemblies are completed and the units are tested to original product specifications. Small units being made in batch quantities (25 or more) are likely to be produced on an assembly line. Larger items, such as machine tools, stationary engines and the like, or smaller products produced one at a time will be assembled entirely at one station, where one or more assemblers will perform all the assembly steps. After assembly, each unit is tested and adjusted. There may be a final painting and labeling operation, followed by packaging and shipping. Shipping cartons are frequently designed to facilitate return of a core when the remanufactured unit is sold.

Throughout the remanufacturing process, quality control is an essential feature. Every person working on the product must be aware of and alert for faults that have occured in the parts that are being used. This requirement obligates management to train all employees in rudimentary inspection techniques, to provide appropriate measuring and inspection equipment and to motivate people to maintain high quality standards. The reputation of the remanufacturer and its ultimate success rests almost entirely upon the quality of the finished product.

1.3 Nature of Products Remanufactured

Although the range of products currently being remanufactured is broad, most share certain common characteristics. Obviously, there must be a core; the product cannot be consumed in its use. The product must be capable of being disassembled (remanufacturers become adept at disassembling even the most intractable units: welded joints, swaged fasteners, hermetic seals, corroded unions and so forth). Its parts must be capable of repair, refurbishing or economic replacement. The final characteristic, from a physical standpoint, is that the original function of the product and its level of performance can be restored by remanufacturing.

From an economic point of view, the core must have a sufficiently high value added (labor, energy, capital) embodied in it even at the end of its useful life. Another way of stating this is that the realizable worth of the core, as measured by the recoverable value still embodied in it, is much higher than its market value as a nonfunctioning product. For many products the market value may approach or even become negative (people are paid to remove the carcass), although there is a high value added still residing in the product.

Another essential characteristic of a remanufactured product is that it must have a market at the level of prices that must be charged. In large measure, this aspect has to do with the technological stability of the product. The fact that the remanufactured product may be as much as ten years older than current models cannot be a deterrent to purchasers. An electromechanical adding machine, for example, might satisfy all other physical and economic criteria for remanufacturing, but the electronic calculator has destroyed its market. The technology of a remanufacturable product will change only slightly over the years.

Products being remanufactured today in the United States can be divided into four general market categories:

- Automotive. The largest number of remanufacturers are concentrated in the replacement parts business for automobiles and trucks. Parts that are remanufactured vary in complexity from simple starter solenoids to complete diesel engines. The remanufacture of whole automobiles on a routine basis (as opposed to custom rebuilding) is a recent and promising innovation.

- Industrial equipment. This category includes such products as process valves, hydraulic equipment, heavy-duty diesel engines, production metalworking machinery, and oil rig drilling equipment. Products in this sector are frequently custom-made for a specific application and must be remanufactured on a one-by-one basis.

- o <u>Commercial products</u> that are commonly remanufactured include office machinery, refrigeration compressors, vending machines, and communications equipment. As with industrial equipment, complex or custom-made products tend to be remanufactured one-by-one.

- o <u>Residential products</u> remanufacturers are relatively rare. The combination of a large, highly disaggregated market for used products, a long product life, and high transportation costs coupled with consumer prejudice towards "rebuilts" limits the number of products in this sector. A small amount of remanufacturing of power tools, lawn mowers, and appliances is being done.

The largest remanufacturer in the United States is the Department of Defense. Weapons systems and military equipment ranging from rifles to radar to aircraft carriers are regularly remanufactured to keep the equipment in optimal operating condition and to incorporate new technology into older equipment.

Chapter 4 contains a description of a systematic ɹpprach to screening products for manufacturability. This was developed by the MIT study team to locate prime candidates for remanufacture in the United States.

1.4 <u>Relationship to Resource Use and Recovery</u>

No matter whether a product is destined for industrial, commercial or consumer use, the alternatives for the product after its first use are about the same. There is a kind of hierarchy of these alternatives in terms of the costs of maintaining or retrieving economic value in the product. Each stage represents a different level of cost to recover a given amount of financial value in the product after it has been used.

Figure 1 is a rather complete model prepared by Michael Bever[17] to describe materials flows in the production-consumption system. In this diagram, loop 3a is the remanufacturing loop, with recycling to recover basic materials indicated by loops 3 and 3'.

<u>Figure 1</u>:

The Materials Production-Consumption System

Source: Bever [17]

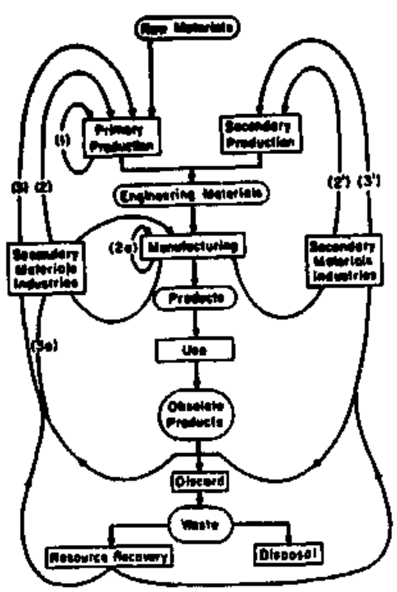

Figure 2 is a somewhat simpler diagram in which the five alternatives--repair, re-use, remanufacture, recycle, and disposal--are depicted. Each stage has its place in the rational utilization of economic value. Repair is the logical first recourse in the event of product malfunction or wear. At some point in use, however, one of several things may occur:

1. The capacity, functions or utility of the product no longer match user needs. Sale of the product and re-use by another party retains a high level of value at low additional cost.

2. It becomes no longer financially attractive to repair the product as an individual unit. Remanufacture may then be indicated.

3. The product is made obsolete by alternative technology or elimination of any need for the product functions. Recycling at least recovers material value.

4. The product is so worn out that it cannot be economically returned to use, and it must be recycled or discarded.

5. The product is lost from the system by corrosion, depletion, dissolution or disposal as landfill.

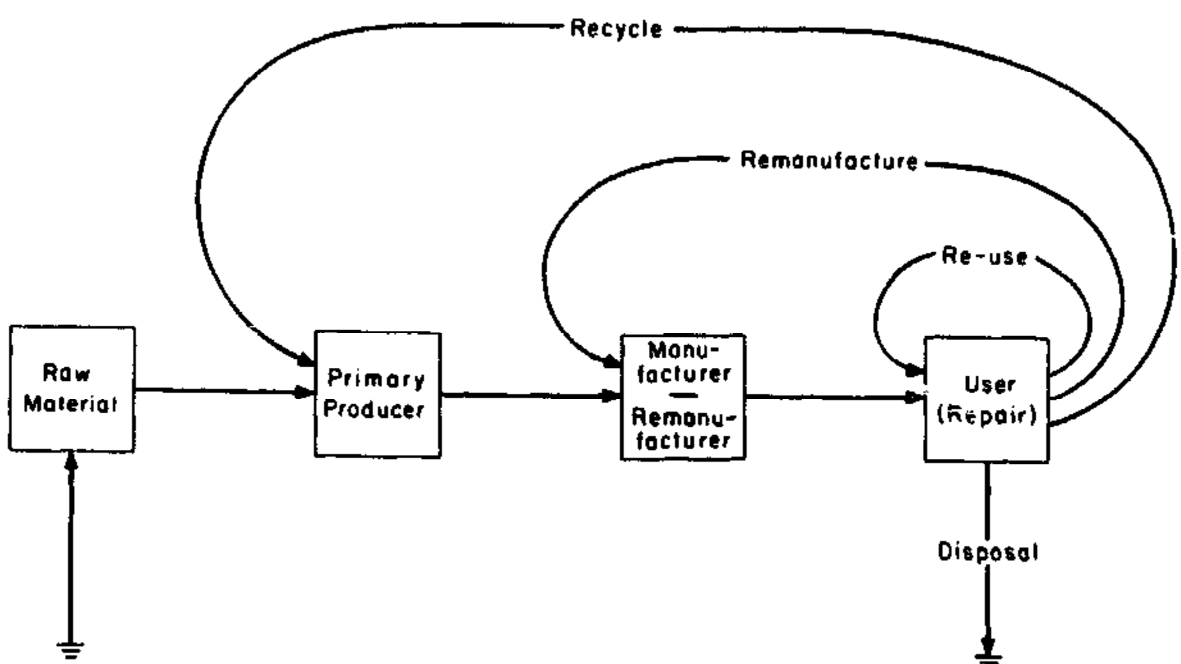

Figure 2: Materials Resource System

For some products there can be added variants in the cycles of use. A major unit, such as an automobile, may be cannibalized or dismantled to provide major components (alternators, clutches, starter motors, engines, etc.) for re-use or remanufacture. Another variant may be to find secondary or tertiary uses for all or part of the product (trailers made from auto chasses, for example). In this latter case, such products might legitimately be considered part of remanufacture, although we have not done so up to this point.

It is not uncommon for products to go through each of the stages of repair, re-use and remanufacture on their way to recycling. In some cases a product may pass through a given stage repeatedly before moving to the next lower stage. The larger remanufacturers of auto components frequently receive cores that have already been remanufactured by them at some earlier time.

The lower in the hierarchy the product sinks, the lower is the value that can be recovered per dollar of recovery effort. By the time the recycling stage is reached, the total input costs to accomplish recycling, which include collection, disaggregation, smelting and/or refining and primary shape formation (ingot, bar, billet, etc.) may actually exceed the value of the recovered material. The only reason that recycling is done at all in these cases is that it has the least net cost for collecting and disposing of the materials.

1.5 Summary of Benefits

Remanufacturing provides an impressive array of benefits for both industrialized and developing nations and for both society as a whole and for the entrepreneur. These benefits are described in detail in Chapter 6, and are summarized briefly here.

Societal and Economic Benefits

- Conservation of resources -- energy, materials, capital and labor
- Reduced costs of durable products mean higher standard of living and greater range of product choice
- Employment opportunities, particularly for low to moderately skilled workers
- Reduced solid wastes and waste processing costs

Benefits to the Remanufacturer

- Low barriers to entry in terms of capital requirements, labor skills and technical know-how
- Profitability
- Added benefits to the OEM remanufacturer: broader market appeal, control of brand reputation, and feedback on product failure modes for improvement of product design.

Benefits to Developing Countries

- o Development of an indigenous industrial base through training of a workforce, acquisition of capital goods, and direct technology transfer
- o Augmentation of foreign exchange by export of remanufactured goods
- o Development of a service and repair infrastructure to keep industrial and commercial equipment operating
- o Opportunity for bringing industrialization to rural areas

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2 REMANUFACTURING IN THE UNITED STATES

2.1 Types of Remanufacture

Remanufacturing enterprises can be classified in several ways: by type of organizational form or structure, by product type or by size. Just as we find a wide variety of products being remanufactured, we also find a variety of organizational forms and sizes.

A major distinction in organizational form is between the independent remanufacturer, whose sole business is the remanufacture of items produced by others, and the original equipment manufacturer (OEM), whose main business is the manufacture of new products and who remanufactures its own products as an added business. Although our statistics are incomplete it is likely that independent remanufacturers outnumber OEM remanufacturers by a wide margin. In terms of annual sales volume, however, the figures may be reversed, because many of the independents are quite small.

The typical independent remanufacturer is a private corporation with ownership closely held. It is an integrated operation, in that it purchases cores, remanufactures them and markets them under its own name or for private labels of others. In some cases, the independent may be operating under a franchise from a major OEM such as Ford or GM's Detroit Diesel/Allison Division, in which case technical assistance and parts are available from the OEM. In a 1980 report the Center for Policy Alternatives presented detailed case studies of two independent remanufacturers: Arrow Automotive Industries (automotive parts) and Rockware International Corporation (power plants). These two cases present several contrasts. Arrow is one of the leading automotive parts remanufacturing companies in the United States, with plants in several locations across the country and with more than a thousand employees. It is a publicly held corporation selling a broad line of automotive components in a national market through about 10,000 jobbers. Rockware International, on the other hand, is an operation run essentially by a single entrepreneur, William Ware, who purchases defunct industrial or municipal power plants, arranges to have them dismantled and the operating units (boilers, headers, tubes, burners, generators and ancillary equipment) reconditioned. He then proceeds to sell units to firms in this country and abroad (a number have been sold in Central and South America). Details of the operations of these two firms are found in <u>Energy Savings Through Remanufacturing: A Pre-Demonstration Study, Interim Progress Report.</u>[1] The description of Arrow Automotives operations is comprehensive and furnishes a particularly helpful perspective of the integrated independent remanufacturer.

Some independent remanufacturers operate solely under contract to others who supply the cores and retain ownership of them. Contract remanufacturers essentially perform a rebuilding or reconditioning service for their clients and they have the advantage of not having to purchase and maintain inventories of cores or finished goods. In some cases the remanufacturer has only a few large OEM's as clients and does all of the remanufacturing work for them. This kind of relationship has some advantages for both parties. For the remanufacturer there is likely to be a fairly consistent stream of business with fewer working capital requirements and risks, and the company can expect to obtain assistance from the OEM in terms of replacement parts, design and testing specifications, and even tooling. For the OEM the advantages lie in being able to provide remanufactured goods to its customers without having to set up an operation considerably at variance with new product manufacture, requiring different labor classifications, wage rates and skills. Our-Way, Inc., in Atlanta, Georgia, is an example of a contract remanufacturer. Its products are refrigeration compressors for industrial and commercial applications. Its clients are Carlyle Compressor Company, a division of Carrier Corporation; Copeland Corporation and Dunham-Bush, Inc. Before arranging a contract remanufacturing agreement with Our-Way and others, Carlyle handled its own remanufacture of its compressors but found it to be more cost effective to have others do the work. A detailed description of Our-Way operations and of the remanufactured refrigeration compressor market can also be found in the study mentioned above. A second contract remanufacturing operation related to industrial process valves is also described briefly in the same report.

Some independent remanufacturers operate in both the integrated and the contract mode. One machine tool remanufacturing firm specializes in installing numerical controls into conventional machine tools during rebuilding. It will remanufacture specific machines sent by customers to the firm and deliver them back to their owner. At the same time, however, it is in the market for used equipment that it can purchase and remanufacture for resale. This firm, formerly known as D and D Electronics, and now operating as U.S. Machine Tool Company, Hartford, Connecticut, provides an excellent example of the opportunities for upgrading the performance or features of a product through remanufacture. Because of its pertinence to possible remanufacturing operations in other countries, a more complete description of this company's operations is found in Appendix A, a section taken from the Interim Progress Report referred to above.

Original equipment manufacturers (OEM's) that go into remanufacturing as a part of their business do so for a variety of reasons, all of which boil down to one fact: it is good business. Not only is the OEM more likely to retain a loyal customer by offering a good trade-in value for the old unit, but it can also give the customer a wider price range on the replacement unit. In addition, the OEM learns first hand what goes wrong with its product during use. This information can be used to improve product designs of future models and to devise modifications that will prevent similar problems in remanufactured units. In other instances the OEM may merely act defensively, to discourage entry of independent remanufacturers of its products. These reasons are important to OEM remanufacturing operations, but a key factor in virtually every remanufacturing operation is that it is highly profitable. During the recent recession the head of the remanufacturing division of a major U.S. firm remarked that his division was the only part of the company that kept the firm from losing money.

Two examples of OEM remanufacturing operations can be found in the diesel engine field. Caterpillar Tractor Company has a sizeable remanufacaturing plant at Bettendorf, Iowa. Diesel ReCon, a division of Cummins Engine Company has its headquarters in Memphis, Tennessee, but has plants in Chicago and Los Angeles. In both firms the engines that are remanufactured come through their dealer/distributor networks as trade-ins. To some extent both firms compete with local dealers or service people who will attempt to repair or rebuild diesel engines on a one-at-a-time basis. Diesel ReCon cites several reasons why they can compete effectively with the small local rebuilder:

- They have higher worker productivity because of their factory methods
- They use facilities, specialized equipment, and energy more effectively
- The quantities they produce are large enough to justify machines requiring less skilled workers
- They salvage more materials, thereby greatly reducing their new materials or new parts costs.

A description of Disel ReCon's activities is provided in the Interim Progress Report.

Another form of OEM remanufacturing operation occurs in the electronic equipment industry. A company may remanufacture replacement circuit board modules or other components returned as a result of warranty or service repairs to their products. One television manufacturer has set up a line to remanufacture defective circuit boards returned to the field. By doing this they are able to offer replacement units to the serviceman (and customer) at considerably lower prices, reduce their warranty claims costs, and monitor both the performance of their equipment and of the people that service it.

Some OEM's, such as AT&T and IBM, lease a large share of their products to their customers. If something goes wrong with the equipment or if the customer returns the equipment for some other reason, there is a need to put the equipment back into first-class condition for use by the next customer. Western Electric, AT&T's manufacturing arm, has operated a very extensive remanufacturing and salvaging operation for many years. Annual volume is in the order of several hundred million dollars. Both telephone handsets and switching equipment are remanufactured in 31 different plants having a total of 3,000,000 sq. ft. of floor space and employing 12,000 people. At a national remanufacturing conference at MIT in 1981, Robert Egan of Western Electric stated that 70% of all handsets then in use in the United States had been remanufactured.[2] During remanufacture the equipment is upgraded, such as converting a rotary dial to a touch-tone or changing incandescent lamps to light-emitting diodes.

At IBM, as at Western Electric, the prospect of having to remanufacture a unit sometime in its lifetime becomes an important consideration during initial product design. By designing for easy access to modules and to easy disassembly of its equipment, both companies reduce the turn-around costs during remanufacture and usually reduce field servicing costs as well.

While we are on the subject of organizational structure of the industry it may be useful to include mention of the supporting enterprises in the remanufacturing system. We have already mentioned distributor/dealer networks though which the products are marketed and thrugh which cores are returned to the producer. On the supply side, however, there are other actors as well. In some sectors there are professional dismantlers who will take apart major structures to salvage re-usable items. This is a substantial business in the automotive sector, for example, where 18,000 firms are engaged in scrapping cars, trucks, buses, motorcycles and farm and construction equipment. It is a $6-8 billion industry that processes 8 million vehicles per year.[3] It has an industry association, Automotive Dismantlers and Recyclers of America (ADRA), that represents about 1/3 of the firms in the industry. About 73% of automotive dismantlers' sales are in the form of used parts. About 4% of sales are to "core brokers," people who collect specific types of used parts for resale to remanufacturers. The combination of dismantlers and core brokers serve to make up for the loss of cores in the normal circuit between remanufacturer, dealer and customer. In the automotive area a large remanufacturer will typically acquire about 30% of its cores through dismantlers and core brokers.

New replacement parts suppliers are another part of the remanufacturing infrastructure. For the most part, these suppliers are the same firms that supply standard bearings, seals, gaskets, assembly hardware, paint, etc. to the OEM's. For parts that are peculiar to a given design and that may be fabricated by the OEM, the remanufacturer has three options. It may attempt to buy parts from the OEM; in many instances the OEM or its dealers will be cooperative, but the parts prices are likely to be high. In other cases the OEM will view the remanufacturer of its products as a competitor and will refuse to furnish parts. The remanufacturer then can either attempt to make the replacement parts itself or try to locate a replacement parts manufacturer who is either currently making the part or who is willing to produce it. In the automotive area, replacement parts manufacturers exist both in this country and abroad. When replacement parts for a given unit are either unobtainable or too costly, that unit will not be rebuilt. Any useable parts obtained from the core are kept for use on other units and the non-useable parts are sold as scrap. A small, but persistent fraction of a remanufacturer's sales income is from the sale of scrap materials that are the segregated discards from the disassembly process.

In addition to parts suppliers there are a few firms that specialize in supplying equipment used by remanufacturers. This includes special machines used in disassembly, in cleaning and refurbishing and in inspection and testing. Most of these firms are found in the automotive sector, where they serve dismantling and repair service businesses as well as remanufacturers.

2.2 Remanufacturers by Product Sector

In addition to identifying each firm with the U.S. Standard Industrial Classification (SIC) code number for the product(s) it produces, it is convenient to aggregate remanufacturers into four general product groupings. As was mentioned in Chapter 1, these four market segments are:

1. Automotive-- including automobiles, trucks, buses, motorcycles and parts.
2. Industrial-- all forms of machinery or equipment used in manufacturing or construction.
3. Commercial-- equipment used in trade or service businesses.
4. Residential-- durable products other than automobiles used by consumers.

These groupings were used in classifying data obtained in a United States national survey described in the section that follows.

2.3 Survey Findings

In 1979 the Center for Policy Alternatives conducted a survey of all remanufacturers known to the research group at that time. A total of 358 questionnaires were sent out and 156 were returned. Of those returned, 143 had useable information. Where time was a factor, respondents were asked to supply the information as of the end of 1978. A copy of the survey document, with the replies to each question tabulated, is appended to this report as Appendix B. Several of the more salient points in the analysis of the data, which was reported in Remanufacturing Survey Findings,[4] are presented in the following paragraphs.

