Environmentally Conscious Manufacturing

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Abstract

Current reuse of manufactured goods is focused on recycling for the material and energy content. However, there is a great potential in reusing the product assemblies and components. With an increasing concern for the environment, increasing world population, decreasing sources for raw materials and energy, the concept of recovering products with the intent of reusing the product and its components holds great promise for sustainability. This paper reports the research of its authors; however, the paper asks more questions than it answers. Designers must design products to be reused both in the whole and in their components. This includes considerations for disassembly, the compution of part lives and the choices of easily separable materials. Manufacturers must overcome the problems of increased variability that this brings in scheduling, inventory, and processes. First and foremost, both designers and manufacturers must develop an attitude that environmentally conscious manufacturing is possible by reusing existing products as a resource.

Introduction

The purpose of this paper is to propose a sustainable design and manufacturing system based upon the reuse of products, product assemblies, subassemblies and parts. This was called demanufacturing previously. However, a better term, "environmentally conscious manufacturing," has emerged. This system is somewhat different than the remanufacturing and recycling programs currently practiced. While some recommendations based upon research findings can be made, the reader will note that this paper asks more questions than it answers. By formulating the questions, it is hoped that answers will be found to make environmentally conscious manufacturing a reality.

It is widely recognized that industrialization has given both the United States and Japan their high standards of living. But this has not come without cost. The consumption of resources such as raw materials and energy necessary to produce the products we take for granted is enormous. It is estimated that 10 tons of materials are necessary per person per year to support our standard of living. 94% becomes waste within a few months after extraction.1 Most of the waste is associated with reducing low grade raw materials to the material forms needed for manufacturing products.

It is also widely recognized that a great number of people on the earth have a substantially lower quality of life than that we enjoy. As they strive to reach an improved quality of life, their consumption of resources will also increase. Within the next one hundred years, the population of the earth, barring calamity, will again double.2 However, the demand on resources is estimated to increase fivefold. This is considerably lower than the potential 16 fold increase should all of the earth's people have the same standard of living of the United States or Japan.3 We are able to predict with statistical certainty the extent of known resource reserves needed to support our society. Can we continue to refine from raw resources the materials necessary to maintain our quality of life? Obviously, the answer is no. Either we sacrifice our standard of living or we must become more efficient in the use of resources.

In the United States, it is estimated that four pounds of waste is generated daily by each person. In Japan the number is less, about two pounds; however this is still significant. In the United States, landfill waste disposal is just starting to become a problem, mainly due to the increased awareness of waste toxicity and the recognition of the potential to transmit the toxic substances to the ground, the water and the air. In the United States, 80% of waste is landfilled, 9% incinerated and 1% recycled.4 While we have yet to effectively reduce the 711 billion tons5 of waste projected yearly, we are reluctant to create new landfills to replace the capacity used. Incineration is also being debated: do we pollute the air with emissions over polluting the earth and water? And at what cost? Current estimates indicate that the costs due to waste disposal are greater than $100/ton. What about Japan? Each year Japan generates 447 million tons of waste.6 With very limited space per capita, Japan is forced to incinerate 70% of its waste (20% is landfilled and 1% is recycled.)

Manufacturing has a well placed role in finding a solution to these problems. As converters of the materials and energy to con-


5. Green Products by Design, Office of Technology Assessment, United States Congress, 1993. Pg. 24. This includes all wastes, hazardous and nonhazardous. In 1988, EPA reports that 180 million tons of municipal waste were generated.

sumer products, manufacturers dictate the usage of the resources by their product and process design. Part of the answer is recycling in the classical sense: the recovery of materials and the subsequent processes to convert waste to materials for manufacturing. However, we believe that there is a more efficient answer: recover the used product and remanufacture the product such that it continues to be used without the materials reverting to their raw or pre-manufactured states. Such a program not only reduces wastes but also eliminates the need for consuming large amounts of energy to reduce a product back to its constituent materials.

This idea is not new: the principles were at work in returnable and reusable glass milk bottles. This idea is also inherent in certain limited applications, primarily those that involve remanufacturing. However, most products are not designed nor are they made with the explicit intent for refurbishment for reuse. This paper discusses a paradigm shift for designers and manufacturers that requires a more efficient resource program. A hierarchy of recovery is constructed based on resource efficiency.

