Capturing Energy and Resources through Remanufacturing

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ABSTRACT

Remanufacturing is a process whereby retired or nonfunctional products or equipment are restored to like-new condition through after-market manufacturing operations. Remanufacturing has significant energy and environmental benefits. The average remanufactured product has five to seven pounds of old material for every pound of new material. The raw material saved through remanufacturing reduces the energy required to extract and process materials. The ratio of total energy required for original production compared to remanufacture is approximately six to one. This means that for every kilowatt-hour of energy spent in remanufacturing, about six kilowatt-hours are recovered. The National Center for Remanufacturing and Resource Recovery (NCR^3) at Rochester Institute of Technology (RIT) is the nation's leading Center for applied research and development in remanufacturing technology.

A critical and costly operation for remanufacturing is surface cleaning, which is often a production bottleneck and the source of health and environmental concerns. Although cost-effective, energy-efficient, and environmentally friendly cleaning processes exist, few remanufacturing companies are aware of these technologies. NCR^3 worked with 23 New York State automotive parts remanufacturers to identify environmentally friendly cleaning technologies that, at reduced cost, clean parts equal to or better than existing processes. NCR^3 subsequently developed a decision tool in to generate customized recommendations to improve cleaning operations for a single part or a group of dissimilar parts. The accuracy of this tool was verified through technology testing at NCR^3 and other locations. Benefits from implementing alternative cleaning technologies are substantial, producing payback periods as short as 12 weeks.

Introduction

The United States economy rapidly consumes natural resources and generates waste. The traditional energy source for our industrial machine, fossil fuels, is not only a finite resource, but it is contributing to a forecasted environmental decline.

The numbers indicate a trend. Global CO_2 emissions in 1996 were nearly four times the 1950 total (United Nations Environment Programme 1999). In 1997, industry consumed one-quarter of the energy used in the United States (World Resources Institute 2001). It also generated one-third of the CO_2 emitted by human activity (United States Environmental Protection Agency 2000).

While it is apparent that alternative and renewable resources and energy are needed as population and industry grow, there is another preventive step toward sustainability whose recognition has lagged well behind the proof of its benefits: remanufacturing.

Detailed below are product life-cycles and options for dealing with products at end of life, emphasizing more sustainable alternatives to land-filling and incineration. Additional information includes why remanufacturing, in contrast to other end-of-life disposition options, offers some key environmental benefits. It concludes with a brief description of RIT-NCR[3]'s automotive parts cleaning project.

Product Life-Cycles

In a conventional product life-cycle, the product begins as raw materials. The materials are processed, refined, and fashioned into a useable product through a series of manufacturing and assembly operations. The product is then put into service. At the end of its life, in this linear model, the product is disposed.

The disposal phase generally returns a product to the earth's ecosystem in a form quite different from its original form. For example, plastic parts begin as liquid petroleum. These parts may be disposed of by incineration, with the gaseous byproducts released to the atmosphere and solid ash returned to the landfill.

Recognizing the need to curb resource use and waste generation, in 1998, a working group of the President's Council on Sustainable Development recommended four options for more efficient materials and energy use in the 21st century: recycle, remanufacture, redesign, and rethink. These solutions were offered as potential means to "close the loops of material and energy flows" (Interagency Working Group 1998). Among the choices for a product at the end of its life-cycle, remanufacturing is one of the most cost- and energy-efficient.

An alternative product life-cycle model can be depicted as the links of a chain, with each link representing a single generation of a product. This sustainable life-cycle approach still draws upon raw materials and makes use of materials processing to fuel its product life-cycle engine, but it is much less dependent on these virgin sources of material. Each link is internally supplied by its own end-of-life products and their constituent components, parts, and recycled materials. Furthermore, as product innovation progresses, each link provides the bounty of its end-of-life products to the succeeding generation's product life-cycle.

Options for Products at End of Life

The life-cycle model suggests at least six options for disposition of end-of-life products. These are:

1. Reuse: removing the component or product from one system and installing it in another system where it performs its original function. An example is the removal of an automobile engine and its subsequent installation, after minor cleanup or repair, into another vehicle.
2. Remanufacturing: the process of disassembling, cleaning, inspecting, repairing, replacing, and reassembling the components of a subassembly or product in order to return it to an "as-new" condition. The subassembly or product is then returned to service in a system similar to that from which it came. Automotive products such as starters, alternators, and water pumps are routinely remanufactured at the end of their useful lives and returned to service.