The data base of the survey included firms from all four product sectors, and from both independent and OEM remanufacturers (see Table 2-1). Because there are no national statistics on the number of remanufacturers extant in the United States, we were unable to state what fraction of remanufacturers our sample represented, or whether the sample was a truly representative sample. Because our knowledge of the existance of 358 remanufacturers came through a networking approach, it is likely that the larger, better known and more active firms are represented in the sample than would have been true of a perfectly random selection from the total population. For that reason, it is not appropriate to use these data to characterize the entire industry. With respect to practices and policies followed by remanufacturers, however, we consider the data meaningful and useful.

2.3.1 Skill Levels

Among the remanufacturers surveyed, about 40% of the labor force was skilled or salaried, with the remainder being semi- or unskilled. More precisely, 21% of remanufacturing personnel were unskilled, 39% semiskilled, 28% skilled, and 12% salaried. These ratios differed with product market and by regions. The automotive rebuilders employed the largest percentage of unskilled workers (32%), while remanufacturers in the industrial and commercial markets had a much higher percentage of skilled workers. Table 2-2 shows the percentage of workers at each skill level by product market.

Table 2-1 Types of Firms Responding to Remanufacturing Survey

	Automotive	Industrial	Commercial	Residential
Independent	54 (89%)	26 (57%)	18 (60%)	4 (67%)
Remanufacturer Unit of OEM	7 (11%)	18 (39%)	9 (30%)	2 (33%)
Other (primarily authorized)	0	2 (4%)	3 (10%)	0
Totals	61 (43%)	46 (32%)	30 (21%)	6 (4%)
GRAND TOTAL	143			

TABLE 2-2
LABOR SKILL LEVEL BY MARKETS (%)

Product Market	Unskilled	Semiskilled	Skilled	Salaried	Count
Automotive	33	37	20	9	56
Industrial	12	43	35	11	46
Commercial	15	36	32	18	30

Note: Percentages in this and following tables may not total to one hundred percent (100%) due to rounding error and/or due to missing data.

2.3.2 Wages

Table 2-3 presents the mean wage rate for firms grouped by product market.

TABLE 2-3
WAGE BY PRIMARY PRODUCT MARKET
(US$/hr)

Primary Market	Wage: Unadjusted	Wage: Adjusted for Skill level	Count
Automotive	5.56	5.68	54
Industrial	6.71	6.61	44
Commercial	6.37	6.29	28

The significance of the market groups is high (p - .01) with or without skill level considered, but skill level does explain a considerable portion of the raw differences in wage levels. Thus firms primarily remanufacturing automotive parts pay a lower mean wage partly because they employ a larger proportion of unskilled workers and partly because they pay lower wages to workers at each "skill level."[5] (See question 29 of the survey.)

Wages paid by independent remanufacturers were also compared with wages paid by remanufacturing units of original equipment manufacturers (OEMs). These wage rates were virtually identical, being $5.98 for independents and $6.01 for the OEMs. When wage rates were adjusted for regional differentials,[6] the difference between OEM and independent wage rates was slightly larger, but still far from significant.

Finally, wages in remanufacturing were also compared with wages in new manufacture. Table 2-4 shows the mean wage computed for each 3 digit SIC group and a comparable figure for new manufacture. The new manufacturing wage is adjusted from the 1976 wage rate.[7]

From these data it is clear that the mean wage for remanufacturers is lower than it is for manufacturers of new products. This is particularly evident in the automotive sector (SIC 371). Differentials among other industry groups tend to be substantially less.

TABLE 2-4
WAGES IN REMANUFACTURING AND NEW MANUFACTURE BY SIC GROUP

SIC Code	Product	Remanufacturing Survey (1978)	New Manufacture (1976 adjusted to 1978 equiv.)	New Manufacture (1976)*	Count
349	Fabricated Metal Products	6.49	6.33	5.42	3
351	Engines and Turbines	6.76	8.19	7.02	24
352	Farm Machinery	3.00	7.40	6.34	1
353	Construction Machinery	6.62	7.63	6.54	2
354	Metalworking Machinery	7.15	7.25	6.22	5
355	Industrial Machinery, Special	7.32	6.50	5.57	2
356	Industrial Machinery, General	6.80	7.10	6.08	5
357	Office, Computing Machinery	6.00	5.89	5.05	1
358	Refrigeration Machinery	6.31	6.65	5.70	20
361	Elect. Dist. Equipment	5.45	6.28	5.38	5
362	Industrial Elect. Equipment	6.95	6.19	5.30	2
363	Household Appliances	3.90	5.95	5.10	2
365	Radios & Television Sets	6.50	5.64	4.83	1
367	Electronic Parts	5.21	5.23	4.48	4
369	Misc. Electric	5.06	6.59	5.65	7
371	Motor Vehicles & Parts	5.66	8.87	7.60	48
372	Aircraft & Parts	5.50	8.12	6.96	1
					133
MEANS:		6.04	7.70	6.60	

* Annual Survey of Manufactures, 1976, U.S. Department of Commerce

2.3.3 Labor Cost and Productivity

Labor cost per unit sales dollar in remanufacturing is more than double that for new product manufacturers. These ratios vary by product market. The survey indicated that labor costs constituted 24% of the sales dollar in the automotive market, 29% in the commercial market, and 35% in the industrial market. For the small group of remanufacturers engaged in remanufacturing consumer goods for the residential market (e.g. lawn mowers, washing machines), labor cost constituted a very high 55% of total sales revenue. Table 2-5 presents these results.

TABLE 2-5
MEASURES OF LABOR PRODUCTIVITY BY PRODUCT MARKET

Product Market	Average Firm Labor Cost per Sales Dollar	Total Average Labor Cost per Output Unit	Average Firm Sales Dollar Per Worker	Total Average Output Units Per Worker	Count
Automotive	.24	2.62	59,717	4,453	57
Industrial	.35	13.30	68,981	1,048	42
Commercial	.29	151.4	55,258	88	22
Residential	.55	3.87	30,866	2,457	5
Mean	.30	3.52	60,881	3,585	126

Most firms generate about $60,000 in sales for each worker. This figure is shared among the market segments, except for the five firms in the "residential" market. The fact that the five "residential" consumer good firms reported an average per worker sales figure of half this amount may help explain the relatively small number of remanufacturers in that market. $60,000 sales revenue per worker is a remarkably high figure, even when compared with figures for automotive manufacturers having relatively high capital equipment investments.

2.3.4 Core Supply

Remanufacturers draw on several sources in their attempts to acquire a sufficient number of cores. Table 2-6 shows the average fraction of total core supply from each source broken down by market segment.

The automotive market relies heavily on nonwarranty service exchanges (37.2%) as a source of cores, followed by core brokers (23.2%) and products returned by owner for rebuild (21.9%). There is some indication that respondents may have been confused about the meaning of each category. The category "returned by owner for rebuild" was intended to mean that the owner maintains title of the product throughout the remanufacturing process. However, in the automotive market survey results show that while an average of 22% of cores are returned by owner

TABLE 2-6
SOURCES OF CORES BY MARKET SEGMENT (%)

SOURCE OF CORES	AUTOMOTIVE	INDUSTRIAL	COMMERCIAL
Warranty Returns	5	5	6
Core Brokers	23	8	8
Nonwarranty Service Exchange	37	17	23
Lessor/Renter	4	1	5
Returned by Owner for Rebuild	22	56	47
Salvage Operators	9	11	11
COUNT	61	43	29

for rebuild, only an average of 4% of users retained ownership during the process. Given the typical operating method in the automotive market, the 18% difference probably should be assigned either to nonwarranty service exchanges or warranty returns instead of the "returned by owner for rebuild" category.

In contrast, the industrial and commercial markets rely primarily on users to return products for rebuilding. User returns account for approximately half of the core inflow, which is an indication of differences between the industrial and commercial markets and the automotive market. For example, industrial and commercial markets often establish direct user-remanufacturer relationships, in contrast to the automotive market, where dealer and distributor networks provide very little contact between the ultimate user and the remanufacturer. Products manufactured in the industrial and commercial markets are more likely to be customized to user specifications. Such products tend to be larger and more costly, and the customer wants a product that meets certain specifications. Nonwarranty service exchanges constitute the other major source of cores for industrial and commercial products.

Core scarcity is a problem for both independent and OEM remanufacturers. Given a list of eight factors, independent and OEM remanufacturers ranked core scarcity as the major limiting effect on growth. Table 2-7 shows the rank each factor received, where the lowest numbers indicate the factors which are most troublesome to respondents.

2.3.5 Materials Costs

The Remanufacturing Survey asked respondents what fraction of total materials costs is invested in used parts and what fraction is invested in new parts and materials. As indicated in Table 2-8, respondents indicated that the materials costs are divided almost equally.

TABLE 2-7
FACTORS WHICH LIMIT GROWTH BY ORGANIZATIONAL FORM

FACTORS	INDEPENDENT RANKING	OEM RANKING
Scarcity of quality cores at an acceptable price	1	1
Labor cost	2	4 (tie)
Unavailability of sufficiently skilled workers	3	6
Cost of new capital equipment	4	4
Competition from other remanufacturers	5	2
Plant production capacity	6	3
Federal and state regulations	7	7
Competition from new products	8	5

TABLE 2-8
MATERIALS COST BREAKDOWN BY MARKET SEGMENT

	TYPE OF MATERIAL	
MARKET SEGMENT	USED PARTS	NEW PARTS AND MATERIALS
Automotive	47%	52%
Industrial	50	50
Commercial	54	46

2.3.6 Product Ownership

When a used product comes to a firm to be remanufactured, it is not necessarily owned by the firm as it would be in a manufacturing operation. Results of the Remanufacturing Survey indicate that remanufacturers sometimes have other ownership arrangements. The respondents were asked if the used product is owned by themselves, the user of the product, the original equipment manufacturer (OEM) or by some other entity. The answers to this question were analyzed by market served (automotive, industrial or commercial) and by firm ownership (independent remanufacturer or OEM/remanufacturer). Table 2-9 below shows the response to this question by market segment where the numbers represent the mean percentage of products in each class of ownership.

TABLE 2-9

PRODUCT OWNERSHIP BY MARKET SEGMENT

Market Segment	Class of Ownership (percent of market segment) Remanufacturer	User of Product	OEM	Other	Count
Automotive	94	4	2	0	54
Industrial	64	25	6	5	45
Commercial	51	39	6.	4	28

Differences in product ownership are predominantly a market segment phenomenon. There was relatively little difference in ownership of cores reported by OEM's as opposed to independent firms.

2.3.7 Product Design

The design maturity of a product is an important factor in the remanufacturability of a particular product. The firms in this survey show a definite tendency to stay away from those products which are undergoing rapid changes in design or materials of construction. Rather, products being remanufactured are described as having a moderate to slow rate of product change from year to year. Because remanufacturers rely heavily on a steady supply of used products, it is important that discarded products can be fed into the core loop for a number of years and do not become obsolete in a short time.

Although only a small percentage of cores are returned with a request for technological updating, the majority of firms do make some kind of change in the product. Only 26 of the 134 firms who responded to a question on reasons for design modification said they did not make any design changes.

The top five reasons given by respondents for making design changes in the automotive market are:

(1) Correct design weakness to yield longer product life
(2) Consolidate models
(3) Improve operating efficiency
(4) Make the product easier to remanufacture
(5) Update to current technology.

2.3.8 Reasons for Market Entry

Although an appreciable number of remanufacturing firms have developed out of service and repair operations, the largest percentage, we found, entered remanufacturing directly as a main area of business (Table 2-10).

TABLE 2-10

REASON FOR ENTERING INTO REMANUFACTURING FOR VARIOUS GROUPS OF FIRMS

Type of Firm	Directly As Main Area of Business	Indirectly, As Original Equip. Manufacturers	Indirectly As a Repair Service	Indirectly, Other	Count
Independent	61%	3%	28%	8%	100
OEM	39%	25%	31%	6%	36
Product Market					
Automotive	62%	5%	23%	10%	60
Industrial	40%	13%	42%	4%	45
Commercial	59%	7%	28%	7%	29
Residential	67%	33%	0	0	6
Sales Category					
Under $1 Million	68%	11%	22%	0	37
$1 Million to $10 Million	54%	6%	34%	6%	65
Over $10 Million	52%	9%	22%	17%	23

Responses by product market do not reveal any marked differences in reason for entry with the possible exception of the industrial market. In this market the largest single mode of entry was as a repair service (42%). Indeed, because of the degree of one by one rebuilding and the extent to which the customer retains ownership in this market, industrial remanufacturing is still similar to repairing.

2.3.9 Competition

Remanufacturers face potential competition from new products, used products and remanufactured products. Respondents were asked to rank the importance of each source of competition.

Overall, remanufacturers believed other remanufactured products to be the most important source of competition. New products were second in importance, while used products were least important. This order of pressure from competitive products was the same for independent remanufacturers and OEM's and for all three major product markets (automotive, industrial and commercial). Only in the residential market (where little competitive remanufacturing exists) was the order different: new products being the most important source of competition followed by remanufactured and used products.

Respondents were asked to assess how important various factors are to potential purchasers of their products. Table 2.11 shows the ranking of these factors, from most important to least.

TABLE 2-11

IMPORTANCE OF PRODUCT FACTORS TO POTENTIAL PURCHASERS BY MARKET

	RANK BY MARKET		
FACTOR	AUTOMOTIVE	INDUSTRIAL	COMMERCIAL
Availability	1	1	1
Performance	2	2	2
Service	3	3	3
Price	4	4	3
Appearance	5	6	5
Warranty Terms	6	5	4
Other Factors	7	7	7

There is uniformity in the importance of these factors across markets. Several of the factors more important to customers than price seem to relate primarily to minimizing costs due to delay. Availability and service are closely related. Both are important in minimizing the delay (or "downtime") associated with a non-functioning unit.

2.3.10 Prices

Respondents were asked to assess the prices of their remanufactured product(s) as a fraction of the price of a similar new product. Table 2-12 lists this fraction by market.

The differences by market in the relative price of remanufactured products are significant. The higher value for the commercial market (in large part consisting of air conditioning compressors) may indicate lower competitive pressures among the products in the commercial market, or it may represent a real difference in costs of cores and remanufacturing operations in this market.

TABLE 2-12

PRICE OF REMANUFACTURED PRODUCT AS A FRACTION OF NEW PRODUCT PRICE

MARKET	PRICE (% of New)	COUNT
Automotive	57%	59
Industrial	51%	45
Commercial	67%	28
Overall Mean	57%	132

2.3.11 Distribution Channels

There are significant differences in distributor channels employed by remanufacturers depending on the product grouping they are in (Table 2.13).

TABLE 2-13

FRACTION OF SALES DISTRIBUTED THROUGH VARIOUS CHANNELS BY MARKET GROUP

DISTRIBUTION CHANNEL	AUTOMOTIVE	INDUSTRIAL	COMMERCIAL	RESIDENTIAL
Direct Sales to User	10%	41%	52%	34%
Distributor Network	85%	39%	25%	65%
To New Lessor/Renter	0%	0%	2%	0%
Other Channel	5%	19%	17%	1%

"Other" distribution channels seem to account for a sizeable fraction of the sales, especially in the industrial and commercial markets. These other channels include sales through the parent company or direct to the original equipment manufacturers, and through service contractors or service organizations.

2.3.12 Sales Levels

The average annual sales revenue per firm differs by market segment. In all categories the average sales figure indicates that the typical firm is the small-to-medium size range (Table 2.14).

TABLE 2-14

SALES REVENUE BY MARKET SEGMENT [3]

MARKET	AVERAGE SALES*	TOTAL SALES*	COUNT
AUTOMOTIVE	$10,060.	$573,410.	57
INDUSTRIAL	$4,790.	$200,369.	43
COMMERCIAL	$3,550.	$78,092.	22
RESIDENTIAL	$3,290.	$16,451.	5

* Thousands of dollars.

Sales volume was found to be positively correlated with the length of time the firm had been engaged in remanufacturing, and with the fraction of its output processed on a production line or in large batches.

Exports accounted for less than 5% of sales in all four market categories. The principal export difficulties listed by respondents were core return problems, lack of a distribution system, and lack of foreign trade experience.

2.3.13 Warranties

The warranty is a specific part of the purchase agreement that guarantees the user service at no cost if all conditions of the warranty are met. Respondents were asked to compare their warranty terms with those of a comparable new product (Table 2.15).

TABLE 2-15
WARRANTY TERMS BY MARKET SEGMENT

COMPARISON OF WARRANTY TERMS RELATIVE TO NEW	MARKET SEGMENT		
	Automotive (n = 61)	Industrial (n = 46)	Commercial (n = 30)
More liberal	24	6	5
The same	27	32	19
Less liberal	7	8	4
Missing cases	3	0	2

For the most part, respondents described their warranty terms as being either "the same" or "more liberal" than the warranty terms of a comparable new product. Less than 20% of the firms in all market segments described their warranty terms as being less liberal than those of a comparable new product.

2.3.14 Key Success Variables

The Remanufacturing Survey report concluded with a summary of six factors evidently critical to the success of an American remanufacturing enterprise:

1. Product design stability. The maturity of the product -- the length of time the product has been in the market without substantial design change -- and the future vulnerability of the product to mandated or voluntary design change.

2. Collection and distribution loop. The source, quantity, quality, and means of collection of cores is a primary limitation to the size of the operation. The compatibility of materials sources with the distribution system for the remanufactured product will affect the overall efficiency of the operation.

3. Relations with OEM's. Not a serious problem if the OEM is the remanufacturer, but important to the independent. Part specifications, product performance specifications, parts sourcing, and information regarding design changes are all needed from the OEM.

4. Competition. Other remanufacturers operating in the same product market constitute the major competition.

5. Marketing strategy. Product availability, performance, service and price are the primary marketing considerations. Price to the customer will be in the range of 50% to 70% of a comparable new product. Warranties must be competitive with new product warranties.

6. Mode of entry. The relatively low capital investment entry fee to remanufacturing makes direct entry feasible, but prior experience in servicing and repair is a useful starting point.

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5. It is important to note that these skill level ratings are subjective and may vary from firm to firm or industry to industry. The difference in unadjusted wage rates between automotive and industrial markets is significant at the 95% level of confidence (p - .05), while the significance of the difference between commercial market wages and the other two is lower.

6. From published BLS data.

7. An adjustment factor of .167 was used which represents the increase in average manufacturing wages in current dollars between 1976 and 1978. The mean in each column is weighted for number of firms.

3 ECONOMICS OF REMANUFACTURING

A major consideration in the MIT studies of remanufacturing has been the economic impact of this form of industrial activity on the resources (energy, materials, labor and capital) of the country. Remanufacturing was viewed as having the potential for substantial conservation effects, but there were no data on the subject. There was no National Association of Remanufacturers (we subsequently suggested the need for such an organization), nor were there any nationally collected statistics on this activity. The economic analysis was a ground-breaking exercise from the start.

We have been able to establish that remanufacturing is, indeed, a socially desirable function from the standpoint of resource conservation. Using data collected from case studies, the national survey, and a variety of federal statistics we were able to establish several findings relative to resource effects, all highly favorable to the industry.

The basic function of the remanufacturer is in recapturing original value added (labor, energy, capital equipment contributions) to the materials in the core. This is done at a small additional input relative to the original value added. Unless this value added is reclaimed by remanufacturing it is of relatively little worth to either its owner or to anyone else. If the product cannot be reused or remanufactured in whole or in part, only the basic materials content (the value of which may typically be in the order of a few percent of the price of the product) provides some residual worth. The gap between what an owner is willing to accept for a defunct durable good and the recoverable embodied value added is the area of opportunity for the remanufacturing entrepreneur.

3.1 Energy

The potential for energy savings was of great interest to the study, because the energy crisis had raised the national consciousness on this issue, and our sponsor, the Department of Energy, was interested in an assessment of remanufacturing's possible contribution. We found that while the figures for energy use per unit of output were at about 60% of that required by new product manufacturers, the real savings in energy came from recovery of the energy embodied in the materials and purchased parts assembled by the new product manufacturer.

Energy is used in every stage of manufacture, from ore smelting and refining through primary and secondary process steps to assembly and test. When the total energy used in producing a product the first time is added up and this figure is compared to the energy required to remanufacture the product, the ratios are in the order of 4:1 or 5:1.[1] What this means is that remanufacturing is able to recapture the benefits of the energy already expended at only a small fraction of that original energy expenditure. For every kilowatt-hour of energy spent in remanufacturing, between 4 and 5 kilowatt-hours are recovered. This is almost tantamount to producing energy.

Appendix C at the end of this report is a reproduction of the section of the report Remanufacturing Survey Findings, in which the development of energy leverage ratios is explained.

One other issue concerning energy must be faced, however. In many cases the products being remanufactured are, themselves, consumers of energy. Diesel engines, automobiles, refrigerators, electric motors, and locomotives are all remanufactured and all consume energy. If, by extending the life of an older machine, we keep in operation a less energy-efficient unit than is now available in the market, are we not actually causing energy waste? It is possible, but as was examined in a recent masters thesis,[2] the question of market acceptance of such remanufactured products will tend to decide whether the product will, in fact, be remanufactured under these circumstances. Market acceptance will tend to be a financial decision. As long as the price of energy to the user is a fair representation of its real economic price, the decision to buy a remanufactured unit can be made in a straightforward manner.