Definitions

**Demanufacturing:** Demanufacturing was first used by the authors to refer to a process of reducing and retrieving usable components from a product successively from the product level through assemblies, subassemblies followed at a lower level by parts and lastly by materials for use in new or used products. The key concept is that the highest level of the product is reused where possible. Neither of the authors particularly likes this term: it gives a negative connotation to the intent. Yet, as pointed out by Boothroyd and Alting, no other term quite meets the needs of what is described. The words “recycling,” “remanufacturing,” “disassembly,” and “rebuilding” all closely relate to the concept embodied in the word “demanufacturing.” Yet the terms fail to carry in their meanings the necessity of a hierarchal product component recovery, the reuse of recovered components in original manufacture and the efficiency of increased product life cycle benefit cost ratio gained by demanufacturing. Note that in this context, component does not necessarily refer to a single part. A component may well be the complete product or an assembly of the product.

**Disassembly:** This is a reduction of a product to its assemblies and subordinate parts. Disassembly is seen as a cost adding step to demanufacturing. Disassembly further does not import the need for reuse of the components or materials. Thus disassembly fails to convey the key concepts of demanufacturing.

**Rebuilding:** Rebuilding returns a product to an as-was condition. For example, if a 1965 machine tool is rebuilt, the attempt is to return the machine to the same condition that existed when it was delivered in 1965. In many cases, this may include adding new controls. Rebuilding implies that the product is essentially a minimally refurbished product with essential worn parts replaced.

Rebuilding is one method of the demanufacturing system.

**Recycling:** A dictionary definition states in part “3a. to extract useful materials from (garbage or waste).” The focus of recycling is on material recovery, not manufactured end product recovery. The term “recycling” is rarely, if at any time, applied to higher level major manufactured components. Again, recycling is but one method within the demanufacturing system.

**Remanufacturing:** Of all of the terms, remanufacturing comes the closest to the concepts embodied in demanufacturing. Spro w defines remanufacturing as “Building today’s machine on yesterday’s base and possibly preparing it to adapt later to tomorrow’s technology.” What remanufacturing lacks is the concept that recovered components might be used in new manufacture.

**Life Cycle Analysis**

Environmentally conscious manufacturing begins with an understanding of the product life cycle. The life cycle begins at the point that material is taken from nature and ends with return of the material to nature. Figure 1 proposes a model for the life cycle. The waste generated as a by-product to the product is not shown. In many cases this waste is more significant than that directly caused by the product. The Resource Conservation and Recovery Act (RCRA) defines solid waste and discarded materials as anything inherently waste-like. Since everything begins and ends with nature, everything taken from nature is inherently waste-like. Within the life cycle of a product there are interior loops for reuse, remanufacturing/demanufacturing and recycling. Nature is the ultimate recycler. In principle, the more interior loops that exist within the life cycle of a product, the more efficient the product.

The life cycle is interpreted in terms of costs and benefits. All too often, commentators on the life cycle of products focus on the costs without examining the benefits. Substitutable products, and manufacturing methods must be compared by examining the difference between the total benefits and the total costs. Unfortunately there are no standard meter sticks for this. As a result, it is possible to support sub-optimal results showing one process is “better than another” by failing to consider the by-products and the total life cycle costs and benefits. The cost of a product, that is, the expenditure of resources caused by the product, is the sum of all costs until the cycle has been completed for the product and its by-products. Amortized into the costs are factors for labor, plant, overhead and transportation. The benefits of a product are typically enjoyed during usage although by-products may have considerable benefit associated with their uses. One can argue that the benefits of a product are reflected by the price of the product.

Initial costs of the product begin with raw material and energy acquisition. For most manufacturing products this is either mining or drilling. The major costs at this point include the energy used to access the minerals, the materials used in the acquisition processes and the waste such as gangue, mine tailings, drilling mud and vented naphtha. The foremost objection to mine wastes is that they

11. Spro w, op cit.
are unsightly and due to their negligible soil are unlikely to grow an immediate ground cover. Many of the mine tailings can be classified as hazardous waste: they often contain high amounts of sulfides, arsenides, heavy metals and other chemicals that when exposed to the air and surface water will create major sources of pollution if not properly treated. There are very little by-products at this point unless the wastes can be used as commercial fill or perhaps if the naphtha can be used as fuel as in the case at Prudhoe Bay, Alaska. In many cases, the cost of prospecting and discovery of the raw material source also must be factored into the costs.