3. Upward remanufacturing: the process of disassembling, cleaning, inspecting, repairing, replacing, and reassembling the components of a subassembly or product in order to return it to as-new condition and incorporate it into a new, or "next generation" system. This might require that new features be built into the product during remanufacturing.
4. Closed-loop recycling: recycling the material from a part or product and using that material to fabricate the same type of part or product. For example, plastic photo film canisters are sometimes ground and used to supplement virgin material in the manufacture of new film canisters.
5. Open-loop recycling: recycling the material from a part or product with no similar product manufacturing process dedicated to the consumption of the recycled material. For example, plastic milk jugs collected from municipal recycling streams are transformed into many different products, including clothing, carpet, and insulation.
6. Treatment and disposal: a form of open-loop recycling where the parts, products, or their byproducts are returned to the ecosystem because they have no viable markets. Incineration and disposition to landfill are two examples of this approach.

Differing Opportunities for Pollution Prevention

The six end-of-life retirement strategies offer very different opportunities for pollution prevention. They can be classified into three tiers based on their potential to prevent pollution at the source:

1. Tier one strategies, those that offer the greatest promise for reducing or avoiding manufacturing emissions, are reuse, remanufacture, and upward remanufacture. With a reuse or remanufacturing approach, the original form of the product is not changed after the product is retired. For example, aluminum castings are not melted down, rather their original shapes and configurations are retained. Typically, the restoration procedures needed to return an existing product to as-new condition are much less energy-intensive and much more environmentally benign than the processes required to manufacture the product from raw materials.
2. With tier two strategies (closed-loop recycling and open-loop recycling) some portion or all of a product will be processed into either material that can be used again to manufacture a similar product (closed-loop) or a degraded material that can be used for other purposes (open-loop). Reducing a product to its useful raw materials through recycling can consume significant amounts of energy and generate substantial waste. Additionally, transforming the recycled raw materials back into useful products requires another pass through the manufacturing and assembly stage, with the consequent resource consumption and waste generation.
3. The tier three methods (treatment and disposal) are the end-of-pipe approaches used to dispose of most industrial pollutants, and should be the last options considered for end-of-life products. These approaches return otherwise unusable substances to the ecosystem in the form of airborne, waterborne, or solid contaminants. Furthermore, replacement of the product requires the use of new resources and the generation of wastes associated with materials extraction, materials processing, and manufacturing.

Understanding Remanufacturing

In remanufacturing, a non-functional or retired product is made like-new through a series of industrial operations.

Most products do not wear uniformly. Often, many viable parts retain their form and function at the end of the product's life. Remanufacturing, if properly engineered, revives a product to like-new, if not better, condition in terms of performance and durability. For a product to be classified as remanufactured, it must go through several steps:

1. Complete disassembly to determine the condition of the components
2. Thorough cleaning and inspection of reusable components
3. Reassembly using a combination of new and refurbished components

Consider a diesel engine for long-haul trucking. The manufacture of a new engine requires a large amount of raw materials, including oil, rubber, iron, copper, aluminum, and silica. These materials must be processed to make them suitable for manufacture and assembly into a working diesel engine.

If, however, a diesel engine were originally manufactured with an eye toward reusing as many components as possible from an existing engine that had been previously retired, there would be a tremendous reduction in the amount of virgin raw materials needed to deliver the functionality provided by an engine. Additionally, the energy needed to transform these materials into useful forms would be substantially reduced, as would the amount of pollutants generated during the product's fabrication cycle.

"Every time a part is reused, all the energy and emissions that were produced in its manufacturing and the processing of its materials are salvaged" (Navin-Chandra 1993). Furthermore, by utilizing the retired engine as a source of components to be returned to useful service, there is less reliance on the waste-generating reduction, treatment, and disposal techniques that are typically used to remove used products from circulation.

As stated earlier, remanufactured product can offer the same or better performance and durability in contrast to a brand new product. It can also offer additional economic and environmental benefits because it recaptures approximately 85 percent of the labor and energy that comprise "value add." Value add includes the cost of the labor, energy, and manufacturing operations that are needed to transform basic raw materials into a product. Value add can be the largest portion of a product's cost.

Environmental and Energy Benefits of Remanufacturing

Remanufacturing is a powerful form of waste reduction. The average remanufactured product has 85 to 88 percent used components by weight, or between five and seven pounds of old material for every pound of new material. The raw material saved through remanufacturing cuts back on the energy required to extract materials and process them.