We prefer to think of such issues in terms of the present value of the total life cycle costs of a product. Total life cycle costs include acquisition costs, operating costs, repair and maintenance and salvage or disposal costs.[3] The future stream of expenditures for operation, service and salvage or disposal is reduced to a present value by discounting each year's outlay, and the sum of these discounted values is added to the acquisition cost to arrive at a total life cycle cost for the product. This approach can be used for both the manufactured and the remanufactured product. For the remanufactured product, the lowered acquisition cost may be offset by higher expected operating costs. If these latter costs are sufficiently high, they may serve to discourage purchasers from buying the remanfactured unit.

It is possible, under certain circumstances, that a unit will be bought on economically justifiable grounds, and still waste more energy than is saved by remanufacture. This could be true where the rate of energy consumption is low. If a unit is grossly inefficient and its consumption of energy is high (as in a continuously running stationary engine), it is quite unlikely that it will be a good candidate for remanufacture. If the price of energy is kept artificially low by regulation or subsidy, this would distort the financial costs and could lead to energy waste.

3.2 Materials

The statistics on materials losses from cores that are remanufactured indicate that a leverage in materials recovery exists that is similar to that in energy, but its magnitude is considerably greater. Core losses include about 10% by weight discarded before release to manufacture and a further equivalent of about 12-15% of core weight issued to manufacture that is lost during processing. This latter figure means that a remanufactured product will have about 85-88% by weight of used components, and the two loss figures combined suggest a core yield of about 80% by weight of usable parts. The 85-88% figure means that for every pound of new materials employed in remanufacture, between 5 and 7 pounds of old material is recovered and used. For the more efficient remanufacturers this ratio may be as high as 8 or 9:1.

Both the energy and the materials conservation figures should be important to countries lacking in domestic resources. For such countries, importing low-cost cores for remanufacture may be considered an inexpensive means of importing energy and materials, in addition to importing the technological know-how.

3.3 Labor

Remanufacturing is labor intensive. Its processes depend on significant human input at each stage. A large fraction (in the order of 60% according to our survey) of the labor force is unskilled or semi-skilled. Some technicians, machinists and mechanics are needed in refurbishing, testing and inspection of some products, but many of these higher skill levels can be acquired on-the-job.

The lower level skills are also those that can be job-acquired and do not entail special education. Disassembly skills are somewhat different from assembly skills, and disassemblers must also learn how to identify model numbers of cores and to classify their component parts. Cleaning, refurbishing, assembly and materials handling pose no unusual skills requirements, except that all personnel regardless of job classification or title must posess a high level of quality consciousness. When each product starts out with materials that are known to be defective in some manner not yet discovered, the only way to ship products that are guaranteed to function properly is to train each member of the workforce in quality vigilance.

For most remanufactured products the location of a remanufacturing operation is not a critical matter, as long as a workforce can be recruited in the vicinity and the sources of cores are not too remote. In many respects this is a highly "portable" industry, one that could be set up in more rural areas, counteracting urbanization pressures.

From a labor resource point of view, remanufacturing is highly suited as an introductory industrial activity in a country whose labor force has had limited industrial experience. It provides initial training in industrial skills and practices and an introduction to both product and process technologies. It can become the starting point from which other industrial activities can draw trained workers and managers.

3.4 Capital

In the survey of remanufacturers we obtained crude ratios of assets to annual sales that ranged from about $.12 to $.36 per dollar of sales. This contrasts with a figure of about $.30 for new product manufacture. We infer from these figures and from other more direct observations that the capital requirements of remanufacturing firms are relatively modest. There are two reasons for this. The equipment needed to make component parts--metal cutting machine tools, presses, molding machines, forges, and the like--tend to be expensive. They are generally not needed in remanufacture, because the parts have already been formed. Except for a few machines for cleaning, refurbishing and testing, the predominant equipment consists of hand tools, jigs and fixtures. Working capital needs are likewise modest, because the major raw material is an inexpensive core, whose cost is substantially lower than its economic worth.

3.5 Operating Costs

We did not attempt to obtain information on operating costs in our national survey, so we have limited information. What we have tends to be quite similar to operating data from conventional manufacturers who have a high labor content in their goods. In the case study of Arrow Automotive Industries,[4] the Hudson Division's figures for costs of sales as a fraction of total costs were as follows:

Labor	29%
Materials	54
Depreciation	1
Overhead	16
Total Cost of Sales	100%

At the time of the study the division was producing automotive and truck alternators, starter motors, water pumps and clutches. Data from annual reports of another major automobile parts remanufacturer, Champion Parts Rebuilders, Inc. of Chicago, show a similar breakdown:[5]

Factory Costs	82.4%
Overhead	17.6
Total Cost of Sales	100.0%

A small remanufacturer of auto parts (33 employees and annual sales of $760,000) had operating cost ratios that showed higher overhead costs as a fraction of total cost of sales:[6]

Labor (including supervision)	35.8%
Materials	41.3
Overhead	29.9
Cost of Sales	100.0%

The calculated cost ratios for estimates used in the study of the feasibility of remanufacturing chain saws[7] varied significantly with the size of the operation:

	Small Scale (2500 saws/yr)	Large Scale (25,000 saws/yr)
Labor	12.3%	6.1%
Materials	42.5	70.0
Overhead	45.2	23.9
Cost of Sales	100.0%	100.0%

In all studies we have made thus far, there are clear indications of economies of scale, particularly in labor productivity and in the distribution of fixed and semi-variable overhead.

3.6 Chain Saw Case Study

On the basis of the screening procedure developed for the selection of product candidates for remanufacturing,[8] we selected chain saws as a product area having high potential for remanufacturing but not yet being remanufactured in any appreciable volume in the United States. During

1981 and 1982 we conducted an engineering feasibility study for the remanufacture of chain saws. The study included an overview of the chain saw industry and appraisals of the market, dealer structure, pricing, product and process technology, core and replacement parts supply, financial and economic aspects and legal considerations for chain saw remanufacture.

Our conclusion was that chain saws could be remanufactured profitably, particularly if the operation concentrated on saws at the high end of the line (professional and commercial saws) and if the volume of saws produced could be in excess of 2000 - 2500 units per year. At 25,000 units per year the operation was seen to be highly profitable. This level of operation still is less than two percent of the average annual sales of chain saws in the United States.

In addition to developing detail process flow charts and parts requirements lists for selected saws, the study also constructed pro forma income statemenets and cash flow analyses to indicate the levels of capitalization required and the time required to recover the investment.

The chain saw study served as the basis for the preparation of two recently issued "guidelines" reports for individuals or firms considering the possibility of launching a remanufacturing operation. One of the manuals is for the establishment of independent remanufacturing ventures;[9] the companion volume is for OEM's wishing to remanufacture their own products.[10]

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4 WHAT CONSTITUTES A FAVORABLE REMANUFACTURING ENVIRONMENT?

It is evident that there are a set of conditions for remanufacturers in the United States that are favorable to the establishment and continuing success of their venture. In the absence of these conditions an enterprise faces a difficult struggle. It is possible that the key success factors in the United States may not be the same for all other countries. Official attitude, as expressed by regulations, laws, ethical codes or behavior patterns, may be so opposed to re-use of certain products, for example, that all other factors have little influence. Because of national differences of this kind it is essential that the climate for remanufacturing in any country be assessed directly.

This chapter summarizes our observations on what are the critically important success variables for remanufacturing in the United States, and their possible application to remanufacturing in other countries. In addition, a methodology is presented for screening product candidates for the selection of those likely to be most successful. This screen can also be adapted for use in other countries.

4.1 Factors Favoring Remanufacturing

As was pointed out in Chapter 1, the nature of the product has a major influence with respect to both physical feasibility and economic value. From a physical standpoint the product must have a reasonably long useful life and its functions should be based on a stable or slowly evolving technology. It should be capable of being disassembled without excessive damage to the unit, and its normal failure modes should be repairable. Failure should leave a large fraction of the product in re-usable condition though refurbishment and only a relatively few parts should require replacement.

The economics of the product require that the original product cost have a large value added component (labor, energy, capital equipment costs) as compared to the material costs. The price of the remanufactured product should be sheltered by well-established prices for comparable new products. Finally, the scale of remanufacture should be large enough to be competitively superior to repair or one-at-a-time rebuilding alternatives.

The type and size of the market is a second major factor. One feature of the receptive market is that the buyers in it are knowledgeable; they know how or they have the means to evaluate remanufactured goods in comparison with new products. The price advantage afforded by remanufacturing is a valid inducement to buy only if the buyer knows his risks are no greater in buying the remanufactured unit than they would be for a newly made unit. Typically, buyers of this kind can be found in industrial and commercial markets, and we find a large fraction of remanufacturers are in these two product markets. Automotive remanufacturing also caters to the knowledgeable buyer, but here the expert is the service mechanic who chooses the unit and reassures the ultimate customer that the part will function satisfactorily, and at a saving. Other forms of consumer products still seem to have a difficult time catching on. Continued economic adversity and/or resource scarcities may cause gradual attitudinal shifts among customers, but this is not likely to occur overnight. Branded products having a reputation for longevity will have some advantage in this market.

The minimum feasible market size depends on the price of the product and the remanufacturer's ability to recover a sufficient number of cores. The number of locomotives in the national market, for example, needs not be large if your firm is assured that you will see a very large fraction of all engines in need of overhaul.

The availability of cores, as has already been intimated, is a critically important factor. It was given by virtually all respondents to our survey as the most important limit to growth of remanufacturing. Cores must be readily available, in good quality and at a reasonable price. Availability involves ease of transportation as well as cooperative sources.

In the U.S. remanufacturing industry a cycle of product sale and core collection through the same distribution system keeps cores flowing to the remanufacturer. This is supplemented in some instances by core suppliers who specialize in collecting them. To establish such a system, the remanufacturer must be able to reach the present product user either directly or through permanently established channels.

In developing countries where the supply of durable products may still be very limited, core supply from within the country may be difficult to establish. In the early years of remanufacture, at least, it may be necessary to obtain cores from used equipment and scrap markets in developed countries. If reliable connections can be established, such an approach could yield high quality cores at moderate cost. This approach requires some study to determine both its advantages and disadvantages, but it may be a very useful way of acquiring capital goods for industrial and commercial growth at low levels of foreign exchange.

A fourth key factor is the presence of a supporting infrastructure. By this we mean the various activities that provide goods and services needed to keep the remanufacturer in operation. They range from a distribution network and transportation system to suppliers of replacement parts, cleaning materials and packaging. As was shown in Chapter 1, remanufacturing is part of a system and is dependent on that system for its success.

A workforce that can be trained in remanufacturing skills is also essential. For many products the skills required for remanufacturing are not very demanding and can be learned on the job. Some key skills will be required--mechanics, welders, technicians, maintenance trades, etc.--to set up and maintain equipment, run product tests and to handle some of the more difficult parts refurbishing operations. If these few skilled occupations can be found, the workforce question becomes a matter of whether other laborers can be found who are willing to be trained in industrial skills.

As with any industrial venture capital funds are required to provide plant and equipment and to provide working capital for inventories, accounts receivable, and operating cash. These capital funds tend to be substantially less than would be required for a factory producing an equivalent volume of new products of the same type. The total asset value of a medium to large sized remanufacturing activity appears to be about 1/2 to 2/3 of its annual sales volume. Because 90 - 95% of the assets are in working capital, careful management of accounts receivable and core inventories can increase asset turnover substantially.

Legal and regulatory leeway is another essential part of a favorable remanufacturing environment. By this we mean that there should be no laws or rules that prohibit, tax excessively or establish unreasonable risks for the remanufacturing venture. A country that forbids the import of used equipment, or taxes it heavily, will not be a good country in which to attempt remanufacture where the cores must be brought in from abroad. Laws designed to protect and encourage infant new product industries may serve to discourage remanufacturing. A favorable regulatory climate, on the other hand, would be one in which remanufacturing is viewed as a desirable industrial activity deserving equal encouragement along with other forms of industrial enterprise.

An enterprising, resourceful management is also important. Remanufacturers are opportunists; they must be constantly looking for new markets, new product opportunities, new sources for cores, and new ways of processing materials for greater savings. At the same time, they must be able to control cash flows, minimize investments and manage both product and core pricing. They must be able to recruit and train people who become highly quality conscious, loyal employees, and they must establish good working relationships with their customers and the distribution network that serves them. Many of these management skills are those demanded of any industrial manager. The emphasis on quality, resourcefulness and training skills is perhaps greater, however, than in most industries.

As a final item in the list of critical success variables, warranties are essential to bolster buyer confidence in the product. Polls that are taken to determine what criteria are important to a buyer when considering a purchase generally show that warranty terms rank fairly low on any list. The absence of any warranty, however, would be a strong signal to a buyer that the purchase is entirely at his or her risk, with little or no recourse to the remanufacturer. Most remanufacturers offer warranties that are at least as liberal as those offered on comparable new products.

4.2 Product Selection Criteria

The following section, taken from reference 1, describes an approach taken by the MIT study team to select desirable products for remanufacture.

In 1980 the Center for Policy Alternatives conducted an exhaustive survey of all products manufactured in the United States, using a series of screens to locate those products having greatest potential for remanufacture.[2] Each successive set of criteria represents a finer "mesh" through which candidate products must pass. The criteria used in that study are listed briefly here. The screening process is not infallible. Many remanufacturable products with only limited remanufacturability may pass through. For a more complete exposition of the approach, the reader is referred to the original report.

Stage 1 Criteria. (First Screen)

1. The product is a durable end product or durable component of an end product.

2. The product typically fails functionally rather than by dissolution or dissipation.

3. There is a "core" - a discarded, malfunctioning, or used product - that becomes the basis for the remanufactured product.

4. Remanufacturing processes can restore the product to its original shape, nature, or condition.

5. The product would be remanufactured with intent to restore its original function.

Stage 2 Criteria. (Second Screen)

1. The product is repairable.

2. The product is factory-built as opposed to field-assembled.

3. The product is standardized and made with interchangeable parts.

4. The product has a high percentage of recoverable value added relative to the original market price of the product. Value added is defined as all product costs and profit above basic raw materials costs.

5. The product has high economic potential (core "economic value" minus core "market value"). Market value is measured by the price a potential remanufacturer is willing to pay and an owner is willing to accept for the core. Economic value is the recoverable materials value and recoverable value added in the core. (In general, the product must have a failure mode that renders it substantially less valuable to its owner, but that still leaves it with a high economic value.)

Stage 3 Criteria. (Third Screen)

1. The product is not currently remanufactured, or, if it is remanufactured, the market in the region under consideration has room for significant growth.

2. There is a high ratio between the value of the original manufacturer's assets and the number of its employees. This ratio gives an indication of the recoverable value added in the product. A high assembly labor cost component,for example, is lost in remanufacturing.

4.3 Feasibility Score

At this stage of screening, it is necessary to examine individual products in detail to determine their potential for remanufacturing. Many important product characteristics are interrelated. Technological life (the rate at which a product is made obsolete by technological change) is a factor to be considered in connection with product durability, for example. Product population, price and life are similarly related. Although important for product selection, these characteristics cannot be used singly for simple accept/reject decisions. However, these characteristics can be scaled as continuous rather than dichotomous measures of remanufacturability and applied as a group to each product to determine a "feasibility score" which gives a general indication of overall product remanufacturability.

Data needed to establish a feasibility score are not commonly published, so experts familiar with the products must be consulted. A questionnaire was developed to evaluate feasibility scores in the 1981 Center for Policy Alternatives study. This questionnaire and its scoring system are included in Table 4.1. A list of all products surviving the first three screens and arranged in order of feasibility score was included in the 1981 study. The questionnaire is here condensed into a fourth screen:

Stage 4 Criteria. (Fourth Screen)

1. There is a high ratio of expected technological life to product life. This ratio screens out products likely to become obsolete before they wear out.

2. Product and core transportation costs from the remanufacturer to the user and back again must be less than the value added by the remanufacturer.

3. There is a low ratio of undifferentiated material to total material in the product. Undifferentiated materials are those which are not formed or wowrked specifically for the product, but which could be used for other products. This is a measure of the amount of value added likely to be found in the product. A length of chain or a brick wall, for example, would have a high percentage of undifferentiated material.

4. The product is serviced or installed by an organized service agency network. This gives an indication of the ease of core recovery.

5. There is a high ratio of the current product population value to average life of the product. This gives an estimate of annual sales as a measure of the size of the potential remanufacturing market.

One other criterion for evaluating market acceptance of a remanufactured product today is that the buyer (or buyer's agent, in the case of a repair person) be knowledgeable regarding the product. There is greater chance of success if the buyer is able to make an informed judgement about the remanufactured product relative to its performance and worth.

As an example of the use of the screening technique, the U.S. SIC Code 35463 category, Power Driven Hand Tools, Engine (Internal Combustion) Driven, passed through all of the go/no-go criteria of the first three screens and received a 6.4 score on the fourth screen ranking. The dominant product in this classification is the powered chain saw, and a further detailed analysis of this product then confirmed that it was, indeed, an appropriate candidate. Hand saws and saw blades (SIC Code 3425), on the other hand, did not survive the second cut, failing on the basis of lack of economic potential.

TABLE 4-1. FEASIBILITY SCORE QUESTIONNAIRE

Responses to these questions are given both a Code and a Score. Where applicable, the score has been listed immediately after the response. For Questions 1, 2, and 7 where the score must be computed from the response, see the instructions after the question.

	CODE	SCORE
1. Product technology becomes largely obsolescent in:		
about 5 years	1	
about 10 years	2	
about 15 years	3	
about 20 years	4	
about 30 years or more	5	
2. Product life is:		
about 5 years	1	
about 10 years	2	
about 15 years	3	
about 20 years	4	
about 30 years or more	5	
SCORING of Questions 1 and 2, ratio of product technology to product life (Answer 1/Answer 2):		
20/5 30/5	1	+2
15/5 20/10 30/10 30/15	2	+1
10/5 10/10 15/10 15/15 30/20 20/15	3	0
5/5 5/10 10/15 15/20 20/20 10/20 20/30	4	-1
5/15 5/10 10/30 30/30 15/30	5	-2
5/30	6	-3
3. Value of undifferentiated material (e.g., tin, sheet, pipe, wire) in factory price is:		
less than 20%	1	+.5
from 20% to 50%	2	-.5
greater than 50%	3	-2
4. Service, and/or installation is done primarily by:		
service agency (authorized or factory owned)	1	+1
independent service agency (e.g., plumber)	2	0
knowledgeable user (e.g., in-house mechanic)	3	-.5
repairable but not currently serviced	4	-1
5. Transportation costs from manufacturer to user as a fraction of new sales price are:		
less than 2%	1	+3
from 2% to 8%	2	-1
greater than 8%	3	-3
6. The average unit price of the (new) product is:		
less than $50 (and the product is either serviced by a knowledgeable user or not at all)	1	-2
Otherwise	2	0

7. Value of current population at replacement cost is:

less than $200 million	1
from $200 million to $1 billion	2
greater than $1 billion	3

To score this question, divide the code for current population value by the code for product life (Question 2). Subtract 1.15. Divide by 0.62. (Scores can range from -1.5 to +3).

The overall score for the product is the sum of the individual questions scores (only one score for the combination of Questions 1 and 2). Scores typically range from -4 to +7.5 for products which might be considered for remanufacturing.

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5 REMANUFACTURING IN DEVELOPING COUNTRIES

During the five years of formal studies of remanufacturing, a number of students have been attracted to the program and have subsequently written student reports and/or theses on various aspects of the subject. Of particular interest to this report are the four studies that have been done on the potential for remanufacturing in developing economies. The titles, authors and regions covered are listed in Table 5.1 Each of these reports is summarized in the paragraphs that follow.

Table 5.1 Studies of Remanufacturing in Developing Countries

Author	Title	Countries
Barnett, Christopher J.	Remanufacture of Durable Metal Products: The Concept and its Potential in the Countries of the Andean Region. (M.S. Thesis, 1980)	Bolivia, Chile, Columbia, Ecuador, Peru, Venezuela
Upaa, Raphael	Is Remanufacturing Adaptable to Nigeria? (CPA Working Paper, 1980)	Nigeria
Deolalikar, Avinash B.	A Survey of the Indian Economy to Explore the Potential for Remanufacturing (CPA Working Paper, 1979)	India
Alauddin, Arif	Remanufacturing in Developing Countries	Turkey, Pakistan

5.1 Andean Region

Barnett looks at three issues he considers important to the question of feasibility of remanufacturing in the Andean region:

1. The scale of remanufacturing activities possible in the restricted markets of the six countries.
2. The logistical and structure framework (system infrastructure) needed to support remanufacturing.
3. Government and private industry acceptance of remanufacturing as a desirable activity.