The next major step in the life cycle is refinement of materials. This stage creates the most waste. Table 1 lists minimum content of certain metals in mineable deposits. Close examination reveals that most of the ore becomes waste to gain the mineral content. During the refinement processes, energy and chemicals are used to concentrate the desired materials to the purity needed for a product. The sources for the materials are two fold: virgin raw materials and recycled product materials. Wastes created at this step are frequently the most polluting in terms of impact upon the environment. Probably at this stage, the greatest number of by-products are created. As a result, it is the most difficult to quantify the product benefits since the by-products may be both numerous and form complex system relationships with other products.

Manufacturing is the conversion of materials into products. The material sources may be from the material refinement stage, by-products of other manufacturing products or discarded products. This paper, focuses on providing materials for manufacturing from discarded products. The manufacturing product costs are driven by reshaping the geometry and mating of the material to other materials. Using the schema proposed by Goldratt and Cox, the goal of manufacturing is to make money. This is quantified by the terms throughput (the money generated by the sales of product to satisfy demand), the inventory (the money used to generate purchased items for things the manufacturer intends to sell) and the operational expenses (the money used to generate things for turning inventory into throughput). The benefit of a manufacturing firm is realized through profit.

Product usage is the performance of the product to provide a function to a user. Typically this stage should generate the most benefits and the least cost. Costs arise in the form of energy consumption and materials used to support the performance of the product. Included in the costs are the wastes generated by the product during its function. Benefits include the results of product function and any by products that may be generated.

Product disposal occurs at the point that the user no longer has

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Table 1: Mineable Deposit Grades

<table>
<thead>
<tr>
<th>Metal</th>
<th>Minimum Content in Ore</th>
</tr>
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<tbody>
<tr>
<td>Aluminum</td>
<td>35%</td>
</tr>
<tr>
<td>Beryllium</td>
<td>0.05%</td>
</tr>
<tr>
<td>Chromium</td>
<td>25%</td>
</tr>
<tr>
<td>Copper</td>
<td>0.3%</td>
</tr>
<tr>
<td>Iron</td>
<td>16%</td>
</tr>
<tr>
<td>Lead</td>
<td>3%</td>
</tr>
<tr>
<td>Magnesium</td>
<td>3.3%</td>
</tr>
<tr>
<td>Manganese</td>
<td>30%</td>
</tr>
<tr>
<td>Tin</td>
<td>1%</td>
</tr>
<tr>
<td>Zinc</td>
<td>6%</td>
</tr>
</tbody>
</table>


Design for Environmentally Conscious Manufacturing

The major tool of environmentally conscious manufacturing is the design of products. It is doubtful that manufacturing can be efficient if design does not accommodate the environment. The opening statement of the now widely read National Research Council publication *Improving Engineering Design* is “Engineering design is a critical component of the industrial product realization process. It is estimated that 70 percent or more of the life cycle cost is determined during design.”

The improvement of the benefit-cost ratio (developed from life cycle analysis) requires that costs be reduced and benefits be increased. By designing for the environment, it is possible to do both. The goals of design for environmentally conscious manufacturing are to

- reduce the energy and material (both hazardous and nonhazardous) content,
- develop products that are possible to be reused by follow on consumers
- create product features that promote remanufacturability/demanufacturability
- and select materials that are recyclable.

Meeting these goals increases the efficiency of using the resources available while reducing the cost of products to the consumer and the environment. Formerly, designers rarely considered the disposal during concept. As a result, products were not design...

for material reuse. Strategic product planning in the business community failed to foresee benefits from the disposal process. This lack of foresight was caused in part by an "end of pipe" mentality that existed with the sale of the product and the transfer of title. Manufacturers assume that their responsibilities ended when the product was sold. Also contributing to this was the abundant existence of low cost virgin materials.

However, recent product liability and environmental laws has change this way of thinking in the US. Product disposal is now a major corporate strategic planning issue. This change has initiated a necessary attitude that products can be reused, remanufactured/demunufactured and recycled. It is believed that this is the most important change that must occur in the manufacturing enterprise if manufacturing is to become environmentally conscious. This is occurring as evidence by recent major corporation statements to designers and suppliers regarding materials. In particular, the Ford Motor Company has issued a very demanding directive that vendors insure and demonstrate the environmental friendliness of their products with respect to the automobile.