By reducing the amount of discarded products, remanufacturing also reduces the greenhouse gas emissions associated with material decomposition in landfills and through incineration. The ratio of total energy required for original production compared to remanufacture is approximately six to one. This means that for every kilowatt-hour of energy spent in remanufacturing, about six kilowatt-hours are recovered.

The Fraunhofer Institute estimates that annual, worldwide savings of energy from remanufacturing activities amounts to 120 trillion BTUs (Steinhilper 1998). This equals the electricity generated by eight nuclear power plants, or 16 million barrels of crude oil (about 350 tankers). In addition, the energy saved from remanufacturing avoids the generation of 6.8 million tons of CO_2.

Savings from specific product categories are even more quantifiable, and can highlight the impact:

- Remanufacturing auto parts preserves approximately 85 percent of the energy expended in the manufacture of the original product.
- Manufacturing one new automotive starter requires over 11 times more energy than remanufacturing one.
- Manufacturing one new automotive alternator requires over seven times more energy than remanufacturing one.
- Remanufacturing the Kodak single-use camera requires 67 percent less energy than manufacturing a new one (Eastman Kodak Company 1999).
- Remanufacturing components in an automotive engine (such as the cylinder block, cylinder head, crankshaft, camshaft, and connecting rods) saves 50 percent of the energy required for a new engine.

The Remanufacturing Industry

Remanufacturing is more than simply repair and resale of used parts. In 1996, the industry was comprised of over 73,000 firms with $53 billion a year in sales (Lund 1996). Although remanufacturing is dominated by the automotive sector, other major segments include office furniture, office equipment, electrical equipment, medical equipment, laser toner cartridges, and compressors.

All basic industries rely on remanufacturing as an activity integral to maintaining their facilities. For example, blast furnaces for steel-making are remanufactured. Although the remanufacturing industry is largely made up of small, independent firms, remanufacturing has been integrated into the production operations of some large original equipment manufacturers such as Xerox Corporation, Eastman Kodak Company, Detroit Diesel, Steelcase, Caterpillar, Inc. and others.

The largest remanufacturer in the world is the United States military. From aircraft to ships and tanks, their remanufacturing is done by either military depots or defense contractors.

A good example of commercial remanufacturing can be found in Xerox Corporation's Document Centre 265, a product designed as part of Xerox's commitment to sustainable design (or the design of products that lend themselves to reuse and remanufacture). The Document Centre 265 was a showcase product intended to help Xerox reach its "zero to landfill" goal. This goal required a number of process and product changes. For example, the Document Centre 265 was designed to include easily removable subassemblies and more durable parts. It was also designed to be more readily upgradable. As a result of design modifications, 80 percent of the parts in the copier are remanufacturable and 97 percent are recyclable.

To ensure the quality of its remanufactured products, Xerox uses signature analysis (a testing technology that determines an acceptable range of heat, noise, and vibration) to evaluate the quality of components and parts. The company has also implemented a product take-back infrastructure to ensure that products are returned for remanufacture.

Xerox finds remanufacturing and resource recovery activities to be a source of profit. The company estimates that, through equipment remanufacture and parts reuse and recycling, it diverted 145 million pounds of material from landfill in 1998. Xerox also saves several hundred million dollars each year with parts remanufacture and reuse.

Advancing the Technologies of the Remanufacturing Industry

Remanufacturers tend to be small or medium-sized enterprises and, as a result, often have few in-house resources. Like any other industry, however, remanufacturers need access to advanced manufacturing and testing technologies to continuously improve their efficiency and the quality of their products.

NCR^3 was created to fill this technology gap. NCR^3 provides technical assistance and applied research and development to companies, trade associations, and government agencies interested in remanufacturing and resource recovery. Work done includes applied research and development, technology benchmarking, creating product design guidelines, life-cycle analysis, and process assessment and improvement.

NCR^3 focuses on six major aspects of remanufacturing and design for the product life-cycle, including intelligent testing and diagnostics, sustainable design, logistics and policy, structural and material analysis, and operational assistance. The sixth focus area, clean technologies, works to make remanufacturing operations more economically and environmentally sustainable. The aim of the clean technologies team is to develop and promote remanufacturing technologies and methods that use little or no hazardous material, generate little or no waste, and are safe for workers, the public, and the environment.