Barnett found consideration of volume requirements reassuring. Using examples from the automotive sector he found that large and small remanufacturers were able to co-exist in the U.S., so despite the much smaller markets for such goods in the Andean region he felt that it would be possible for such activities to exist in that area. Core supply, on the other hand, presents a serious logistics problem: "Core exchange policies are weakened because the factors which keep the quality of exchanged cores high in the United States do not work or work differently in less-developed countries. The domestic supply of used equipment in the Andean countries is of poor quality and too small to provide a steady turnover of cores. This turns the prospective remanufacturer to overseas sources of supply, where a core exchange policy is impracticable, and where the inspection of cores prior to purchase incurrs high costs in time, administrative effort, and money."

Costs of transportation and handling overseas core purchases are not seen as penalties, however, because new product imports also experience these costs, but "the major cost which is unique to remanufacturing is the cost associated with reducing the uncertainty of core quality. The Andean remanufacturing firm must secure a dependable overseas supply of rebuildable cores, without burdening itself with the need to inspect each lot of cores prior to shipment. This is particularly important if the cores must be of specific makes, models and model years, as in the case of products which, when remanufactured, will be used as spare or replacement parts."

Obtaining an economical and reliable supply of replacement parts is also seen as a problem: "If parts production and supply are the controlled exclusively by the original manufacturer, remanufacture in the Andean countries will depend on the manufacturer's willingness to supply parts to a prospective remanufacturing venture there. ... There is little incentive for the original manufacturer to supply parts to a remanufacturing firm if the firm is outside of the manufacturer's distribution system . . ."

Barnett sees remanufacturing as possible "where new replacement parts are available in the requisite volume for the United States or other foreign countries," even though costs for these parts may be somewhat higher than would obtain for U.S. remanufactures. He suggests that cannibalization of cores should be a source of parts in all cases except where parts are routinely replaced, as in the case of bearings and seals.

The availability of product and process technology and of requisite labor skills are seen as limiting factors for the remanufacture of certain types of products. Barnett identifies several categories of product, however, where neither of these factors are likely to be constraints: light and heavy duty automotive products, mining and construction equipment, and distribution transformers are examples.

After citing examples of Andean countries acquiring used machines and equipment from abroad with government sanction, Barnett describes instances of abuse or fraud that have led countries to ban the import of used equipment. One commonly practiced abuse was to overprice the used equipment in order to siphon funds out of a country. He concludes by recommending an approach to overcome such barriers: "Remanufacturing, by its nature, does not lend itself to large, showy industrial development projects. It is a relatively small-scale activity in the United States, and it is likely to be even more so in any of the Andean countries. Policy intiatives to encourage remanufacturing (and for the moment, we can extend this argument to lower-volume rebuilding activities) should entail a commensurately low level of effort and risk. This suggests that the thrust of such initiatives should not be to create conditions in which remanufacturing can flourish, but rather, to selectively lessen the obstacles that stand in the way of the small firm setting out to remanufacture. This could mean, for example, devoting energies to securing the lifting of bans on the import of used goods, where such goods are to be imported for the sole purpose of complete rebuilding."

5.2 Nigeria

In his short working paper on prospects of remanufacturing for Nigeria, Raphael Upaa points out that 45-53% of the total value of Nigeria's imports are for durable goods and equipment. This represents a substantial outflow of foreign exchange. To stem this flow the Nigerian government has set about developing its own industries, giving this effort a priority second only to its agricultural development. To encourage development of local industry, the government has, among other things, placed high tariffs and import restrictions on certain products (autos and trucks, for example).

Service and repair agencies are rare and poorly equipped. Their personnel are ill-trained. Replacement parts are difficult to obtain. The consequence is that fairly new equipment is frequently abandoned or discarded for lack of service or repairs. Because of inefficient scrap collection systems in the country, many of these abandoned items of equipment are likely to be available, still having "high retained value due to early failure of a few parts." Another element in favor of remanufacturing is the fact that high tariffs tend to inflate the prices of new products, thus increasing the profit potential for remanufacturing of these product types within the country.

Problems for remanufacturing, as seen by Upaa, include high internal transport costs, requiring the remanufacturer to establish its own means of transporting cores and products. Basic labor skills are being taught in the nation's schools, but advanced skills will have to be taught by the remanufacturing firm. Importation of replacement parts will be expensive and difficult to arrange. Perhaps the most difficult problem cited by Upaa is a general attitudinal bias against used goods by people in Nigeria. This attitude, which is not unique to Nigeria, seems to couple a strong national sense of pride with unfavorable experience with unscrupulous firms who have taken advantage of buyers' technical naivete in sales of useless equipment.

Upaa lists three possible strategies for the introduction of remanufacturing to Nigeria:

1. Set up remanufacturing operations as training centers for industrial skills in conjunction with technical or vocational schools. The remanufactured items would be considered "byproducts" until the value of these items became apparent in the economy.

2. Encourage small independent remanufacturing firms with incentives of the kind extended to other industrial ventures.

3. Encourage existing OEM's to establish remanufactuaring operations.

5.3 India

It is not appropriate to consider India a "developing country," when it is in truth the tenth largest industrial nation in the world. Its severe problems of poverty, unemployment and resource scarcity, however, put it in need of even much greater economic development. It is in this context that Avinash Deolalikar examines the remanufacturing situation in India. In his working paper he surveys what was known about U.S. remanufacturing in 1979, reviews the Indian economy with respect to supply of capital, skilled and unskilled workers and technology, and assesses the prospects for remanufacturing for India and for lesser developed countries.

Deolalikar describes the rapid development of heavy industry in India since 1950, during which a ten-fold increase in output of the engineering industries has occurred. Currently, over [illegible],000,000 people are employed in these industries and annual sales are approximately $10 billion. With its present capacity, India's heavy industry is able to export significant quantities of its products. About half of the production in these industries comes from small scale enterprises, many of which are suppliers to the larger firms.

In contrast to this industrial growth, largely confined to urban areas, rural regions of India have remained depressed, causing population migrations that exacerbate the unemployment problems of the nation as a whole. The rate at which people eligible to work have joined the ranks of the unemployed has exceeded the rate at which new job opportunities are being created. The result is that over 20,000,000 are unemployed.

High unemployment is not linked to lack of industrial skills, however. Deolalikar points out that India's greatest asset is its enormous numbers of skilled people, trained in many different disciplines. India "has the third largest reservoir of qualified scientists, engineers and technicians in the world."

Remanufacturing that is presently carried out in India is largely concentrated in the heavy industry sector: "Among the products that are being reconditioned are: machine tools, equipment needed for power generation, transmission and distribution, machinery for iron and steel plants, sugar, cement, paper, textile, jute, rubber, chemicals, petro-chemicals, fertilizers and dairy and food processing, road transportation equipment, rail transportation equipment, tractors and farm machinery, mining and metallurgical equipment, earth moving and other construction equiment and defense equipment.

"Remanufacturing is carried out by original equipment manufacturers. The raw material, i.e., the used machines are either warranty returns due to defects or just worn out machines. Remanufacturing is offered as a service to loyal customers of the OEM's."

In addition to remanufacture by OEM's, "remanufacturing in the unorganized sector is wide-spread. Among the products that are being reconditioned in this sector are: automobile engines and other auto parts, transistor radios, bicycle parts, other household appliances including small kitchen appliances, refrigerators and air-conditioners, sewing machines, watches and water heaters.

"Remanufacturing is carried out by hundreds of thousands of small service agencies scattered across the country. Many are concentrated in urban areas. These service agencies mostly employ from one to five employees who receive on the job training. They enter the trade as unskilled workers but within a short time pick up enough skills to be classified as semi-skilled. The production process in these units is also area or bench work type. They are basically repair shops but their work often goes beyond repairs. Selective remachining and also manufacturing of components is a regular activity of these shops.

"Most often products are not remanufactured to a point of complete restoration of their original value. Remanufacturing stops when the functional value of the product is restored."

Deolalikar points up the differences between the U.S. and Indian economy relative to remanufacturing: "Unlike the U.S., product durability does govern the life of consumer durables in India.

"Moreover, factors like rising service costs relative to new appliance prices, consumer affluence, population mobility, and product appearance which cause premature product discard in the U.S. are evidently absent in India.

"Because of surplus labor, service costs are a fraction of the new product prices. This encourages servicing or selective reconditioning rather than outright discard.

"Moreover, the Indian consumer is less affluent than his American counterpart and is therefore more aware of resource scarcity. Discard of anything runs counter to an Indian's belief.

"If the product fails, the consumer takes it to his neighborhood service facility. Reconditioning is done only to an extent where the functional value is restored. Cosmetic repairs are avoided as they add to the service costs.

"Consumer durable manufacturers are aware that factors like product durability figure prominently in the purchase decision of the consumer. The products are therefore made to last."

In India, "remanufacturing in the organized sector is mostly carried out by OEM's. This is because spare parts are more easily available with the OEM's, and also, due to low volume of remanufacturing, independent remanufacturers have been reluctant to enter this market. ... the remanufacturing industry in the unorganised sector is thriving and its present small-scale structure is appropriate to Indian conditions. It has been successful in generating employment for millions and has acted as an excellent technical education trainer to millions of unskilled workers in the country.

"Its further growth depends on increased production of consumer durables. ... the consumer durables industry is at present in demand recession due to the goverment's policy of restricting output by heavy taxation. The government believes that agriculture and heavy industry must receive priority over consumer durables, which it considers as mainly luxury items."

Deolalikar find the potential for future remanufacturing initiatives lie mainly in the area of remanufacturing foreign consumer and capital goods to be sold in foreign markets. He suggests the establishment of remanufacturing operations in duty free export processing zones such as the one at Santa Cruz airport near Bombay. He states that India has the plants, capital goods, skilled and semi-skilled labor and technological know-how. It can remanufacture complex products. His preliminary evaluation is that because of low labor costs such ventures in India could be highly profitable despite the transportation costs for cores and products.

As part of his paper on India, Deolalikar made several observations about developing countries of Asia, Africa and Latin America, emphasizing the differences that exist between these nations and India: "Unlike India, the manufacturing industry in many of these countries is in an embryonic stage. There is a shortage of skilled and semi-skilled labor in these countries. Moreover, many of them are also short of natural resources.

"Many of these countries import most of their consumer and capital goods from the developed world. Because of the uneven trade with the developed world the foreign exchange reserves of many countries is negative."

Deolalikar's conclusion relative to developing countries is that "potential for remanufacturing of simple durables for home and foreign markets is great. These countries do have facilities to handle such an activity and the gains realized from such operations should make it economically worthwhile.

"Firstly, these countries could remanufacture the products at considerable savings due to low wage rates prevailing in these countries.

"Secondly, export of these products could bring in much needed foreign exchange earnings.

"Thirdly, it could provide jobs to the unemployed and increase the skill levels of the workforce.

"However, remanufacturing is not a panacea for all their problems. The importance of the task of building infrastructural capability cannot be underestimated if balanced development is to be made possible."

5.4 Turkey and Pakistan

Arif Alauddin prepared a masters thesis on the subject of remanufacturing refrigerators in Turkey and then expanded it to include consideration of the same subject for his native country, Pakistan. Alauddin describes Turkey as being advantageously placed with industrially developed countries on its west, developing oil-rich nations to its east, and undeveloped nations in the south and southeast. It is financially troubled by high inflation, inability to maintain a satisfactory balance of payments, and a shaky international credit standing. It has poor domestic energy resources, and tends to be dependent on foreign sources parts to keep its industries running. Over half the aggregate industrial output is from state owned or controlled enterprises. The country offers substantial incentives to investors in the development of certain priority industries. To stimulate exports the Turkish government has granted liberal incentives and is proposing to set up export free zones and ports to facilitate trade and export-oriented industry.

Although Pakistan's economy has grown substantially since it was established as a nation, it shares with Turkey the economic problems of development. It has the same resource constraints and financial difficulties. Manufacturing represents 15% of GNP, but its growth rate of 9% per year is approximately double that of the large agricultural sector. As in the case of Turkey, Pakistan has a trade deficit, is trying to stimulate exports, and has established a tariff-free export processing zone at Karachi.

Remanufacturing is seen to be a desirable economic activity for Turkey, especially if the products can be exported for consumption by neighboring countries. Alauddin uses the product selection screening process developed by the MIT research team to identify potential candidates for remanufacturing and then performs a market survey before selecting, somewhat subjectively, household refrigerators as the case example. He then examines availability and sources of cores, sites for a remanufacturing operation, marketing strategies, and extent of a supporting industrial infrastructure. Remanufacturing ventures for both domestic and export markets are considered.

Based on his findings, Alauddin recommends that the Turkish government explore further the prospects for remanufacturing, with the intent of sponsoring a demonstration project. He supports the idea of refrigerator remanufacturing, both as a domestic enterprise and in an export processing zone in Istanbul.

Because of similarities between the two countries, it is likely that the same recommendation can be made up for Pakistan, but, in the case of refrigerators, both domestic and export ventures would be dependent on foreign core sources.

6 REMANUFACTURING BENEFITS AND BARRIERS

The basic function of remanufacturing is to prolong the lifetime of products, thus conserving their useful value. Longer product life provides the advantage of less wasteful consumption of resources for a given standard of living. Viewed another way, it can yield a higher standard of living for a given level of expenditure. It reduces the size of the solid waste stream. A four-year increase in the lifetime of a product currently lasting eight years, for example, means a 33% reduction in the amount of that product that has to be collected, processed and recycled, or disposed of.

6.1 Strategies that Increase Product Life

There are various approaches that can be used to prolong product life, and remanufacturing has a place in these strategies. To keep matters in perspective, however, it is useful to consider some of these alternatives before focusing on the advantages and disadvantages of remanufacturing.

There are at least six ways in which the functional life of a durable product can be prolonged:[1]

1. Make it more durable. A manufacturer can design a product so it will not wear, corrode or break at an early date. Stainless steel can be substituted for common steel, ball bearings for bronze bushings, and solid state parts can replace mechanical switches, timers and relays. Greater durability has appeal because it implies lower future repair costs and a long period of uninterrupted service. It may mean higher initial prices, however. Non-corroding materials are more expensive than those more vulnerable to the elements. Low wear designs are more costly than simple sliding contacts. Stronger parts may use more materials or use more expensive materials, or both. The results are likely to produce higher first costs. Perhaps, because of added weight, as in an automobile, higher durability will mean higher operating costs as well.

2. Make the product easy and inexpensive to repair. Where durability is an expensive or technically difficult alternative, products can be designed to make repair and replacement of worn or damaged parts simple and economical. This can involve designs that make parts easily accessible, parts that are standardized and available locally, and clear instructions on repair routines. Ease of repair provides the user with low maintenance expense and assurance that when the product fails it need not be out of service long. The product lifetime may not be trouble-free, but it can be long. Repair service, however, frequently involves calling in a person to handle the repair, sometimes from considerable

distances. The costs of a service call, even if the parts costs and the time to diagnose and fix the problem are small, can be high because of travel time. This strategy also implies that stocks of replacement parts will be maintained at convenient locations to cover the entire lifetimes of products that could operate for 20 to 30 years or more.

3. Train the user in product use and care to reduce failure due to neglect, overstress or accident. Both manufacturers and users would agree this is a desirable objective, but both fail to do as much as they might to accomplish it. Companies spend large sums preparing operating manuals, conducting training classes and providing field representatives, but instructions are frequently inadequate or overly complex and users seldom heed them. Further, for commercial or industrial equipment employee turnover may result in a loss of operating know-how.

4. Provide incentives to people to repair rather than replace, durable products. This is an public policy alternative, not one likely to be favored by manufacturers. It might be possible, for example, to allow repair agencies and parts warehouse distributors to write off the cost of the parts they stock as they are obtained, rather than holding them in inventory as a capital asset until sold. This would make longer-term holdings of parts more feasible and increase the chances that an older item of equipment would be repaired at reasonable cost when it fails. Allowing consumers to treat the cost of repairs as a deduction for income tax purposes (as is now done for health maintenance expenses) might encourage them to hold products longer. Businesses already have this option, so this incentive only applies to individuals.

5. Encourage used goods markets. Used product markets exist for industrial and commercial equipment, but such markets are very weak in all consumer durable areas other than automobile parts. The simple rules of supply and demand appear to operate effectively in these markets, except that customer bias against used equipment tends to discourage demand, especially in the individual consumer area. There is little government encouragement of used product markets, but there is little government interference, either.

6. Remanufacture the product when it can no longer be repaired economically. Remanufacture is a generally viable alternative when re-use is no longer possible or when the uncertainties of re-use without overhaul are too great. It is a strategy frequently overlooked in an affluent, resource-rich society such as that of

the United States, and it appears to be underutilized in countries lacking in affluence or resources. A better appreciation for the benefits of and the barriers to remanufacturing may serve to put this activity more solidly in the array of strategies for longer product life.

6.2 Remanufacturing Benefits

Remanufacturing activities in the United States provide general social and economic benefits as well as more restricted benefits to the entrepreneur or operator of a remanufacturing venture. Virtually all of the general benefits are appropriate to other countries, whether industrialized at present or trying to develop an industrial base. There are additional opportunities we believe exist for the application of remanufacturing practices in developing countries, and these are detailed after our cataloging of the advantages for U.S. society and industry.

6.2.1 Social and Economic Benefits

First among the general economic benefits of remanufacturing is its conservation of resources. It recaptures value of energy, labor and capital equipment going into the original manufacture of a product, and it maintains the product's materials in a high value state. Relatively small amounts of additional energy, labor, capital equipment and materials are needed to recapture most of the product's original value. The ratios of energy leverage are on the order of 4:1 to 5:1. The ratios of materials leverage are about 5:1 to 7:1 or better. In a society troubled by energy and materials scarcity and rising prices, these features of remanufacturing are important contributions to the country's future well-being.

Because of the relatively low value attached to an inoperable, worn out product, the differential between the cost of a core and the price that can be obtained for a remanufactured product can be substantial, yet the price will average 40% less than that for a comparable new product. This means that users can buy equipment at lower cost or in some instances, buy higher grade equipment at prices competitive with new but lower grade items. The ability to get more goods and service for a given level of expenditure is an increase in standard of living. A greater range of product choice is available to the buyer and the lower prices stimulate competition from new product manufacturers.

Despite the fact that remanufacturing serves to recapture labor that does not have to be duplicated, the activity itself is labor intensive, and furnishes employment opportunity for a range of laborers, particularly those entering with only moderate skills. It can contribute to the re-employment of people in labor surplus areas, because it is a fairly portable activity. Its activities also bring income to other suppliers of goods and services in the area.

The fourth societal benefit from remanufacturing has already been described earlier in this chapter. By prolonging product life remanufacturing reduces waste. Although the amount of durable products in the solid waste stream is only a very small fraction of the total, in the United States it is still measured in the millions of tons annually in the United States.

6.2.2 Benefits to the Remanufacturer

The barriers to entry into remanufacturing are low. Capital requirements are modest and can be scaled with growth. For remanufacturers in developed countries, labor skills requirements are rather easily met. In developing countries skills may be less available, but most can be provided by plant-level training. Technological know-how is readily available or can be developed through means such as "reverse engineering," the process of deducing the design of a product by disassembly and analysis of individual parts and their interactions.

Modest levels of investment, however, can produce high return. Remanufacturing has been a profitable form of enterprise in the United States. Two factors seem to account for this. Few prospective entrepreneurs are even aware of the opportunities in this business because of its low visibility and status. Secondly, there remains a large economic gap between the market value of a non-functioning core and its economic worth to a remanufacturer. This gap is the remanufacturers' profit source.

For the OEM, remanufacturing offers several additional benefits. If there is price elasticity in its product markets, an OEM may be able to offer remanufactured versions of its products at substantially lower prices. This can broaden market appeal and increase overall sales. (For products in an inelastic market the converse can be true -- remanufactured goods could cut into new product sales.) Arrangements for good trade-in prices for old units creates customer loyalty to the company's brands. By controlling remanufacture of its products a company also protects the reputation of its brand or trademark from inferior workmanship.

Knowledge gained from the condition of products returned as cores gives the OEM valuable information on what goes wrong with the product. The effect of the environment in which the product is used is also readily apparent. Where there are design flaws that lead to excessive wear or breakage, the OEM can correct these faults and upgrade the performance of its older products as well as improve its new products. Finally, the prospect of having to disassemble the product for remanufacture forces the company to adopt design practices that facilitate both repair and remanufacture, a benefit to both the firm and its customers.

Many firms today are moving strongly toward advanced forms of automation that have the potential to displace a great many workers. Those companies that do not wish to see these employees laid off or terminated may find that the establishment of a remanufacturing operation helps to absorb these displacements in a gainful manner.

6.2.3 Benefits to Other Countries

For other highly industrialized countries the benefits of remanufacturing are likely to run parallel to those listed above for the United States. We have indications that this is true from a paper by Warnecke and Steinhilper of the Frauenhofer Institute for Manufacturing Engineering and Automation[2], where benefits similar to those cited by our studies were reported for Germany.

The position of a highly industrialized country such as India is almost unique in its great contrasts between aggregate capability and individual deprivation. For this country, and others like it, remanufacturing must be a way of life. The extension of the concept to the remanufacture of imported cores for export as products is a logical and potentially advantageous move, since it provides employment and foreign exchange with minimal drain on the country's energy and materials resources.