Change in designer mentality occurs when the corporate leaders require design staffs to demonstrate the product designs proposed meet environmental specifications. One way of insuring that design considerations be considered at the front end of a project is to place environmental requirements in the Quality Function Deployment (QFD) matrix requirements list. The design features are then evaluated in terms of their environmental performance. Such requirements as "be easily disassembled," "failed parts easily removed and replaced," "ease of service," "efficient use of materials," and "potential of recovering components and recycled materials" all are suitable entries for the left hand side of the QFD matrix.

Disassembly is a critical issue to design products for the environment. The disassembly must be controlled and efficient. This has several implications for fasteners, adhesives and welds. Fasteners must be designed to be two way. Screws, nuts and bolts have long been a favorite of the mechanical designer; however, these items are not necessarily the most efficient fasteners when both manufacturing and the environment are taken into consideration. Special purpose assembly machines have been designed to insert and place screws but the problems associated with automated screw, bolt and nut removal for disassembly are large unsolved. While newly constructed bolt connections can easily be disassembled using automated methods, the problems associated with corrosion, soilage and damage to both the heads and the threads of the screws, bolts and nuts while in use create problems during automated disassembly. Minimal motion fasteners such as releasable snap fasteners are preferred.

Adhesives and welds must be used with care. While discussing demanufacturing with an appliance manufacturer, the problems of recycling refrigerators was addressed. One of the major difficulties with the demanufacturing of this device was that the insulation was glued to the panels. There appears to be no way to efficiently separate the foam from the panels. Clearly, dissimilar materials must not be joined by permanent adhesives. Welds and adhesives in general prevent the disassembly processes. However, certain joints may designed to fail under the disassembly processes and then reassembled using currently available joining methods.

The designer should consider the systematic aspects of the disassembly of a design as well. If certain parts are likely to fail in use, the product should be designed such that these parts can be quickly removed. In addition, if the product contains a hazardous chemical or material, the product should provide the ability to remove these substances early in the disassembly. If this is not done, extra costs associated with the handling of these substances may preclude demanufacturing and recycling as an option.

Modern design does not address the reusability of parts. For parts to be reused, the designs must permit standardization of shapes and sizes. It is highly recommended that shape selection be performed using the techniques of group technology. Parts with nonstandard characteristics must be avoided. Such parts when recovered will have marginal utility at recovery. In addition, the parts subjected to cyclic loading must be designed using infinite fatigue life techniques. Currently a few critical parts are designed for fatigue. The remainder of parts are designed knowing from experience that they will not fail during a single user life of the product. However, the design for environmental conscious manufacturing violates this basic assumption: parts will conceivably be reused over many product lives.

The design of product finishes and their ability to be cleaned is yet another consideration. When a consumer buys a product, frequently their attitude towards the product is controlled by the packaging and exterior finishes of the product. While certain products are designed with an "antiqued, distressed surface," this is usually not desired. Products and components designed for reuse must have finishes that resist surficial incidental wear or have coatings that permit efficient restoration. A particularly worrisome problem of recycling is the contamination of the reclaimate by coatings. Paints, protectants and labels must be compatible with the demanufacturing processes. For example, one manufacturer stated a supplier delivered polyethylene bags designed to be recycled. However the manufacturer negated that ability of the bag to be recycled by applying a paper label to the bag. The problem was solved by developing a polyethylene label for this usage.

The design choices of materials has ramifications for remanufacturing and recycling. Materials at the recycling stage must be separated. The designer therefore should design into the product the ability to quickly recognize what the material is. Comparable coding systems to SAE J1344 for plastics is absolutely necessary. In addition, the designer may also be able to design the parts so that part features readily support the separation processes. A recommended principal is to reduce the number of differing materials where ever possible.

In summary, the designer must develop an attitude that fosters efficient uses of materials. In doing so, considerations will be given to including environmental specifications in the design cri-

teria, providing products which facilitate disassembly, choosing parts based upon standards established to support component reuse, selecting materials that easily identified and separated and reducing the number of materials to execute a design.

Production Systems

Environmentally conscious manufacturing invokes on the production system rather unusual circumstances. The manufacturing industries of both the United States and Japan are based upon virgin materials of high purity. In addition, the success of these industries is largely due to the ability to both control the variations of the processes and the product. However, demanufacturing requires that manufacturers accept products with considerable variation in state due to wear, tear and damage. In addition the variable rate of recovery of products for demanufacturing effects inventory, the scheduling and the choices of processes.