Importance of Surface Cleaning Operations in Remanufacturing

Surface cleaning is an integral part of almost all remanufacturing processes but is often a bottleneck operation. In many cases, remanufacturers use less efficient, energy-intensive, or manual operations using hazardous chemicals. These processes are a drain on the bottom line and may be a risk to workers and the environment. However, identifying alternative cleaning methods can be challenging and time-consuming for remanufacturing companies. They often rely on equipment or chemistry vendors for information on new technologies. Vendors often speak only about their technology and may not be an unbiased source of information. Companies can become frustrated by the effort required and disruption caused by testing technology recommendations that fall far off the mark.

For the past five years, NCR^3 has been assisting remanufacturers in optimizing their surface cleaning operations via assessments. These assessments have helped many companies lower the cost and improve the cleaning, energy, environmental, and safety performance of their operations. These one-on-one, direct assistance projects can require significant effort, particularly for alternative technology testing. In an effort to enhance the efficiency of these services, and thereby make them more accessible to companies of all sizes, NCR^3 has embarked upon several initiatives aimed at delivering its cleaning expertise better, faster, and cheaper.

Automotive Parts Cleaning Project

The automotive remanufacturing sector is the largest subsector of the remanufacturing industry both in numbers of firms and economic importance. Firms in this sector remanufacture numerous car and truck components including engines, transmissions, clutches, alternators, front wheel drive axles (CV joints), brake calipers, wiper motors and starters. In New York State alone, there are an estimated 945 firms engaged in rebuilding automotive parts.

In partnership with 23 New York State automotive parts remanufacturers, NCR^3 recently completed a project aimed at developing and providing practical information to the state's automotive rebuilders on how to identify and select high-performance cleaning technologies. High-performance means those technologies that are effective, cost-effective, energy efficient, and safe for workers and the environment. Funding for this project was provided by the New York State Energy Research and Development Authority (NYSERDA). NYSERDA's focus is on research into energy supply and efficiency as well as energy-related environmental issues.

The project produced the following:

1. Documentation and evaluation of current cleaning practices used in automotive rebuilding. Through visits to the 23 partner companies, NCR^3 collected baseline data on the types and performance of cleaning practices currently in use (see Figure 1).
2. Creation of the NCR^3 Surface Cleaning Technology Evaluation Facility. This facility houses 10 production-scale cleaning units, including agitating and non-agitating ultrasonic cleaning systems, baking soda abrasive blast cabinet, multimedia abrasive blast cabinet, high-pressure spray washer, mid-pressure spray washer, vibratory degreaser, shot blast cabinet, thermal oven, a variety of chemistries and abrasive media, and analytical equipment for testing cleanliness, hardness, and other surface properties of parts.
3. Documentation of results from testing 10 high-performance cleaning technologies on 76 different automotive parts. The results have been published in seven technology-focused fact sheets and were also published in a cleaning handbook for rebuilders (got to http://www.reman.rit.edu/reference/publications.asp for sample fact sheets) (see Figure 2 for an excerpt from the fact sheet on the performance of baking soda abrasive blasting).
4. Public demonstrations of technology implementation at two rebuilders. A high-pressure aqueous spray washer, agitated aqueous ultrasonic parts washer, and wash water filtration equipment were installed and demonstrated at two New York State rebuilders. The technologies, and their costs and benefits, were described in three technical reports (see Figure 3 for highlights from one report).