For developing countries, where there is likely to be a shortage of cores, the concept of core import seems to be a reasonable way of starting or augmenting a remanufacturing venture. Remanufacturing can be viewed as an easily achievable early step in the development of an indigenous (as opposed to foreign-owned) industrial base in the country. It provides training in essential industrial skills and management. It accomplishes permanent transfer of the technology of the goods being remanufactured by requiring managers and workers to develop solutions to problems of disassembly, refurbishing, reassembly and test. This approach provides excellent opportunities for learning, regardless of whether the product is a refrigeration compressor, a truck, an electric motor or a computer.

Remanufacturing provides a bootstrap approach to countries that need capital goods for industry, transport, communications, and other vital services but are lacking in foreign exchange. If remanufacturing were to concentrate on these essential products, its activities would not only provide trained workers but it would also provide the machines for them to use.

A remanufacturing operation can also supply replacement parts and service people for maintenance of equipment already in the country but which is only marginally productive because of lack of repair. As was pointed out in the Nigerian study[3], relatively new equipment is frequently abandoned because of the user's inability to keep it in working condition. A remanufacturing firm could provide parts and repair service as an adjunct to its main rebuilding operations.

Remanufacturing can be the first stage of development for a firm that eventually will be producing its own new products. Barnett[4] cites the experience of two South American firms that started out as remanufacturers but when they had assimilated the technology began to manufacture the products as well. This would appear to be a reasonable evolutionary path for many remanufacturing ventures.

For some developing countries, too rapid urbanization has had a destabilizing effect on the economy. The fact that remanufacturing operations can be located wherever cores can be brought, makes this a possible instrument of government policies aimed at bringing industrialization to rural areas.

6.3 Barriers to Remanufacturing

As any person who has gone into remanufacturing can attest, this is not a perfect world. There are serious barriers to this form of activity, and these must be recognized and dealt with if the venture is to be successful. Some of these are the normal problems incurred in starting up or operating any form of business, but there are others that are peculiar to remanufacturing. These are the barriers discussed here.

Market attitudes against used products can be a very intractable problem, particularly in product areas in which the customer is not likely to be an expert buyer, or where newness is considered at least as important as utility. The price advantage enjoyed by remanufactured products is a powerfully persuasive argument, but if buyers are convinced that a used product, even if remanufactured, is inferior and entails high risk, the product will not sell. This attitude may carry over into public policies that are designed to discriminate against used products. Laws requiring that products containing used parts be so labeled serve to discourage firms from adopting practices that might, in fact, provide real savings to the custcmer.

A lack of cores of high quality and reasonable cost can limit the scale of a remanufacturing operation. This aspect of remanufacturing should be checked out carefully before launching any new venture. This was considered a serious barrier by most of the respondents to our remanufacturing survey.

Independent remanufacturers face other obstacles to their success. Opposition from OEM's that make the products being remanufactured can make life very difficult. An OEM can refuse to sell replacement parts to the remanufacturer at reasonable prices. It can refuse to divulge design or specifiction information needed by the remanufacturer to make the parts and/or to test product performance. An OEM can use its influence with its suppliers to discourage them from dealing with a remanufacturer, and it can exercise similar influence over its dealer network. Relationships between OEM's and independent are seldom cordial (unless the remanufacturer is under contract to the OEM), but it is fairly rare that an OEM will actually campaign actively against a remanufacturer.

There are also more subtle ways of causing trouble for the remanufacturer. Frequent design changes that make parts for newer models incompatible with older units tends to discourage remanufacturers from taking on a given brand of products. Suarez' study on motorcycle remanufacture[5] indicated that this tended to be the situation for Japanese-made motorcycles.

Remanufacturers in developing countries may experience additional antipathy toward used equipment because of prior unfavorable experiences with unscrupulous importers or with multi-national firms that used the mechanism of charging high prices for "used machinery" that was little more than scrap metal as a means of repatriating earnings from a subsidiary. Tariff barriers that are designed to encourage domestic industry may make it difficult to obtain new replacement parts, and this can discourage remanufacturing.

It is expected, however, that the greatest barrier to remanufacturing in developing countries will be the lack of demonstrated successes in remanufacturing, which will lead to entrepreneurs having an appreciation for the opportunities of remanufacturing and the know-how to establish such an activity. This basic problem must be resolved before any appreciable progress can be made.

6.4 Societal Issues

It would not be appropriate to close this chapter on the benefits of remanufacturing without mentioning two fundamental issues that need to be considered before making decisions on the appropriateness of remanufacturing for any given situation.

6.4.1 Labor Effects

The first of these issues is that of its effect on labor. Remanufacturing both saves labor and uses labor. Is the net effect beneficial or adverse to labor? The answer to this question, it would seem, depends on the market response to the remanufactured product. If the lifetime of a product is prolonged and its average cost reduced by remanufacturing, one of three things can happen:

1. People need not buy as many of that product, or
2. People can now afford to have more of the product, or
3. More people can afford to have some of the product.

In the first case people will spend that part of their income saved to buy other items, in effect shifting demand to other products, or they may bank their savings and thus supply others with the capital to spend on other things. In either of these actions there will be a reduction in annual demand for the product whose life is prolonged, and the effect will be displacement of workers from OEM producers. Some of the displacement will be offset by employment in the remanufacturing sector and some by employment in the companies whose products are now more in demand.

In the second and third cases there may be no labor reduction in the OEM's because other customers are attracted to the remanufactured products and demand for new products is unaffected.

In all three scenarios, more goods are available to society than heretofore and at minimum increase in economic cost. The efficiency of the system has improved. This is a net increase in the standard of living for the society.

The problem for labor, then, is the perennial problem of displacement that can occur with any change in technology, market response or economic conditions. It is the problem of the inequitable burden placed on those who must adjust to the change with little or no compensation for doing so. The long-term effect is societal gain, but the short-term consequence may be transitional hardships for some of society's members.

6.4.2 Innovation Effects

The second major issue concerns the effect of prolonging product life on innovation. If the system of manufacturing/remanufacturing operates so as to keep things functioning virtually forever, will that not stifle technological change and product and process improvement?

This is a subject that deserves more consideration than can be be devoted to it here, and the views that follow are offered as only a very preliminary assessment.

Longer product life will not serve to stop truly innovative, "breakthrough" technology. The durability of electromechanical adding machines did not deter the sweep made by electronic calculators, nor did the durability of steam locomotives stop the transition to diesel engines. Important changes that modify the performance or cost of a product will continue to cause switching to new products.

Remanufacturing may even facilitate the transition to new technology, particularly if the new technology is somehow compatible with major parts of the old product. The installation of microprocessor controls in conventional machines is an example of an instance where remanufacturing serves to speed technological change.

Remanufacturing may also facilitate change by providing a ready market for used equipment. Firms wishing to make changes may do so at lower cost because of the trade-in value of the old equipment. Changes may not necessarily be for reasons of modernization; they may be to increase capacity, shift products or modify processes.

On the other hand, remanufacturing may serve to discourage more superficial product changes, because the market may be smaller and the rewards from making trivial changes may be small. Whether this effect is ever seen will depend heavily on the presence or absence of competition, because the forces of competition are more likely to influence product change much more strongly than product life.

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7 IMPLEMENTATION OF REMANUFACTURING IN DEVELOPING COUNTRIES

The MIT studies summarized in this report are the first comprehensive approach to the subject of remanufacturing that has been attempted. Most importantly, the studies have made it quite clear that remanufacturing remains an area of economic opportunity both in industrial and developing countries of the world.

Our studies reveal an industrial activity that has low visibility in society, has only rudimentary organization as an industry, obtains very little public encouragement for its efforts and yet provides an impressive list of benefits to society. The members of this industry have profited from the opportunities that exist and they are proud of the service they provide.

Economic trends in the United States and abroad point toward the need for encouragement of remanufacturing. Growing demands for increasingly scarce materials and energy resources, unemployment in developed countries, and underemployment and rising expectations in third world countries are all conditions that remanufacturing addresses. Few other activities produce as much good while placing such a small claim on our physical resources. The question is, what needs to be done to stimulate remanufacturing activities? The following sections present some of our views on this subject.

7.1 Recommendations for Industrialized Countries

Most industrialized countries or regions of countries have the sources of capital funds, technical know-how, core supply, replacement parts and product markets that make remanufacturing feasible. When financial and economic opportunities for remanufacturing become manifest, entrepreneurs and agencies will show up to exploit them. In this environment, three forms of encouragement appear appropriate:

1. A program of information dissemination that calls attention to opportunities for remanufacturing and that provides guidelines to people interested in starting a remaufacturing operation.

2. An examination of the public and private policy climate for remanufacturing, with the objective of (a) identifying unnecessary barriers and suggesting ways to eliminate them and (b) recommending policies that could stimulate growth of this activity.

3. A cooperative study of remanufacturing practices and policies in other developed countries for the purpose of exchanging ideas, identifying opportunities, and raising public awareness.

These suggestions imply that, with sufficient information and a favorable environment, market forces will operate to stimulate the growth and development of remanufacturing operations in these countries.

7.2 Options for Developing Countries

In countries where many of the essential ingredients for spontaneous industrial development are missing or in very short supply, a very different program is called for. Because it appears that some of the most impressive opportunities for remanufacturing reside in these developing countries, this is an area that deserves attention and support from international agencies for economic development as well as allocation of national resources on its behalf.

At this time our understanding of all the issues involved in the application of remanufacturing to developing countries is far from complete. For this reason it is impossible to identify all the measures needed to promote remanufacturing among these countries. Some of the main thrusts for a program of this kind, however, are fairly clear. They include:

1. The development of international sources of and markets for cores.

2. The establishment of remanufacturing operations within developing countries.

3. The development of internal and foreign markets for remanufactured goods.

Some of the steps that are needed to accomplish these objectives are presented below. If a program of this type is initiated it is very likely that other tasks will become apparent as a result of problems or opportunities encountered.

7.2.1 Survey of Existing Remanufacturing Activities

An assessment of existing remanufacturing activities in selected countries is needed as a first step in providing knowledge about the local economic climate for remanufacturing, local sources of expertise, problems being experienced, and the extent of support needed to establish new remanufacturing pursuits. There is a high probability that some form of remanufacturing or rebuilding is being carried out in every country that has ambitions for industrial development. It is necessary to examine these activities for clues on how to expand them or to introduce new modes of remanufacture such as that of using imported cores. In any event, the four phases listed in Section 4.2 and 4.3 for selecting a product for remanufacture are essential.

7.2.2 Investigation of Core Sources

Because core supply is such a critical item in any remanufacturing operation, a key study will be the evaluation of core sources for selected industrial and commercial products. It probably will be necessary to do such studies with reference to a specific country or group of countries because trade relationships vary. Each study should have two facets, one being the location of core sources in readily accessible industrial countries such as the United States, Germany, France, Italy, Japan, Sweden and Great Britain. The second facet would be to find and appraise possible core sources from within the developing country or its neighbors.

7.2.3 Detailed Market Surveys

In each country embarking on a remanufacturing program it will be necessary to conduct a product selection screening and surveys of the markets for prime candidates. These surveys will guide the selection of a product for demonstration purposes. Markets to be examined should include not only that indigenous to the country but also markets within their trading neighbors and, more broadly, international markets.

7.2.4 Demonstration Projects

It is essential to establish one or more demonstration remanufacturing activities in each country of interest. The purpose would be to show how it can be done and to identify the problems likely to be encountered. The several demonstrations should be based on different models. Four options have been identified:

1. An "educational" model, based on a connection with a technical or vocational training institute

2. A commercial model in which the venture is an independent enterprise

3. A commercial model in which the remanufacturing is done by a branch of an OEM.

4. A public agency model, where the remanufacturing operation would be a governmental or quasi-governmental function.

7.2.5 Information Agency

A final recommendation in this preliminary listing of the elements of a remanufacturing program for developing countries is the establishment of an organization or agency that acts as a clearinghouse for information on all aspects of remanufacturing, provides expert support for demonstration projects and is an advocate for greater recognition of remanufacturing. Such an agency would serve as a repository of data, and would assist in the exchange of information on materials sources and product markets. It would probably be associated in some manner with an organization responsible for international industrial development programs.

7.3 Conclusion

In putting together this series of recommendations we have focused on concepts, not on how each step should be accomplished or on who should do it. These latter items are best left until a sponsor or sponsors for these tasks are found. The World Bank has taken a first step in sponsoring the preparation of this report. It is hoped that that agency will take the lead in championing the development of an international program for remanufacturing.

APPENDIX A

CASE DESCRIPTION OF A U.S. MACHINE TOOL REMANUFACTURER

(Excerpt from Energy Savings Through Remanufacturing: A Pre-Demonstration Study, Interim Progress Report, CPA-80-6, MIT Center for Policy Alternatives, August, 1980.)

V. A U.S. MACHINE TOOL REMANUFACTURER

A. INDUSTRY BACKGROUND

1. The U.S. Machine Tool Industry

The U.S. machine tool industry is a small industry in terms of sales (value of 1978 shipments is estimated to have been about $4.5 billion), but it is one which is critical to the performance of other sectors of manufacturing. The most recent Census of Manufactures (1972) reported more than 1,200 machine tool building establishments, but of these, nearly two-thirds employ fewer than 20 persons.* Only ten machine tool builders employ more than 1000 employees, with an average for this group of 2,500 employees per firm. Geographically, the industry is concentrated in the Middle Atlantic and Midwestern states, with smaller concentrations of firms in New England and on the West Coast.

Metal cutting machines make up about 73 percent of shipments by value (value of shipments is estimated to have been $3.25 billion in 1978). They are produced by 894 establishments, of which 275 have more than 20 employees.

The major types of metalcutting machine tools are drilling, milling, boring, turning, and planing and shaping machines. All of these machines remove metal from a workpiece by the relative motion of a cutting tool and the workpiece. Other types of machines usually included in the metal cutting category are grinding machines and machines which remove metal by electrical or electrochemical action.

2. Numerical Control of Machine Tools

The direction of cutting tool paths by electronic means, using servomechanisms and position feedback devices, was first accomplished in the early nineteen-fifties. Numerical control, in which a tool path is generated off the machine and fed to the control as a sequence of numerically-coded instructions, was promoted by the U.S. Air Force as a means of performing some of the complex milling and drilling operations required in aerospace work.

Although numerical control did permit the machining of complex hole patterns and contours without the use of templates, the technology was hampered by the limitations of available controls and electronics. The first electronic controls were bulky and unreliable, consisting as they did of hundreds and even thousands of discrete electronic and hydraulic components (the control for the Pratt & Whitney Tape-O-Matic Model "A"

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* The Census of Manufactures tends to focus on large establishments; coverage of small firms is thus not reliable.

drill, introduced in 1958, contained over 160 separate printed circuit cards). The number of electronic components and electrical connections created very high opportunities for failure. These were increased by the surroundings in which the controls were placed; the dirt and vibration of the shop environment, and the heat dissipated by the electronics themselves all contributed to machine downtime.

Developments in electronics have brought rapid improvements in machine tool controls. The relays and vacuum tubes used in the earliest controls have been replaced successively by transistors, integrated circuits, and micro-computers and microprocessors. The increasing reliability and sophistication of these controls has greatly expanded machine capabilities, while at the same time lessening many of the drawbacks of early machines.

Electromechanical equipment has been improved as well, although less dramatically than electronics. Tape readers have all but replaced the plug board program loading devices used on some early machines. The readers themselves have been upgraded, from the slow and failure-prone mechanical readers of the nineteen-sixties to pneumatic readers, and finally to the optical readers used on many machines today. Even these readers are increasingly being bypassed, with flexible magnetic disks becoming the main means of active program storage and retrieval. Electromechanical memory may itself be replaced with semiconductor or magnetic bubble memory storage in the near future.

Improvements have also been made in drive motors, actuators and position feedback mechanisms. DC shunt motors have replaced AC motors and speed reduction units for many machine tool applications; work table positioning, for example, can now be accomplished directly by DC motors driving the ends of the table lead screws. Developments of this type have permitted simplification of machine tools, and diminished many of the inaccuracies and inefficiencies inherent in mechanical transmissions.

Simplified machines and controls have reduced the complexity of shop maintenance for numerically-controlled machines. The early controls, besides being prone to failure, contained so many components and connections that tracing a malfunction became a difficult and time-consuming task. Although the use of plug-in modular circuit boards did somewhat simplify maintenance of early controls, diagnosis of malfunctions did not become significantly easier until the nineteen-seventies, with the advent of integrated circuit controls with built-in diagnostic capabilities.

The development of numerically-controlled machine tools has been a process of gradual integration of machines and control units. Within recent years, as controls have become more flexible and machines have been adapted to their capabilities, the control has become a part of the machine tool, rather than a unit that was added on to it. This process has opened up many opportunities for machine redesign.

As a consequence of the evolution of controls and machine/control units, many early numerically-controlled machine tools have become outdated. Their mechanical elements remain sound, but their aging drives and controls cannot match current machines for reliability, accuracy, repeatability, or maintainability. Moreover, they are outdated by the lower noise levels and electric power consumption of current models.

3. Machine Tool Rebuilding

Machine tool rebuilding characteristically takes two forms; (1) the rebuilding of a machine by its owner or an outside contractor, and (2) rebuilding by dealers in used machinery. These two types of rebuilding differ in several important respects.

Many dealers in used machine tools maintain some machine repair capability on the premises, and it is common for a machine to be functionally tested, cleaned, repaired and repainted before being offered for sale. These machines are sold as "refurbished" or "reconditioned," and may be covered by some limited form of warranty (many dealers offer a 30-day return policy). Occasionally a used-machinery dealer will completely dismantle a machine and rebuild it to original specifications (machines rebuilt in this way are also referred to as "reprecisioned"). High-value or high-precision machines, such as boring mills, are rebuilt in this way, but for most used machinery, complete rebuilding does not raise the value of the machine sufficiently to offset the additional cost.

Users of machine tools rebuild their own machines to preserve their accuracy or to upgrade them to current standards. This is usually less expensive than buying a new machine, and avoids the long lead times associated with new-machine orders. Larger manufacturing establishments, particularly in industries which are heavy users of machine tools, may have dedicated machine tool rebuilding and repair facilities. Several aerospace companies rebuild their own machine tools at regular intervals over a machine's lifetime, so as to maintain new-machine precision for as long a period as possible. One incentive for this is the high cost of new machines; rebuilding programs of this nature may help explain why over 50 percent of the machine tools in the aerospace industry are over 20 years old (This compares with 34 percent for metalworking as a whole).

In-house rebuilding programs of this type are, however, vulnerable to economic cycles. At Boeing Aerospace, for example, the decline in aircraft orders at the end of the 1960s forced the in-house rebuilding shop to seek outside work in order to survive.

This vulnerability, together with the high cost of maintaining a dedicated rebuiding shop, make the use of outside rebuilding services attractive to many firms. Some of these rebuilding services will perform work on the customer's floor, while others operate rebuilding facilities of their own.

A number of machine tool manufacturers offer rebuilding of machines as a service to their customers. At least one of these firms also buys and rebuilds popular models of its milling machines and machining centers.

In addition to these services provided by original manufacturers, there are independent firms which specialize in machine tool rebuilding. Some of these companies have specialized further; one firm, for example, rebuilds only large, one-of-a-kind machines, while at least six have specialized in numerically-controlled (N-C) machines. D & D Electronics, one of the leading N-C machine rebuilders in the United States, is the subject of this case study.

B. D & D ELECTRONICS*

1. Company History

D & D Electronics, located in Hartford, Connecticut, is an independent rebuilder of numerically-controlled drilling, milling and boring machines, and also manufactures a sophisticated N-C chucker.

The company was formed in 1967, by two specialists in N-C electronics. Both partners had worked for Pratt & Whitney Aircraft until 1962, and were skilled in the service and repair of the first-generation electronic machine tool controllers which began to be introduced into the aerospace industry in 1957. After leaving Pratt & Whitney, they started an independent N-C repair service. The type of service they provided, troubleshooting and repair of N-C controllers, was very much in demand at that time, as experienced N-C technicians were in short supply even among the larger firms in the area. They continued as a repair service until 1964, occasionally rebuilding complete controllers for clients. Gradually they began to coordinate the rebuilding of complete machines on the customer's premises, although their work still concentrated primarily on machine electronics.

During this time, the partners purchased a broken-down N-C machine tool, which they rebuilt, renting some space in a warehouse for the purpose. David Duquette, now President of D & D Electronics, recalls that they showed the machine to a prospective buyer before it had been tested as a unit. When he turned the machine on for the customer, the fuses blew out in the building. He recalls that the buyer calmly wrote them a check in the dark.

D & D has grown steadily since its formation. In 1967, the company occupied 3,000 square feet of leased shop space. In 1971, it moved into a 10,000 square foot facility, and by 1977 it had ougrown this shop, and moved to its present 25,000 square foot plant. With each move, the number of persons employed by the firm doubled, reaching a total of 70 employees, of which 45 are shop employees, after its most recent move.