The starting place for manufacturing is demand. Customers must want the product and be willing to pay for the product some value in excess of the costs and a fair profit. Thus, the demanufactured product must be as similar to the new product as possible in value. Its quality and its ability to function should be indistinguishable from the "virgin" product. However, previous experiences with used products and the stigma attached requires that demanufactured product be labeled as such and that it be sold at a discount. This is not necessarily all bad: if the consumer discovers that the demanufactured product is indistinguishable from the new product but cheaper to purchase, there should be a transfer of demand from the new product to the demanufactured product. The paper recycling industry has established a precedent in this regard. A large portion of the paper used in the United States today is recycled. Originally, it was thought that recycled paper was inferior. However, with improved recycling technologies modern papers with recycled constituents are indistinguishable from virgin paper to the user. As a result there is a demand now for paper with a recycled content.

Another concept for generating demand is to create demanufactured products for purchase in the lesser developed countries (LDC). In these countries there is insufficient capital to purchase full price new products. Whereas the new product might not sell in the LDC, a lower cost, demanufactured product might. These markets are much greater than those existing in the developed nations.

The demanufacturing system inventory costs and the operational expenses are lower than initial manufacturing. In Figure 1, as a product moves from nature to the user it incurs costs. A hierarchy of a product is listed in Figure 3. The gaps between stages in the hierarchy represents cost. When demanufacturing a product, the least movement down the hierarchy results in the least cost expended to return a product to a marketable state. The savings exists in both material inventory (less raw materials needed) and operational expenses (less processing required). However, to efficiently use this hierarchy, the product must be designed such that it is possible to move down the hierarchy without exceptional costs. The reduced inventory and operational expenses has been exhibited clearly in the remanufacturing of machine tools. A machine tool that originally costs $500,000 can be remanufactured for approximately $100,000. This is based on a single machine absorbing all the costs of engineering and operational expenses. In an unpublished economic study of demanufacturing, it was found that the key variables to controlling costs are the amount of engineering required, the cost of product recovery, the volume of the product to be demanufactured and the value of the product after demanufacturing. In many cases the cost of recovery is nearly negligible. If the costs of engineering can be amortized over sufficient volume, it is possible to have returns of investment in excess of 30% for demanufactured products selling at 80% of the original price. These returns on investment reflect the efficiencies that exist if the materials in the product do not have to be purchased and that the greatest majority of the parts within the product do not have be processed except for inspection and testing.

Manufacturing efficiency is achieved by product schedules. Current manufacturing practice focuses on optimizing the inventory scheduling needs against holding and order costs. Demanufacturing occurs some time after the original manufacturing based upon the wear out and replacement of the product. If not otherwise controlled, this time gap could be significant. For example, discussions with an appliance maker suggested the replacement time on refrigerators was approximately twenty years. The remanufacturing of machine tools also indicates a similar period of replacement. For other items such as automobiles, the period is shorter but still significant. Therefore, the growth of inventory due to remanufactured products will be delayed if it is to rely upon products that in design at this time.

There are two clear solutions to this: first, demanufacturing techniques need to be developed for products on the market at this time. While the designs have not considered, in general, the product reuse, there are more than ample indications that current products if demanufactured could improve the material efficiency of a manufacturer. It was recently reported that GM is still using an engine design developed in the 1960's for their latest luxury automobiles. If models of this engine can collected and demanufactured, the need for "virgin" parts would be impacted.

Secondly, the period between demanufacturing can be influenced by lease times. Assuming that the consumer will always need the services of the product of consideration, the product could be leased for a period, replaced and then returned to the manufacturer for demanufacturing. This would remove the variability associated with the period of product lives. A lease policy allows the manufacturer to better forecast the need for materials and their sources.

Products when returned for demanufacturing requires different routings depending upon the failure modes experienced, the wear and tear on the product and any unusual product failures. In current manufacturing practices, the flow of material through a plant is well defined by the process routing. However, demanufacturing requires variable routing depending upon product state. Current scheduling systems are inadequate to handle this variability. The

17. Sprow, Pg 39.
Figure 2: Demanufacturing of a washing machine

The first step in the process is classification. Then routings can be prepared dependent upon failure modes. Batching and machine scheduling will be dependent upon volume. In batching is a preferred method, then a segregated holding area is necessary to accumulate batch lots. Disassembly lines will require decision forks. Often, product defects can not be determined until several operations have passed. The defects need to be separated perhaps resulting in a different process routing than was originally intended. This leads to complexities in the manufacturing flow and in the production scheduling. Manufacturing control systems based on MRP, JIT or TOC methods will have a difficult problem attempting to deal with the changing requirements and the decisions required from demanufacturing.