Figure 1. Cleaning Processes used by Partner Companies

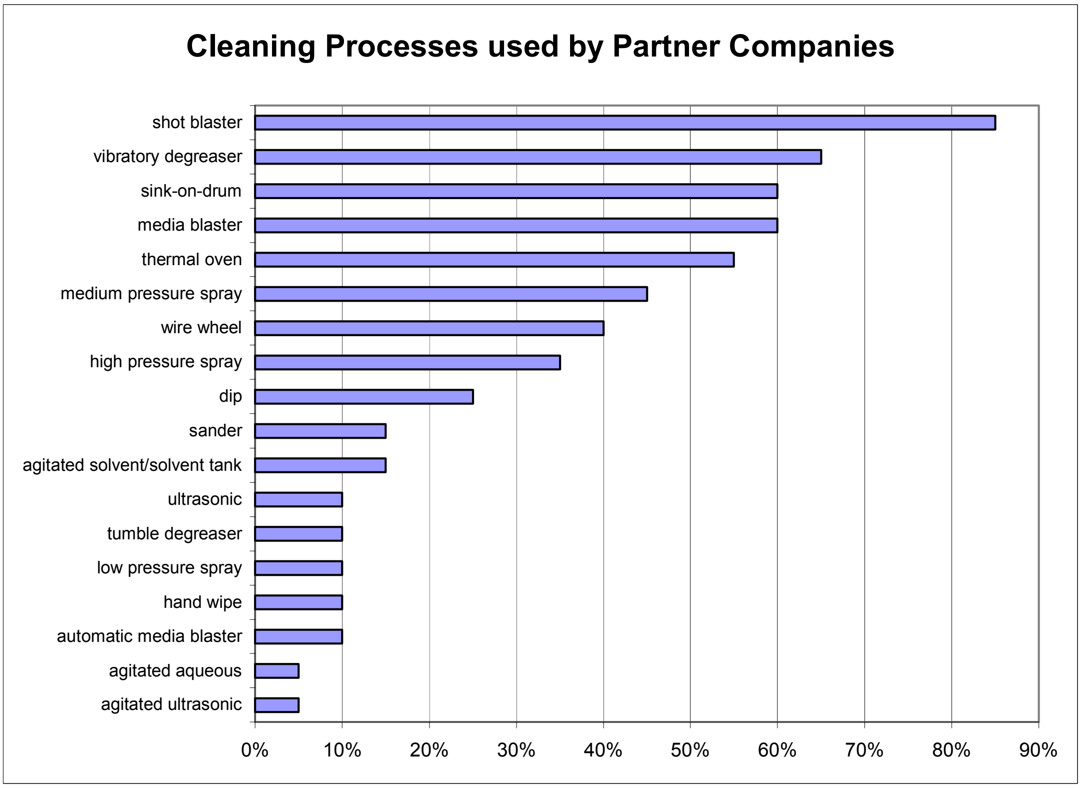

Figure 2. Performance of Baking Soda Cleaning on Several Automotive Parts

Part Information					Cleaning Data							
									Cost ($/part)			
Part	Component	Materials of Construction	Contam-inants	Level of Contamin-ant	Pre-cleaning	psi/cfm	Cycle Time	Results	Media[1]	Energy[2]	Labor[3]	**Total**
Intake Valve	Engine, Cylinder Head	Steel	Carbon Grease Dirt	High Medium Medium	none	75/80	45 sec - 1 min.	very clean	$0.44	$0.03	$0.18	**$0.65**
Housing	Heavy Duty Fuel Injector (12"x10"x5")	Aluminum, Brass	Oil Carbon Grease Dirt	High Medium Medium Low	Enzymatic Cleaning	75/80	4 min.	excellent	$2.00	$0.14	$0.80	**$2.94**[4]
Pump Housing	Fuel Pump, Heavy Duty (5"x3"x1.6")	Aluminum, Copper	Grease Dirt Paint Gasket	Medium Medium Medium Medium	none	50/57	3 min.	adequately clean	$1.50	$0.09	$0.60	**$2.19**
Throttle Body	Carburetor	Aluminum, Zinc	Grease Gasket Oxidation	Medium Medium Medium	none	75/80	1-2 min.	very clean	$0.75	$0.06	$0.30	**$1.11**

Notes:
1. Based on media consumption rate of 1lb/min and cost of $0.5/lb
2. Assume 90% efficiency of compressor and average electricity cost of $0.10/kwh
3. Based on fully loaded wage rate of $12/hr.
4. Total cost represents baking soda only-does not include pre-cleaning cost of enzymatic cleaning.

NCR^3 Surface Cleaning Expert System

With the goal of increasing the efficiency of its cleaning assessments, NCR^3 developed a decision tool, the NCR^3 Surface Cleaning Expert System, which will produce a customized set of recommendations to improve the cleaning operations for a single part or a group of dissimilar parts. This tool, coupled with NCR^3's extensive database of cleaning technology performance data, will significantly reduce the number of technology tests that will be needed in a cleaning assessment by narrowing in on a handful of process options that are optimal from a performance, cost, energy, and environmental and safety standpoint. Each process recommendation provides specific details on:

1. Equipment type (e.g., high-pressure spray washer, agitating ultrasonic cleaning system)
2. Chemistry or abrasive media type (e.g., alkaline aqueous detergent, soft steel shot w/10-15 Rockwell C-scale hardness)
3. Operating conditions (e.g., concentration of detergent, blast pressure, cycle time)
4. Expected performance and operating costs (including energy costs, labor, chemistry, maintenance, and waste disposal)

Figure 3. Cleaning Up Axles in a Jiffy at Arc Remanufacturing

Arc Remanufacturing, Inc. in Astoria, N.Y. remanufactures a variety of automotive parts including power rack and pinions, front wheel driveaxles, and disc brake calipers. During a technology demonstration at NCR^3, Arc was impressed with the cleaning power of the high-pressure spray washer and saw it as a potential alternative for cleaning of axels. Their interest paid off.