2. Product Line

D & D Electronics' remanufacturing activities began with the remanufacture of Pratt & Whitney Tape-o-Matic drills. The Tape-o-Matic was introduced by Pratt & Whitney Machine Tool (now a division of Colt Industries) in 1958. At the time, the machine, a numerically-controlled drill, was the least expensive N-C machine tool on the market. It had a

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* Since publication of the report containing this case, the name of the firm has been changed to U.S. Machine Tool Company.

simple point-to-point positioning control, and the Model A, which had a 30" by 20" table, could be purchased for $8,500. The Tape-o-Matic was popular, and it introduced a great many machine shops to N-C. Pratt & Whitney subsequently added a Model B, which included a more powerful spindle drive and longer quill travel, and a Model C, with a larger table (45" by 29"), a 5 hp spindle, and improved features. Paul Seelbach, Vice President of Marketing of D & D Electronics, estimates that over 3,500 Tape-o-Matics had been sold in the United States by the time Pratt & Whitney discontinued the model line in 1971.

Pratt & Whitney Machine Tool is located in Hartford, Connecticutt, and many early Tape-o-Matics were sold to metalworking firms in the New England region. D & D's specialization on the Tape-o-Matic was natural. In its early years, the company repaired and rebuilt a wide variety of numerically-controlled machine tools, but it frequently was asked to rebuild Tape-o-Matic drills. Moreover, the Tape-o-Matic was attractive to D & D because it was mechanically simple by comparison with other N-C machines. It had only 2 axes of table positioning, and contained no hydraulic components. Its control hardware was, in fact, more costly than the rest of the machine tool. In addition, Pratt & Whitney's location in Hartford provided convenient access to machine documentation and spare parts.

In addition to the Tape-o-Matic, D & D Electronics specialized in the remanufacture of Cincinatti's Cintimatic line of vertical and horizontal machining centers (according to Paul Seelbach, "it was a toss up as to which machine we would concentrate on. We chose the Tape-o-Matic because Pratt & Whitney was nearby."). The Cincinnati machines, which were introduced a little later than Pratt & Whitney's Tape-o-Matic, were similar in their simplicity and rugged mechanical features. Like the Tape-o-Matic, the Cintimatics were built in relatively large numbers as standard machines.

D & D Electronics also remanufactures boring machines, chiefly numerically-controlled Lucas and DeVlieg (Jigmil) horizontal boring mills. These machines are extremely rigid and durable, built for precision in heavy production work. Both the Lucas and DeVlieg machines were well-established before the advent of N-C, and numerically-controlled versions of both have been popular.

In addition to these four machine tool types, D & D occasionally rebuilds other machines which have not become part of the regular remanufacturing product line. These include multifunction numerically-controlled machining centers, N-C lathes, N-C drilling, milling and boring machines of other manufacturers, and a small number of manually-controlled jig borers.

The company does not plan to remanufacture numerically-controlled lathes on a regular basis. Paul Seelbach explains that because N-C lathes were developed later than N-C milling, drilling and boring machines, they are not yet available for remanufacture in large numbers. Furthermore, turning machines are quite different from other metal cutting machine tools (This distinction is evident among machine tool builders as well - turning machine manufacturers tend not to build other machine types, and vice-versa). D & D has also chosen not to rebuild multifunction machining centers, because these machines employ hydraulic or pneumatic actuators for clamping, indexing, and tool changing. These actuators cannot be satisfactorily replaced with electronic devices, and they add significantly to the cost and complexity of remanufacturing a machine.

The company intends to continue adding new machine models to their product line, but plans to do so slowly. There is a temptation, its managers say, to add models too rapidly, which they fear would strain the firm's engineering resources, increase shop floor and administrative costs, and reduce profitability. Instead, they prefer to wait until they have turned down a number of requests to rebuild a specific model of machine before considering its addition to their remanufacturing line.

Ralph Thompson, who joined D & D as Vice President of Engineering in 1977, explains that requests for quotes on specific machines are a first indication that the machine may be a good candidate for remanufacture. If D & D is interested in the sales potential of a machine model, he adds, it is frequently possible, through the firm's contacts in the machine tool industry, to learn roughly how many units of that model have been sold. Since most machine tools which are sent to D & D for remanufacture are between 8 and 15 years old (10 to 12 years is the most frequent age range) the sales data of interest to D & D are often a matter of historical record to the manufacturer, and are thus available.

According to Ralph Thompson, other criteria used in the initial evaluation of the "remanufacturability" of a machine tool include the original cost of the machine, the current cost of a comparable model, and the proportionate cost of the "iron" (machine bed, table, column and headstock) and the control and drive system. Rework and replacement of the controls and drives constitute a major part of the cost of remanufacture, as the castings and major mechanical components of the machine tool can nearly always be remanufactured for a small fraction of their new cost. The cost of remanufacture relative to original cost therefore varies according to the type of machine. In the case of early-model Tape-o-Matics, for example, the cost of the control originally exceeded the cost of the mechanical assemblies, and the cost of remanufacturing the machine is therefore high relative to original cost (and may even exceed it), although it is between 50 and 60 percent of the cost of a comparable new model.

D & D Electronics has added one machine model to its product line each year since Ralph Thompson joined the company, and expects to continue expanding its product line at this rate.

C. REMANUFACTURING OPERATION

1. Engineering

Remanufacturing of machine tools at D & D Electronics almost always includes the updating of machine controls and drives. The principal exceptions are the Pratt & Whitney Tape-o-Matics. The controls for these machines are rebuilt to original specifications, because this is less expensive than fitting the machine with a modern control (the

Tape-o-Matics require only point-to-point positioning; modern controls offer continuous-path capabilities which could not be used on these machines). Updating may include replacement of the AC spindle motors and hydraulic axis drives with DC silicon-controlled rectifier (SCR) motors driving the spindle and axis lead screws directly. In addition, the numerical control unit may be replaced with a new, more reliable and more compact unit, and new features may be added to the operator control panel.

The addition of these systems requires considerable re-engineering of the machine. This is a time-consuming process, and D & D is unwilling to invest the engineering effort necessary to remanufacture a machine unless a sizeable pool of machines of that model and vintage exists. The company expects to break even or even lose money on the first one or two units of each new model it remanufactures, and remanufacturing may not become profitable until 3 to 5 units have been remanufactured. The profitablility of D & D's remanufacturing depends on continuing to attract machines of a specific model after it has made the initial investment in learning how to remanufacture that model. The company has therefore concentrated on widely-used models, which it can expect to remanufacture frequently. For these machines, D & D can develop comprehensive documentation and standards, and apply systematic rebuilding procedures, thus streamlining the process of rebuilding.

The involvement of the engineering department in the remanufacture of a machine begins as soon as the Sales Department receives a request for a quote. The engineering department requests from the prospective customer any documentation and manuals the customer may have for the machine. Engineering will accept or turn down the job based on D & D's experience with the machine type, its similarity to machines already in the model line, and the existing engineering work load.

When D & D undertakes the remanufacture of a new type of machine tool, the machine is put into the hands of the engineering staff from the moment a quote is prepared. Redesign and re-engineering of the machine begins with a decision on the level of technology to be incorporated into the machine. Depending on the machine and on customer requirements, the unit may be:

1. remanufactured to original specifications,
2. fitted with new DC axis drives and new numerical control or computer numerical control, or,
3. fitted with new DC axis drives, a DC spindle drive, a computer numerical control, and contouring capability.

In the second of these cases, the rebuilt machine exceeds original performance characteristics, but may not match the performance of current models. The third level of remanufacture not only exceeds original specifications, but may even match the performance and features of new machines.

The level of technology to be incorporated into the machine is decided before a cost estimate for the job is submitted. Once the decision has been made, the engineering department must select DC axis-drive and spindle-drive motors, transmissions, and spindles and axis lead screws. Spindle drive motors must be sized to deliver the same horsepower as the original drive motor in each spindle speed range, and must be able to fit within the headstock. The design of adaptors, brackets and modifications to castings may be required to accept the new components. Great care must be taken when upgrading the machine so as not to exceed its original design specifications. New axis and spindle drive specifications are submitted to the customer as part of D & D's remanufacturing quote.

When a new job arrives at the plant, the engineering staff dissasembles the machine, inspecting parts before and during disassembly. Parts which will need to be replaced routinely during remanufacture are identified, as are parts which may be reusable or reworkable on a case-by-case basis. Original horsepower, speeds, accuracies, and features of the machine tool are determined from its accompanying documentation, inquiries to the manufacturer, and inspection of the machine.

Following the receipt and disassembly of the machine, orders are placed for those items which have long order lead times. On the first machine of a new type, these orders are placed once inspection of the machine has corroborated the preliminary engineering work. Such orders have customarily been placed within two weeks of the arrival of the machine at D & D Electronics. Long-lead items required for the remanufacture of a machine tool typically include the electronic control, delivery of which may take 24 weeks; lead screws, which are either sent to the manufacturer for regrinding or replaced, in which case lead time will be between 8 and 10 weeks for a low precision screw; and axis and spindle drive motors, which can usually be obtained in 8 weeks. High-precision leadscrews take 3 times as long to obtain and cost twice as much as low-precision versions. Their accuracy is seldom necessary, however, as modern controllers can be calibrated to compensate for the positional errors of less accurate lead screws.

The engineering and documentation of a remanufactured machine tool requires the production of drawings for some 70 to 80 engineered parts, and represents between 200 and 300 hours of engineering effort. The engineering department also produces drawings, electrical layouts and wiring diagrams for use in the assembly of the machine.

Fitting the new control unit to the machine, and testing and debugging the machine and control, can take two to three weeks for a new combination of machine and control. A typical state-of-the-art control has some 96 input-output (I/O) terminals that must be tested. Once this work is completed, each axis is calibrated by means of laser interferometry. Finally, the engineering department prepares owner's and operator's manuals for the machine.

The function of the engineering department has changed over the past two years. When Ralph Thompson became Vice President of Engineering, he and the rest of his staff were spending approximately 70 percent of their time in the shop, and 30 percent on design development. Today, he estimates that the department spends 50 percent of its time on development, and that only 50 percent is spent in the shop. This reduction in time spent in the shop may be a result of improved engineering documentation, or it may indicate that Engineering is no longer involved in documenting procedures that had been developed and implemented before the effort to develop comprehensive standards began. The engineering department is continuing to develop remanufacturing programs for machines which D & D has not remanufactured before.

2. Process

The thoroughness of D & D's "new" product engineering plays a role in the subsequent remanufacture of machines in the product line. Inquiries from prospective customers are relayed to the engineering department, which prepares a quote and cost estimate based on its own documentation for the machine type, additional documentation supplied by the customer, and special customer requirements (which range from the degree of updating desired to choice of control and specification of special tool holders). The final quote includes a delivery forecast, based on current workload and known component lead times. D & D currently offers delivery within 12 to 16 weeks of receiving a machine, although lead times vary considerably according to the type of machine being rebuilt, from as little as 8 weeks for a small Pratt & Whitney Tape-o-Matic, to nearly a year for a large boring mill. If the quote is accepted, D & D supervises the removal of the machine from the customer's shop floor and its shipment to Hartford.

When the machine arrives in the shop it requires little involvement on the part of the engineering department, except inspection of the machine during disassemby to verify critical machine details which may vary from unit to unit or from one model year to another, and to make any consequent adjustments to the standard remanufacturing procedure.

Once it arrives at D & D, the machine is first stripped down to its castings. Worn parts, including bearings, bushings, ball bushing blocks, springs, belts, and seals, are discarded. Electrical wiring and pneumatic and lubrication tubing is also discarded. Other parts, including motors, pulleys, clutches, gears, shifter forks, guide rails, spindle assemblies and lead screws are inspected and either reworked to original specifications or replaced.

The castings themselves, including the machine bed, column, headstock, saddle, and table, are cleaned and resurfaced. Resurfacing of large areas, such as bed ways, requires planing to restore flatness, followed by scraping to a finished surface. Castings are sent out to local machine shops for planing, as D & D's volume is insufficient to keep a large planer fully employed. Work tables are resurfaced by drilling out and plugging any holes and gouges. This work is done at D & D, after which the table is sent out for final planing and, if necessary, milling of the "T" slots. All castings are sealed and repainted after machine work is complete. Tables and ways are then scraped to restore their surface to original condition. Scraping is a very specialized manual operation, and skilled scrapers are in short supply. D & D employs three scrapers.

All other components which affect the accuracy of the machine tool also receive attention. Leadscrews are inspected for wear and, if required, are sent to the manufacturer for regrinding and lapping. The quill sleeve, in which the quill slides, is replaced with a hardened steel sleeve which is ground on its inside diameter and shrink-fit into the headstock. The new sleeve is then lapped to the quill to produce a rigid, exact fit. Electrical motors which are not replaced with new DC motors are cleaned, tested, fitted with new bushings, and rewound if necessary.

When remanufacturing Pratt & Whitney Tape-o-Matics, D & D cleans and thoroughly restores the existing electrical system, which is then reused. The machines' electrical panels are removed and completely disassembled. Printed wiring boards are cleaned ultrasonically and tested, and any faulty electronic components are replaced. Solenoids are cleaned and their contacts changed if they are to be re-used. Printed wiring board backplanes are reworked to ensure positive contact of all boards.

In the case of all machines except Tape-o-Matics, the existing electrical system is removed entirely and replaced with new components and wiring, in panels and housings of D & D's own design. The panels are designed to Joint Industrial Congress standards, and are laid out in roomy housings, which simplify both installation and subsequent service of the electrical system.

When remanufacturing machines other than Tape-o-Matics, the machine's existing numerical control is removed, partially disassembled and stored. It is replaced with a new NC or CNC unit and optical tape reader. The point-to-point control originally used on the Tape-o-Matic is retained, because no inexpensive comparable new unit is available. The Tape-o-Matic control, which consists of up to 160 separate printed wiring boards (by comparison, the McDonnell Douglas Actrion III control, a typical newer unit, has between four and seven circuit boards), is completely disassembled. Each board is cleaned and tested individually, and its connector pins are tightened and gaged to ensure good electrical contact. Damaged components and boards are replaced and the control is reassembled and tested. The mechanical tape reader which is usually found on Tape-o-Matics is replaced with a more reliable photo-electric tape reader.

D & D stores salvaged controllers, tape readers, and other accessories as a source of spare parts both for use in rebuilding machine tools and for customer service. It also actively searches for certain types of parts for older N-C machines, as some of these are now scarce. One transistor required in the Tape-o-Matic control, for example, is no longer manufactured, and no satisfactory substitute exists.

Reassembly of the machine tool takes place in the same manner as original assembly. Like original assembly, it is a labor intensive process, requiring careful attention to the flatness of surfaces and the alignment of the bed, column, saddle, table and headstock. Documentation prepared by the engineering department for use in the shop includes assembly drawings and assembly procedures. Once mechanical, electrical amd electronic assembly are complete, the control and machine-control unit are calibrated, functionally tested and debugged. Precise measurement of positioning accuracy and repeatability is accomplished using a laser interferometer and positional deviations are recorded and corrected by calibrating the controller's error compensator.

Final inspection and testing may include a customer acceptance test at D & D's plant. D & D then ships the machine back to its owner, and supervises its installation, connection and testing in the customer's shop. Calibration and software tapes for the machine are generated by D & D's applications engineers and supplied to the customer. In addition, D & D trains the customer's machine operators, programmers, and maintenance technicians in the use and servicing of the remanufactured machine.

3. Infrastructure Requirements

D & D Electronics relies on outside suppliers for many products and services. In addition to having heavy machine work done by outside machine shops, the company obtains weldments, many machined parts, and sheetmetal work for housings and enclosures from independent suppliers. In some instances, D & D sends parts to the machine tool builder for rework; regrinding of ball lead screws is an example.

Original manufacturers of machine tools and independent component manufacturers are the source for most of the standard parts D & D replaces or incorporates into the machine tools it remanufactures. Both Ralph Thompson, Vice President of Engineering, and Paul Seelbach, Vice President of Marketing, point out that in this respect D & D is, like the majority of the small machine tool builders in the United States, a sophisticated assembler of specialized components. Controls, electric motors, position feedback devices, and even parts such as ball screws and ball bushing blocks can be obtained from specialty firms. In addition, rebuilding of machine tools is a common practice, and machine tool manufacturers are therefore well prepared to supply parts which may be necessary for rebuilding.

D & D's reliance on outside vendors for machining and fabricating work stems in part from the company's background as an electronics firm, and in part from a combination of the large variety of machining and fabricating tasks required with the relatively low volume in any single type of work. In the company's early years, it did not remanufacture sufficient numbers of machines to justify extensive in-house machining capabilities. Now, as its sales volume expands, D & D is beginning to do more machine work in its own shop. In addition, the company has turned a small part of its plant into a job shop, turning out screw machine products on its own Mini-Turn II bar machines. This job shop serves the double purpose of testing the Mini-Turn II design and familiarizing D & D with the operation of a machine shop. Concern over quality and delivery of machine work from outside suppliers may dictate the expansion of D & D's part fabricating and reworking capabilities.

4. Workforce

D & D's workforce has, since the beginning, been a highly skilled group of individuals. Initially, the company hired service technicians with several years of experience with N-C electronics from the larger metalworking firms in the Hartford area. As work volume increased, D & D added specialists in various aspects of machine repair to its payroll. Technicians have been attracted to D & D by working conditions which are better than those encountered in field or plant maintenance.

Remanufacturing of numerically-controlled machine tools requires a wide range of skills. In addition to the engineering work already described, remanufacturing involves a thorough understanding of electronic machine tool controls and interfaces between the control and the machine. As with new machine tools, the selling of remanufactured numerically-controlled machines requires expertise in applications and in field installation. The remanufacturing process requires mechanical and electrical skills even at the disassembly stage, not only to dismantle the machine without damaging it, but also to identify worn or damaged components and pinpoint the sources of any unusual damage. The rework of parts and subassemblies which are rebuilt at D & D requires specialists in machine repair, asthough some employees have been trained on the job in this type of rework. Finally, reassembly is perfomed by experienced machine fitters and electrical specialists. The remanufactured machine tool and its subsystems are then tested. These tests are conducted by assembly technicians and by the engineering and applications engineering staff, and include tests of machine functions, and measurement of positioning accuracy and repeatablility. Many of the tests require knowledge of electronic systems, and familiarity with the uses of sophisticated measuring instruments.

D. MARKETING

1. Sales

D & D Electronics' marketing department consists of a Vice President and five regional sales managers, who service the accounts of some 25 machine tool dealers nationwide. Marketing activities are split between sales of the company's new products, the Mini-Turn II chucker and bar machine (soon to be joined by a Mini-Turn III slant-bed design) and sales of remanufactured machines and remanufacturing services.

Sales of the Mini-Turn II are carried out through dealers who receive a commission on their sales. Dealers in the machine tool industry carry little or no inventory of machines (although they may have a demonstrator unit on hand), and usually represent several machine tool builders. The dealer places an order for a machine only after securing and order from a customer.

This method of selling has not proved entirely satisfactory for D & D's remanufactured machines, and D & D's ways of selling remanufactured machine tools and remanufacturing services have remained much the same as they were before the company introduced the Mini-Turn and acquired a dealer network. Although dealers are paid a finder's fee for each remanufacturing customer they locate, their sales efforts center on new machines. A dealer who knows that a customer needs a boring mill, for example, is more likely to try to sell the client a new one than to suggest the remanufacture of one of the firm's existing machines. Dealers do, however, know which firms in their sales area own older N-C machine tools of the types that D & D remanufactures, and can be sources of this information. Occasionally, a dealer may accept a used machine as a trade-in, and offer it to D & D for sale.

Most sales of remanufactured machine tools and inquiries about custom remanufacturing, however, take place directly between D & D and the customer, rather than through one of the dealers. Inquiries are frequently initiated by the customer, and repeat orders, primarily from large, sophisticated metalworking firms, result in an important fraction of sales.

2. Advertising

D & D relies heavily on advertising as a means of establishing contact with prospective customers. Advertisements are placed in national and regional metalworking trade publications, and are backed up with brochures which describe D & D's remanufacturing program for specific machines. A sample advertisement is reproduced in Exhibit 1; Exhibit 2 is a sample brochure. D & D's advertising and promotional literature stresses the thouroughness of its remanufacturing work, the improvement in machine performance and productivity which can be realized through remanufacturing, the low cost of remanufacturing when compared to replacement, and the short turn-around time D & D can offer compared to lead times for obtaining new machines. In addition, D & D makes an effort to establish remanufacturing as a concept, and to distinguish remanufactured machine tools from used or refurbished machines. It does so by contrasting its work with that of military remanufacturing programs (e.g. the periodic renewal and updating of airframes and avionics on military aircraft). The company also eagerly discusses its remanufacturing activities with trade magazines and other interested parties. As Paul Seelbach puts it, "Before you can sell a remanufactured product, you have to break the association between it and used or refurbished machinery."

3. Collection of Used Machines for Remanufacture

D & D's "custom remanufacturing" makes marketing the remanufactured product and collection of the old machine, or "core", a single activity. When a machine tool is remanufactured for its owner, the sale of the remanufacturing service automatically provides D & D with a used machine to work on. The customer, in effect, supplies the castings from which the remanufactured machine is built.