The disassembly processes are more complex than those of assembly. Automated assembly is possible if the parts are uniform and only a limited amount of flexibility is required. Automated assembly processes do not handle part variations and process variations well. When demanufacturing a product, one can expect to see parts broken, dirt, corrosion and other conditions. Bolts may be “burred” because of “backyard mechanics” improper use of tools. Screws may be stripped of their threads. Parts may be broken and jamming the normal means of disassembly. Therefore automated disassembly will require far more intelligence that does the automated assembly processes. Given the nature of the variabilities that can exist, automated processes probably can be adapted with sensors to handle the “run of the mill” disassembly problems. However, exceptions must be sensed and moved to an area for manual labor, if manual labor will be inefficient, to a shredder for material recycling.

Quality control is critical to meeting the concepts of environmentally conscious manufacturing. The goal is to produce a product from returned parts of quality equal to or exceeding virgin manufacturing. This cannot be done without a firm understanding of statistical quality control applied not only to the manufacturing processes but also to the use of the product. One can consider the use to be yet another process that the product experiences. For products to be successfully reused, remanufactured/demanufacture and recycled, the variation of the product over its life must be quantified, the sources identified for the variation and if possible, eliminated.

One method investigated by the authors for planning quality control is the use of loss functions for predicting costs associated with varying quality characteristics. The quadratic Taguchi loss function takes into account the costs associated with the product at the time of manufacturing. This has been weighted by the product reliability Weibull function and integrated over time to determine...
the costs associated with product quality characteristics that vary over time while the product is in use. The results of this work has been submitted for publication. The conclusion that may be drawn from this work is that optimum point suggested by the Taguchi loss function may not be the optimum point if the quality characteristic varies with time. If the nature of wear and failure can be predicted statistically, the optimum values might be shifted into a region of higher cost predicted by the Taguchi function in order to reduce total life time product costs due to quality. A similar analysis is currently being conducted with product benefits.

In summary, production systems must account for variations of the product that occur from its uses and ultimate failure. The demand for demanufacturing production is built by providing a superior quality product at a discount. Examination of the machine tool remanufacturing industry indicates that a discount is reasonable: the inventory and operational expenses of remanufacturing are less than virgin material manufacturing. Maintaining an inventory through demanufactured products is delayed from original manufacture but can be influenced by beginning demanufacturing of products currently available and by establishing lease-replace-return policies. Process routings must be variable with the ability to fork based upon the state of parts found during disassembly. Disassembly operations are more complex than those of assembly requiring more intelligence but not totally impervious to automation. Quality is a key issue: an understanding of quality characteristic changes over time need to be understood to determine the optimum targets and limits.

Conclusions
This paper attempts to give the reader a broad overview of the field of environmentally conscious manufacturing based upon ongoing studies of the authors. The research is needed: as society approaches an age where resources become more expensive, there is more competition for the resources, population increases, there is more concern over environmental wastes and a there is need for greater manufacturing efficiencies, the concepts embodied in demanufacturing hold, in part, the solution to these problems. We can make better use of our energy and material resources if we consider the products in use an additional, largely untapped, resource.

Recycling is a step in the correct direction; but recycling for materials requires additional energy that need not be expended to manufacture parts. There is no need to create a new 1/2" bolt if one already exists and is recoverable. There is no need to build a new fan motor for an automobile is one already exists and has statistically sufficient service life. By demanufacturing, the recovery of components which can be reused saves energy, material inventory costs and operational expenses.

This field has many unanswered questions. Designers and manufacturers need answers to such questions as what makes a product “green”? How should products be collected? How can the goal of a manufacturing firm (to make money) be better achieved through demanufacturing? In this paper, several recommendations have been made based upon the authors' current research. First and foremost, is the necessity of the designer and the manufacturer to develop the mindset that products can be reused, remanufactured/demanufactured and recycled. If this attitude can be developed in both the US and Japan, the remainder of the problems associated with demanufacturing are solvable.

References


Resources Conservation and Recovery Act, 42 USC 6901 and 42 USC 9601.