The collection and purchase of used machines for remanufacture and sale as remanufactured machines presents different problems. D & D has found that sound, used N-C machine tools are scarce and frequently expensive. They are seen as too valuable to scrap, with owners preferring to have them repaired or rebuilt. Those which appear on the used machine tool market (and a reading of publications which list used machine tools for sale will show that few are advertised) are usually offered in running condition, and are expensive. Figure #1 lists recent asking prices for used machines of the types which D & D remanufactures, taken from the September, 1979, issue of Industrial Machinery News.

D & D prefers to purchase only Tape-o-Matics, which are comparatively inexpensive (a used Model B can be bought for $10,000 or $11,000), easy for the company to remanufacture, and in great demand. A remanufactured Tape-o-Matic Model B or C may sell for $40,000 or more, depending on the model and level to which it has been updated. Used Tape-o-Matics are, however, difficult to find for sale in any condition, and, although D & D advertises aggressively to its dealers and customers, it has not succeeded in attracting as many machines as it would like.

FIGURE 1

Sample Prices for Selected Used* Machine Tools, September 1979
(Prices advertised by various dealers)

Pratt & Whitney	
Tape-o-Matic Model A, 1962,	$9,500
Cincinatti	
3 HP Single Spindle, 1969	$19,750
Cim-X-Changer, rotary table, 1967	$29,500
DeVlieg, horizontal boring mills	
3" Spiramatic, 1955 (manual control)	$97,500
4" Spiramatic, Tapac III NC, 1962	$95,000
3" Jigmil, rotary table, Cincinatti Milacron point-to-point NC, tooling, 1968	$198,500
3" Spiramatic, 1970 (manual control)	$139,500
Lucas, horizontal boring mills	
3" 41848, 1955, rebuilt 1969 (manual control)	$59,500
4" NC	$95,000
Other	
Brown & Sharpe Hydrotape NC Drill, 1970	$35,000
Burgmaster 2BHTL 6-spindle Turret Drill, 1968	$19,500
Burgmaster 3BHTL-SH 8-spindle T. Drill, 1964	$32,500
Burgmaster 25BHTL-SH 8-spindle T. Drill, 1964	$24,500
Burgmaster 3BHTL-SH 8-spindle T. Drill, 15 HP	$45,000
Burgmaster 8-spindle Turret Drill, 2000 RPM	$42,500
Giddings & Lewis 1-spindle Numerimite, 1963	$12,750
Kearney & Trecker Milwaukee-Matic EA Machining Center, 5 HP, 1964	$32,500
Kearney & Trecker Milwaukee-Matic EA, 1965	$37,500

Source: Industrial Machinery News, September 1979.

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* Not remanufactured.

APPENDIX B

REMANUFACTURING SURVEY FORM

Company Name:______________________________

Address:______________________________

______________________Zip__________

* * *

Person Responding:______________________________

Title:______________________________

Department:______________________________

Telephone:(______)____________________Extn.__________

Response Date______________________________

Alternative Contact:______________________________

* * *

This survey is intended to provide information from which we can create a comprehensive picture of remanufacturing in the United States. There are questions on your plant operations, products, markets, resources and problem areas. Your cooperation in this voluntary survey is valuable because remanufacturing is a field about which little data are available. Individual company responses will be kept completely confidential, and will not be available outside of the immediate M.I.T. project team. Our reports to the Department of Energy will be statistical summaries and sector aggregates -- you will in no way be identifiable with your response. This cover sheet will be detached upon receipt.

If you have any questions, please contact:

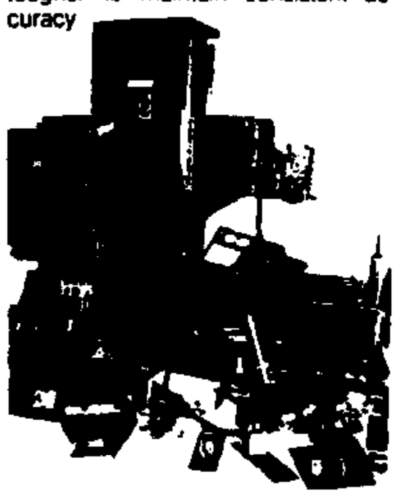
Robert T. Lund
Center for Policy Alternatives
Room W59-21, M.I.T.
Cambridge, MA 02139
Telephone: (617) 253-1666

U.S. Department of Energy Form CS-405, (authorized under P.L. 93-577)
Approved by Office Of Management and Budget No. 038 - S 79081

EXHIBIT 1 SAMPLE ADVERTISEMENT FOR NC MACHINE TOOLS

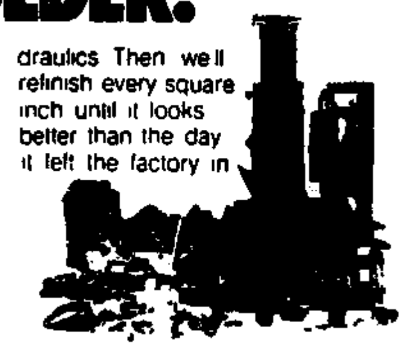
WHY SOME MACHINE TOOLS CAN GET BETTER WHEN THEY GET OLDER.

Let's say you're working with an old NC machine tool. Maybe 15 or 20 or 25 years old. The machine tool is still servicable, but you're logging a lot of downtime and it's getting tougher and tougher to maintain consistent accuracy.



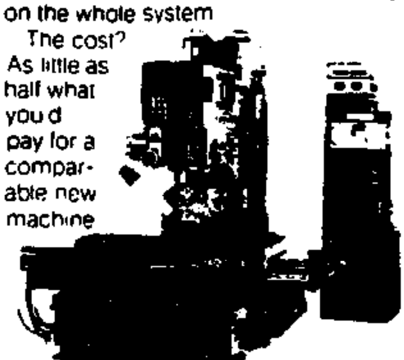
What do you do? You can scrap the machine or trade it in on a newer model or continue to put up with it. Or you can call D&D.

We'll take that old machine of yours, strip it right down to the frame and replace every worn or out-of-spec component. We'll replace the old NC control with the most up-to-the-minute NC system. We'll upgrade the machine to improve productivity and reliability by adding DC drives in place of hydraulics. Then we'll refinish every square inch until it looks better than the day it left the factory in



the first place, and we'll run it in to make sure it holds the tolerances you expect it to. Finally we'll give you an unconditional parts and labor warranty on the whole system.

The cost? As little as half what you'd pay for a comparable new machine.



Get the whole D&D remanufacturing story. Tell us about your old machine and we'll tell you how much better it will be when we finish with it. Write now. We're D&D Electronics Incorporated, 90 Murphy Road, Hartford, Connecticut 06114. 203/522-8306

D&D

REMANUFACTURING.

EXHIBIT 2 PORTION OF D & D BROCHURE

8 STEPS TO RE-MANUFACTURING

Re-manufacturing your Cintimatic machining center involves a complex sequence of operations. Regardless of machine, model, or capacity, however, these are the basic things we do to all Cintimatics that we re-manufacture:

1 COMPLETE RECONDITIONING . . .

Your Cintimatic is disassembled and cleaned, with the major casting components repainted to seal and protect them from corrosion and rust. Critical surfaces including the worktable are plugged, planed, and scraped. Lead screws are either re-manufactured to original tolerances or replaced, and new Thompson rails are fitted and installed together with new ball bushings and seals. And, of course, all other worn parts also replaced.

2 HYDRAULIC DRIVE SYSTEM . . .

The old hydraulic drive system is replaced by a 3-phase SCR drive motor system to improve machine setting time and accuracy. The new SCR drive also eliminates the problems of noise, heat, oil, dirt, downtime, and maintenance associated with the hydraulic system. To control vertical positioning of the carriage assembly, horizontal positioning of the worktable, and the quill feed, three new 1.5 HP DC permanent magnet drive motors are fitted.

3 CONTOUR MILLING CAPABILITY . . .

With the installation of analog feedback resolvers along with new carriage and table drive motors, we provide 2-axis contour milling ability. For full 3-axis contour milling, analog feedback scales are installed to control the quill feed drive.

4 SPINDLE DRIVE ASSEMBLY . . .

To enhance spindle stability, greatly improve tapping ability, and provide infinitely variable spindle speeds, we replace the variable sheave pulley system in your Cintimatic with a new, 7 HP SCR drive unit. This new drive provides greater speed selection and better control of machining operations and eliminates many mechanical parts.

5 SPINDLE HEAD ASSEMBLY . . .

Also removed and replaced is the original spindle head assembly. In its place we fit a new Universal #300 Qwik-Switch to enable you to make tool changes with much greater speed, ease, and efficiency.

6 ELECTRICAL SYSTEM . . .

The original electrical system is completely eliminated and replaced with new components and D&D-engineered interface wiring. By completely refurbishing the electrical system, we eliminate several sources of maintenance problems which might, otherwise, later appear as downtime on your production floor.

7 NUMERIC CONTROL SYSTEM . . .

To replace your older numeric control system, we offer smaller, more reliable, NC or CNC units, representing the latest state-of-the-art electronic reliability, capability, and flexibility. D&D warrants and services all these controls to provide a single source for all machine subsystems.

8 PENDANT STATION . . .

Although the original pendant station is retained, the features in your Cintimatic are changed to allow better on-station operator control. For instance, while feed rate and spindle speeds are normally controlled through programming, they can now be easily and immediately overriden by the operator right from his work station.

These major machine tool modifications make a D&D re-manufactured Cintimatic the most reliable and precisely re-manufactured machine tool you can use to cut metal.

REMANUFACTURING SURVEY FORM

Instructions:

* Partial responses are preferred to omissions.
* Where you find it necessary to make multiple answers to a question in order to answer it completely, please do so.
* Where an explanation or a longer answer is needed, please use the back of the page.
* The term "core" is used throughout to indicate non-functioning products which are returned to you for remanufacture.

I. OPERATIONS

1. What classification best describes your firm?

   a. 102 Independent remanufacturer

   b. 36 Original Equipment Manufacturer (OEM) and remanufacturer

   c. 5 Other ____

2. List principal products remanufactured and enter code of primary market served: (categorized by 3-digit SIC list)

	Product		Market	Code:
a.	SIC 349-- 3	SIC 357-- 1	SIC 367-- 4	
b.	SIC 351--26	SIC 358--22	SIC 369-- 7	A = Automotive
c.	SIC 352-- 1	SIC 359-- 1	SIC 371--50	C = Commercial
d.	SIC 353-- 2	SIC 361-- 5	SIC 372-- 1	F = Farm
e.	SIC 354-- 5	SIC 362-- 2	SIC 374-- 2	I = Industrial
f.	SIC 355-- 2	SIC 363-- 2	SIC 375-- 1	R = Residential
	SIC 356-- 5	SIC 365-- 1		

3. How long has your firm been involved in remanufacturing? 24.15 years

4. What were your total remanufacturing dollar sales and number of units of production for 1978?

	MEAN	RANGE
a. Sales	$ 6,837,188.	Min -$17,424. to $81,000,000.
b. Units	76,017,938	Min - 3o to ?

5. What portion of your total sales is associated with your remanufactured products?

   21 0-10% 12 11-25% 14 26-50% 12 51-75% 20 76-95% 58 96-100%

6. Is your firm 37 publicly held, or 105 privately owned? (Missing - 1)

7. How many employees are engaged in remanufacturing? 134.7 employees Range: 3 to 2650

8. What average hourly wage is paid to shop or factory employees (remanufacturing only)? $ 6.066 per hour Range: $3.00 to 12.00

9. How many separate remanufacturing plants do you operate? 2.6 plants

10. What is the area of your remanufacturing production space? 93,236 square feet Range:450 to 1,916,640

11. For your remanufacturing operation only, what is your total asset bracket (current and fixed assets)?

    a. 16 Up to $100,000
    b. 41 $100,000 to $500,000
    c. 16 $500,000 to $1,000,000
    d. 62 Over $1,000,000

    (8 Missing Cases)

12. For your remanufacturing operation only, what is your total investment in production equipment?

    a. 32 Up to $100,000
    b. 37 $100,000 to $250,000
    c. 27 $250,000 to $500,000
    d. 15 $500,000 to $1,000,000
    e. 29 Over $1,000,000

    (3 Missing Cases)

13. What percent of your remanufacturing volume is processed by each of the following methods?

a. One at a time	38.7 %
b. Batches of like items	34.89%
c. Continuous production lines	25.57%
d. Other ____________	1.31%
	100 %

14. What is your average lot size? 210.8 units Range: 1 to 10,000

15. In addition to remanufacturing activities, does your company:

	Yes	No	Missing
a. Rebuild or repair products on a one-by-one basis?	112	30	1
b. Perform general services (e.g. machining)?	64	72	7
c. Undertake salvage activities?	73	59	11

16. Rank your sources of replacement parts (1 = largest dollar volume, 2 = next largest, etc.):

		Overall Ranking	TOTAL # of responses (Total Possible = 143)	
Over-	a.	3	82	Make them ourselves
all	b.	4	66	Have made for us by subcontractors
	c.	1	119	Purchase from Original Equipment Manufacturers
Rank-	d.	2	100	Purchase from other parts vendors
ing	e.	5	26	Other ______

17. If your company is not an operating unit of an OEM, what assistance do you get from the OEM?

	Much	Some	None	NA/OEM	M.C.
a. As source of parts	49	62	12	16	4
b. Drawings	20	52	48	16	7
c. Manufacturing specifications	37	53	32	16	5
d. Collection of cores	4	34	78	16	11
e. Marketing and distribution	8	27	83	16	9
f. Other: ______	3	6	89	16	13

g. ______ Not Applicable, we are the OEM.

18. About what percentage of cores do you obtain from each of the following sources?

a. Warranty returns	4.99 %
b. Core brokers	14.66 %
c. Non-warranty service exchanges	27.91 %
d. Returned by lessor/renter	3.27 %
e. Returned by owner for rebuild	38.00 %
f. Salvage operators	10.39 %
	100%

19. What portion of your cores become available to you for each of the following reasons?

a.	Worn out, damaged, or defective	91.75 %
b.	Expiration of lease/rental	1.39 %
c.	For technological updating	5.07 %
		100%

20. What portion of the cores that you receive are immediately rejected as unusable? a. 10.08 % Range: (0-60)

For those cores that you accept, what percent by weight is discarded during remanufacture? b. 12.85 % (0-60)

21. What is the average yearly change in the following quantities, over the last three years?

		% Decrease	No Change	% Increase
a.	Remanufacturing sales ($)	____	____	____
b.	Unit volume	____	____	____
c.	Order backlog	____	____	____

d. If increases are indicated, were they due primarily to acquisition of other firms? 4 Yes 113 No 26 Missing

22. Break down product ownership during remanufacture?

a.	Remanufacturer (respondent)	74.5 %
b.	User of the product	18.5 %
c.	Other owner (OEM, other)	4.46%
d.	Other ____________________	2.57%
		100 %

23. How do your inventories break down into the following categories?

a.	Cores	27.46 %
b.	New replacement parts	24.39 %
c.	Work in process	18.34 %
d.	Finished goods	29.84 %
		100%

e. What was the value of your total remanufacturing inventories as of the end of the 1978 accounting year? $ 1,824,714.
Range 0 - 20,000,000

24. For a typical product, how are your materials costs divided among the following?

		Percent of Total Materials Cost
a.	Re-used Parts	48.94 %
b.	New Parts	44.44 %
c.	Other Mat'ls	6.24 %
		100%

25. Rank the following factors in order of their limiting effect on your ability to grow. (1 = most important, etc.)

# of responses (Total possible = 143)

Overall Ranking		Rank	# of responses	Factor
	a.	1	123	Scarcity of quality cores at an acceptable price
	b.	7	114	Competition from new products
	c.	3	118	Competition from other remanufacturers
	d.	2	115	Labor cost
	e.	4	121	Unavailability of sufficiently skilled workers
	f.	6	117	Plant production capacity
	g.	8	108	Federal and state regulations
	h.	5	109	Cost of new capital equipment
		9		Other

26. How important are the following factors to your selection of a remanufacturing plant location for your product line? (Circle the appropriate number on each line.)

Overall			Very Important			Not Important	Missing
6	a.	Location of parent facility	1-32	2-24	3-30	4-46	5
2	b.	Skilled workers available	1-51	2-38	3-35	4-11	8
1	c.	Access to good transportation	1-59	2-42	3-17	4-12	13
3	d.	Market concentration	1-50	2-43	3-22	4-20	8
5	e.	Core availability	1-40	2-33	3-33	4-27	10
4	f.	Low-cost labor	1-43	2-44	3-31	4-15	10

27. Which statement best describes each stage of your remanufacturing process? (More than one "X" may be appropriate.)

Missing		Energy Intensive	Cap'l Equip. Intensive	Labor Intensive	Energy & Equip	Energy & Labor	Equip &Labor	All Three
3	a. Disassembly	4	1	117	-	5	10	3
3	b. Cleaning	15	21	45	28	12	11	8
9	c. Reworking	3	33	52	8	2	29	7
3	d. Assembly	2	10	101	1	1	20	5

28. For the remanufacturing portion of your production only, what was the cost of your total 1978 annual consumption of:

a. Oil	$ 4,789	Range:	0 -- 75,000
b. Gas	$ 14,519	Range:	0 -- 118,085
c. Coal	$ 147	Range:	0 -- 8,978
d. Electricity	$ 38,321	Range:	0 -- ?
e. TOTAL ENERGY COST	$ ________		0 -- 850,000

29. For direct labor employed in each major remanufacturing activity, enter the average skill level required and how this skill is acquired:

Average Skill Level
1 = Highly skilled
2 = Semi-skilled
3 = Unskilled

Training Mode
1 = Formal, in-house
2 = Learn by doing
3 = Trained elsewhere

	Average Skill Level							Training Mode						
	Missing	1	2	3	1+2	1+3	2+3	1	2	3	1+2	1+3	2+3	Missing
a. Disassembly	2	6	78	57	-	-	-	25	101	1	9	1	1	5
b. Cleaning	2	2	53	84	-	1	1	19	84	-	6	-	-	34
c. Reworking	4	69	51	4	4	-	1	45	57	4	14	9	3	9
d. Assembly	3	61	67	7	5	-	-	53	53	2	11	9	2	8
e. Inspection	2	105	34	2	-	-	-	65	39	4	8	10	3	8

30. What is the percentage breakdown of remanufacturing personnel in each of the following classifications:

Hourly

Unskilled	a.	21.5
Semi-skilled	b.	38.72
Skilled	c.	11.6
Salaried	d.	______
Total		100%

31. Does your staff include professional specialists in the following areas:

	Yes	No	Missing
a. Process and plant engineering	61	78	4
b. Production control	79	60	4
c. Design	44	93	6
d. Quality assurance	91	48	4
e. Purchasing	90	49	4
f. Industrial engineering	52	87	4

II. MARKET FACTORS

32. When your firm entered into remanufacturing, did it do so

a. __76__ directly, as the main area of business, or

indirectly, as a result of being

b. __13__ original product manufacturer

c. __41__ repair service for product

d. __10__ other ______________________

__3__ missing

33. How important are the following sources of competition to your business? (Circle the appropriate number on each line.)

	Overall	Very Important			Not a Concern	Missing
a. New products	2	1-36	2-33	3-40	4-27	7
b. Used products	3	1-18	2-21	3-39	4-58	7
c. Remfg. products	1	1-81	2-31	3-15	4-10	5

34. How important are the following factors to a potential purchaser of your remanufactured product:

	Overall	Very Important			Not a Concern	Missing
a. Availability	1	1-123	2- 12	3- 2	4- -	5
b. Price	4	1- 69	2- 56	3-12	4- 1	5
c. Warranty terms	6	1- 42	2- 62	3-30	4- 3	6
d. Performance	2	1-105	2- 27	3- 6	4- -	5
e. Appearance	5	1- 49	2- 58	3-26	4- 4	6
f. Service	3	1-84	2- 36	3-11	4- 5	7
g. Other ________	7	1- 8	2- 3	3- 1	4- 2	129

35. What is the price of your remanufactured product relative to that of a new product? __57.79__ percent. Range: 20%-90%

36. To whom do you advertise?

	Yes	No		Missing
a.	75	63	End users	5
b.	76	62	Dealers	5
c.	77	61	Distributors	5
d.	15	123	Others	5

37. What percentage of your remanufactured products do you sell directly to the United States government? __1.34__ %

Range: 0 - 15%

38. What portion of your sales volume is distributed through each of the following channels?

a.	Direct sales to users	29.96%
b.	Distributor network	56.58%
c.	To new lessor/renter	.58%
d.	Other ______________	12.10%
		100 %

39. What is the approximate number of your:

a.	Own salespeople	8.9	Range: 0 - 100
b.	Distributors	247.6	Range: 0 - 16,000
c.	Dealers	1212.9	Range: 0 - 50,000
d.	End-user customers	9808.9	Range: 0 - 600,000

40. This question applies only to companies which remanufacture several different products (not just multiple models of the same product). Do your products share the following features?

		Yes	No	Missing
a.	Same group of users	66	9	68
b.	Same collection/distribution system	68	7	68
c.	Same field service facilities	62	9	72
d.	Same product technology	55	18	70
e.	Same remanufacturing technology	54	21	68

41. a. Do the products you remanufacture become part of larger products (e.g. engines become part of automobiles)? 99 Yes 37 No 7 Missing

b. If YES, what portion of the value of the overall product is represented by the value of the remanufactured component?

33 0-10% 22 11-25% 20 26-50% 10 51-75% 3 76-99% 2 100%

42. What portion of your remanufacturing sales volume is presently exported?

79 None 49 1-10% 5 11-25% 1 26-50% __ 51-75% __ 76-100% Missing-9

43. Have you experienced any of the following difficulties in exporting your remanufactured products?

	Yes	No	Missing
a. Lack of foreign trade experience	49	41	53
b. Core return problems	69	26	48
c. Domestic market already adequate	22	63	58
d. Distribution system lacking	50	37	56
e. Management indifference	19	64	60
f. No foreign market for product	10	70	63
g. Other ______	14	56	73

III. PRODUCT DESIGN

44. What factors significantly hin[illegible] your remanufacturing activity?

Missing		Yes/No	Characterist[illegible]	Example
			Materials:	
32	a.	32/ 79	Component construction	______
33	b.	16/ 94	Hazardous materials	______
33	c.	20/ 90	Other	______
			Original Manufacturing Processes:	
33	d.	7/103	Forming	______
33	e.	25/ 85	Assembly & fastening	______
33	f.	4/106	[illegible]her	______
			Other [illegible]actors:	
33	g.	57/ 5[illegible]	Number of models	______
33	h.	40/ [illegible]	Technology changes	______

45. How stable i[illegible] the design of the products you remanufacture?

a. 13 Undergoing rapid changes in design and/or materials.
b. 69 Moderate change from year to year.
c. 58 Slow rate of product change.
3 Missing

46. Do you remove the original nameplate or other identifying marks from the product? a. 41 Yes 93 No 9 Missing

Do you affix your own nameplate or label? b. 109 Yes 29 No 5 Missing

47. If the product is still being manufactured, have you recommended product design revisions to the OEM? a. 57 Yes 77 No 9 Missing

How has the OEM responded?

b. 36 Made changes

c. 16 No response

d. 3 Refused

88 Missing

48. Rank the reasons for which you make design modifications during the remanufacturing process? (1 = most important, etc.)

Overall rank/# of responses (Total possible = 143)

a. 2/ 83 Update to current technology.

b. 6/ 49 Comply with current product, health and safety regulations.

c. 7/ 44 Comply with current pollution control regulations.

d. 3/ 82 Improve operating efficiency.

e. 1/ 89 Correct design weakness so as to yield longer product operating life.

f. 4/ 56 Consolidate several models.

g. 5/ 60 Make the product easier to remanufacture.

h. 8/ 35 Use different materials of construction.

i. 9/ 6 Other: ______________________

j. 10/ 26 Not applicable -- we do not make any design changes.

49. Has your company ever experienced difficulties arising from a need for proprietary (patented) information or processes? 26 Yes 111 No 6 Missing

If YES, whom we may contact for further information:

Name: ______________________ Phone: ______________

50. Has your firm been party to a products liability suit concerning a remanufactured product?
24 Yes 111 No 8 Missing

If YES, whom in your company we may contact for more information:

Name: ______________________ Phone: ______________

51. Does your remanufacturing process or product involve any unusually hazardous materials or operations? 29 Yes 104 No 10 Missing

IV. PRODUCT SERVICE

52. Who commonly performs service on your product?

	Missing	Yes	No	
a.	8	59	76	Customer
b.	8	18	117	OEM's service representative
c.	8	60	75	Dealer or contractor
d.	8	53	82	Independent service agency
e.	8	70	65	Your own service representatives

53. What is the most common method for servicing the products that you remanufacture?

	Missing	Yes	No	
a.	2	116	25	Replace inoperative unit
b.	3	44	96	Repair in field
c.	2	9	132	Other ______________

54. What is the warranty period of your remanufactured products? ________

55. What is the warranty period of comparable new products? (If your product is used as a replacement part, what would be the warranty of a new part used in replacement service?) ________

56. How do your warranty terms compare with those of a comparable new product?
    a. 39 more liberal
    b. 80 the same
    c. 19 less liberal
    5 missing

Please enclose a copy of your standard warranty statement

Thank you for your cooperation.

APPENDIX C:

Excerpt from Remanufacturing Survey Findings, MIT Center for Policy Alternatives Report 81-12, January 1981.

Energy

Survey data has shown that the remanufacturing process relies significantly on used products as a source of material, and also to be labor intensive. These factors lead to the hypothesis that remanufacturing requires less energy than a new manufacturing operation, if the product and volume are equal.

A. Energy Consumption

The Remanufacturing Survey provided limited data on energy consumption. One question asked respondents to describe each stage of the remanufacturing process by its energy, capital equipment or labor intensiveness. Only the cleaning process was described with some frequency as being energy intensive (see section on process). All other stages were described as being labor or capital equipment intensive.

Another survey question asked respondents to state the dollar value of their energy consumption in 1978. This information was used together with sales data to calculate energy cost per sales dollar. First, aggregate totals for sales and energy (for 1978) were found, using the data from all firms that responded to both questions. Then a ratio of total dollar value of energy to total dollar value of sales was computed. For the 94 firms which contributed to the totals, the ratio for remanufacturers was .88%, which would appear to be a remarkably low energy cost.

Calculations for comparable new product manufacturers produced a ratio similar to that for remanufacturers. The SIC codes that best described each survey respondent were used as a basis for comparing manufacturers and remanufacturers of the same group of products. Data giving total sales and total energy consumed were gathered for new manufacturers in each respective SIC code.[1] Because the information required was only published to 1976, appropriate inflators[2] were used to adjust both sales and energy to 1978. The producer sales index was 1.14 and the energy index was 1.21. Using the inflated 1978 figures, the same procedure used to calculate the remanufacturing energy ratio was followed. Total figures for sales and energy consumed were found by aggregating the data from each SIC code. Then the ratio of total energy dollars to total sales dollars was computed. For new manufacturers, this ratio was .89%. However, because this ratio is based on sales, it is important to remember that remanufacturers typically sell products for 60-70% of the new product price. It thus appears that the average energy consumed by the remanufacturer is less than the average energy consumed by the new manufacturer. Table 2-19 shows this calculation.

TABLE 2-19

RATIO OF ENERGY COSTS TO VALUE OF SHIPMENTS FOR NEW MANUFACTURERS[3]

SIC CODES	1978 Weighted Fuels & Electric Energy ($ mil)	1978 Weighted Value of Shipments ($ mil)
349	.252	16.439
351	22.258	1963.87
352	.004	.362
353	2.117	203.708
354	3.878	257.165
356	8.757	667.315
358	2.429	203.750
359	.120	6.741
361	1.634	139.561
362	10.131	584.260
363	.286	24.136
367	3.847	248.002
371	528.149	61,256.375
372	.825	83.408
374	1.462	128.792
	587.659	65,903.913

$$\frac{587.659}{65{,}903.913} = .0089 = .89\%$$

* Each column is weighted by the proportion of sales represented by remanufacturing respondents in a particular SIC group to total remanufacturing sales.

B. Embodied Energy

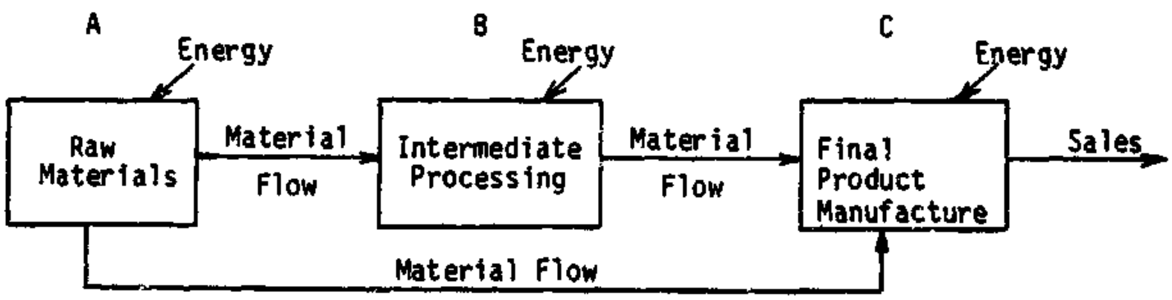
The above ratios of operating energy costs fail to account for the most important aspect of energy conservation through remanufacturing, however. The cores used in remanufacturing have energy embodied in them that was used originally to produce the materials and process the parts. This energy does not have to be respent to make any of the parts re-used during remanufacture. In contrast, a firm making a new product must purchase, through intra- or inter-firm transactions, 100% of the materials required for the final product.

As we have seen, new materials cost is about one-half the remanufacturer's materials cost. Because core costs are significantly lower than the equivalent new parts costs, the amount of embodied energy salvaged is well over half of the energy embodied in an equivalent new product.

To pursue this concept a bit farther, we attempted to calculate the value of embodied energy as a percent of sales for two new product areas using input-output tables. The calculations were carried far enough to demonstrate it is highly likely that the final product producer "buys" more energy in the materials and parts that make products typically remanufactured than it buys directly as energy.

The picture for inputs into a manufacturing process would, on a highly aggregated level, be similar to Figure 2-1.

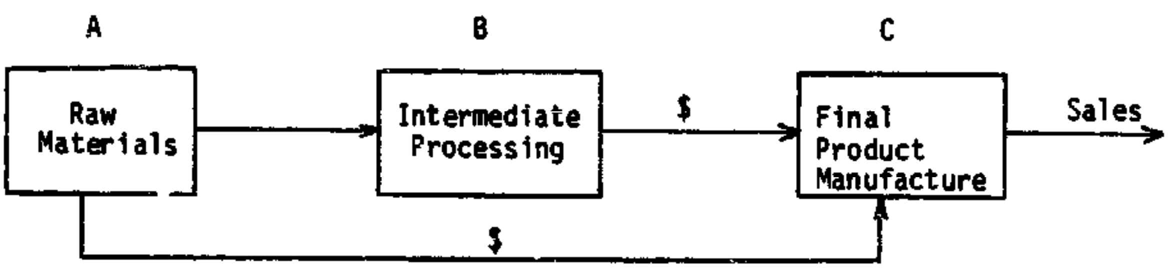
FIGURE 2-1
SCHEMATIC DIAGRAM OF MATERIAL FLOWS IN MANUFACTURING



Each box in the diagram represents a point where processing of some form is done; each arrow represents a possibility for material transfer from one process point to another. Embodied in the material flow is the energy used at the processing point from which the material is coming. For example, there is a material flow from point A to point B. Material going into point B has embodied in it the value of energy consumed at point A. To get an estimate of the total energy used to produce the goods that flow to the market from point C, one must consider not only the energy used at point C but the energy used to produce the material that flows from A to B, B to C, and A to C. Using two SIC codes as examples (351 - Engines and Turbines, 371 - Motor Vehicles and Motor Vehicle Equipment), the above schematic was used as a framework to trace energy inputs into a finished product. A publication called The Detailed

Input-Output Structure of the U.S. Economy: 1972[3] has one table which is a complete matrix of the dollar value of material inflows from one industry to another. Although this publication has its own system of classifying industries, it also includes an index to cross-reference their classification system with the SIC code. It was therefore possible to get a list of all material inflows into SIC numbers 351 and 371. The list of inputs can be divided into two mutually-exclusive groups: those which fall into major SIC group 33, Primary Metal Industries, and those which do not. The sum of each group provides an approximation of the dollar value of raw materials flowing to the final product manufacturer (A to C) and the dollar value of intermediate goods flowing to the final product manufacturer (B to C). In addition, by cross-referencing to the index, the group of SIC codes which contributed to each total can be obtained. Referring back to the schematic diagram, two arrows, theoretically now, depict the value of material flows (indicated by the double lines).

FIGURE 2-2
SCHEMATIC DIAGRAM OF VALUE FLOWS IN MANUFACTURING



The next step is to determine what portion of the materials value can be attributed to energy costs. A ratio to establish the relationship of energy cost to sales revenue is calculated for process A and process B. If the appropriate ratio is then applied to the dollar value of shipments from A to C and B to C, a dollar value representing the energy expenditure in each flow of materials will result. Earlier in this section, a method was used to estimate the ratio of energy cost to total sales revenue for original equipment manufacturers of final products and remanufacturers. A similar process is used to find that ratio here, described in general terms so as to apply to any SIC code and to any particular stage of the process. The steps are listed below.

(1) Establish the group of SIC codes (at the 3 digit level) which contribute to the flow of materials from one stage of processing to another (e.g., from A to C).

(2) For each 3 digit SIC code in the group, establish the value of shipments (sales) for 1972.[4]

(3) Adjust each value of shipments from 1972 to 1978 with an appropriate inflation index.[5]

(4) For each 3 digit SIC code, establish total value of purchased fuels and electric energy for 1972.

(5) Adjust each fuel value from 1972 to 1978 using an appropriate inflation index.[5]

(6) Sum the adjusted values of purchased fuels and electric energy so there is one total which includes all SIC groups.

(7) Sum the adjusted values of shipments so there is one total which includes all SIC groups.

(8) Establish a ratio of energy cost to sales dollars for a particular process by dividing the sum of energy expenses (from Step 6) by the sum of value of shipments (from Step 7).

$$\frac{\text{(Sum of Energy Cost)}}{\text{(Sum of Value of Shipments)}}$$

Table 2-20 illustrates a specific example of this method. The ratio of energy to value of shipments is calculated for primary inputs (raw materials) into SIC 351. On the diagram, this ratio is for the flow of materials from point A to point C.

TABLE 2-20

RATIO OF ENERGY COST TO VALUE OF SHIPMENTS AT POINT A

Primary Inputs to SIC 351	1972 Value of Shipments ($ mil)	1978 Adjusted Value of Shipments ($ mil)	1972 Purchased Fuels and Electric Energy ($ mil)	1978 Adjusted Fuels and Electric Energy ($ mil)
331	28,671	53,901	1,437.6	3,908.8
332	5,686	10,689	255.5	694.7
333	6,004	11,287	340.3	925.2
335	12,651	23,783	203.3	552.7
336	2,344	4,406	53.4	145.1
339	805	1,513	39.1	106.3
		105,579		6,332.8

$$\frac{\text{(Sum of Energy Cost)}}{\text{(Sum of Value of Shipments)}} = \frac{6,332.8}{105,579} = .0599 \text{ or } 5.99\%$$

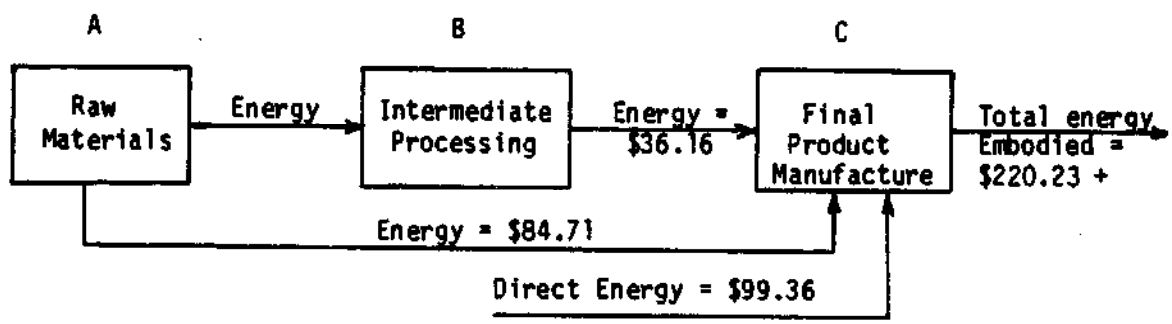
At point A, which represents the processing of primary materials, the estimate of energy usage in this case is 5.99% of sales. The input tables detail the dollar value of shipments from this group of primary metal industry groups to SIC 351. Inflated to 1978 dollars, this value times the energy ratio would give an approximation of the dollar value of energy embodied in the primary material shipments to SIC 351.

Value Shipments ($ mil)	X	Energy Ratio	=	Value of Energy Used ($ mil)
1,414.3	X	.0599	=	84.71

On the schematic diagram the above value of energy used represents the energy value embodied in the flow of materials from A to C. The same procedure used to calculate this value can be used to calculate the energy embodied in materials flowing from B to C. The energy used at point C comes directly from a Purchased Fuels and Electric Energy Chart for SIC 351, inflated to 1978.[6] All of these values are shown in Figure 2-3.

FIGURE 2-3

SCHEMATIC DIAGRAM OF ENERGY COST FLOWS IN MANUFACTURING SIC 351 ($ million)



The information in the material input table leads directly to the calculation of energy embodied in the material flow from A to C and B to C. However, the data on material flow from A to B are not readily accessible. This would require tracing all inputs to 23 SIC groups which flow out of B to C and even then, only a fraction of these inputs are attributable to the material flowing to SIC 351. The point of the exercise described in this section is to draw attention to the total energy picture rather than just that energy consumed in the final production stage. The analysis also shows how the energy consumed increases when the material flow is considered, important because the survey data indicate that in remanufacturing, only about 50% of material costs are for new materials. Calculating the material flow from A to B was not necessary to highlight the above points.

As mentioned earlier in this section, this analysis was done for two SIC groups: 351 - Engines and Turbines and 371 - Motor Vehicles and Motor Vehicle Equipment. When considering the energy consumed in only the final production stage, the ratio of energy consumed for each dollar of sales was 1.19% for SIC 351 and 0.91% for SIC 371. When the value of energy embodied in raw and intermediate material flows were included, the ratio for SIC 351 increased to 2.64% and for SIC 371, to 2.12%. Both ratios more than doubled in size. Also, because the material flow from A to B has been excluded, the increases observed are conservative estimates. Though the increases may not look too impressive, the dollar values involved are large enough to make a small percentage increase into a fairly substantial dollar volume. For example, the value of shipments for SIC 371 in 1978 was approximately $80 billion. An increase in the ratio of energy consumed to value of shipments from .91% to 2.12% is an actual dollar increase in energy expenditures of $ 970 million.

Energy Leverage

If we use the logic and data developed in the preceding section, plus other information obtained by the survey, we can get a feel for the potential for energy savings represented by remanufacturing. Let us take the case for SIC 351 -- Engines and Turbines. For new product manufacture the energy embodied was shown to be at least 2.6% of the value of shipments, with an important energy component (the energy embodied in raw materials shipped to intermediate processors) missing. The survey found that the energy used to remanufacture all products was about 0.9% of the value of shipments. Because a substantial fraction of the survey respondents were automobile component remanufacturers, this value is probably similar for the above SIC sector.

We can then infer the ratio of the cost of energy to remanufacture a product to the cost of energy embodied in that product that is saved by remanufacture. First we must adjust the remanufacturing energy value to make it a fraction of the equivalent new product price. Remanufactured goods prices average about 60% of new product prices. (See section 4-C.) Thus the amount of energy used in remanufacturing a product is 0.9% x 60% or .54% of the price of a new manufactured product. The ratio between energy of remanufacture and embodied energy in SIC 351, then, is 0.54/2.6, or about 1:5. This means that, for every dollar spent on energy to remanufacture an engine, at least five dollars of embodied energy are saved. For the automotive sector (SIC 371) the ratio is 0.54/2.12, or about 1:4.

A dollar example may be useful. According to our calculations, the 1978 value of shipments of SIC 371 of $80 billion contained at least 2.12% or $1.7 billion of embodied energy. If only 1% of the output of SIC 371 were to be salvaged through remanufacture, the remanufactured output would contain $17 million of embodied energy. The amount of energy used to remanufacture this amount of product would be roughly 0.9% x60% x 1% x $80 billion, or $ 4.3 million. Thus, the $4.3 million energy expenditure would have "saved" $17 million of energy needed for an equivalent amount of new product.

To be more rigorous would require that we identify the raw-to-intermediate energy component for new products (the energy between points A and B of our diagram), and that we take into account the embodied energy in the new parts and materials purchased by the remanufacturer to replace unusable components. Transportation energy costs would also have to be included for both manufacturing and remanufacturing. These corrections tend to offset each other, however, and it is not likely that the sense of energy efficiency inferred here would be greatly altered by a more comprehensive treatment.

This concept of energy leverage is an important reason for encouraging this form of reclamation of discarded durable products. No other mode of producing a finished product is as energy efficient.

REFERENCES

1. From Annual Survey of Manufactures, 1970-71, Department of Commerce.

2. Taken from statistical tables in Economic Report of the President, 1980.

3. U.S. Department of Commerce: Bureau of Economic Analysis.

4. 1972 data are used in this exercise for value of shipments and energy consumed to be consistent with the input-output data, which is published only as recently as 1972.

5. Can be obtained from Economic Report of the President, 1980 which has a section on indices.

6. From Annual Survey of Manufacturers, 1970-1971, Department of Commerce.

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