Old Process: Axle components were carefully arranged in baskets and washed in a mid-pressure spray washer at 190 degrees Fahrenheit for 30 minutes. One week after a fresh cleaning bath was introduced, approximately 10% of axles needed re-cleaning. The bath lasted three weeks. A small percentage of axles required pre-cleaning in a vibratory cleaner with mineral spirits.

New Process: Components are placed in a high-pressure spray cabinet, although there is no need to arrange them carefully. Parts are washed at 190 degrees Fahrenheit for five minutes. There is no need for any pre-cleaning or re-cleaning. The bath lasts six weeks.

Costs: Equipment cost was $67,000 (including installation)

Benefits of Process Change:

- - Annual savings in labor, chemicals, waste disposal, water, and energy total $105,000 (payback less than 8 months). This savings is for axles only. The company will be using the equipment for other components.
- - No more pre-cleaning or rework.
- - No more mineral spirits.
- - Shorter cycle time.
- - Lower energy consumption (almost 1200 kWh/year from shorter cycles).
- - Longer bath life saves on soap, water, and waste disposal costs.

Recommended processes might consist of one operation or a series of operations, such as ultrasonic cleaning followed by steel shot blasting, if multiple steps are required to achieve desired results. Technology testing can be used to verify and optimize the processes recommended by the system.

Verification, Implementation, and Demonstration of High Performance Cleaning Technologies and the NCR^3 Surface Cleaning Expert System

NCR^3 has launched a new project with the aim of showcasing the benefits of high-performance cleaning technologies and the benefit of utilizing a systematic process of evaluating alternative cleaning technologies – for example, the NCR^3 Surface Cleaning Expert System.

This project is being executed in partnership with NYSERDA and several New York State remanufacturing companies from the aircraft, machine tool, rail, imaging products, transmission, and automotive industries. These companies have:

1. Provided operational data necessary to utilize the expert system.
2. Implemented the recommendations developed by NCR^3 for cleaning system improvements.
3. Publicly demonstrated the recommended cleaning processes.

The results to date have been very encouraging. For example, Dial Transmission of Long Island installed a non-agitating ultrasonic parts washer based on the recommendations of the Expert System that were subsequently verified by technology testing conducted at NCR^3. At a burdened labor rate of $20 per hour (not Dial Transmission's actual labor rate), the system was shown to pay for itself in 12 weeks -- an outstanding investment. Additional benefits of the system include:]

- Reduced energy costs due to smaller loads in solvent parts washers (hence fewer distillations) and less use of compressed air
- Reduction in direct labor of over 100 minutes per transmission
- Improved air quality due to less entrainment of solvents in shop air from drying operations
- 80 percent reduction in use of solvents
- 67 percent reduction in use of compressed air for cleaning parts washed in solvents
- Higher product quality due to superior cleaning results

These results show that manufacturing and remanufacturing companies can improve product quality while simultaneously reducing costs and energy consumption and minimizing adverse environmental impacts. In addition, the quick payback on installed equipment costs places these strategies among the best business investments available to these companies.

NCR^3 has also estimated the impact of installing alternative cleaning systems on a statewide basis. For example, if washwater recycling systems were installed at all of New York State's 945 automotive remanufacturing facilities, the potential benefits would be a reduction in natural gas consumption of more than 27.6 million cubic feet per year and a reduction in power consumption of more than 4.39 million kWh per year. In addition, annual reductions of more than 125,000 gallons per year of hazardous waste, and 560,000 gallons of non-hazardous waste, could be realized.

Conclusion

Remanufacturing has substantial energy and environmental benefits. In close partnership with the industry, NCR[3] is working on many fronts to enhance the efficiency – cost, energy, and environmental – of remanufacturing operations to continuously improve the quality of remanufactured products. Surface cleaning is a critical process. Like many of their original equipment manufacturer counterparts, many remanufacturers are not taking advantage of newer, high performance technologies on the market today. The work described here will enable the industry to better evaluate the potential benefits of these technologies for their bottom line and for the environment.

References

Eastman Kodak Company Health, Safety and Environment Department. 1999. *1999 Annual Report*. Rochester, N.Y.: Eastman Kodak Company.

Interagency Working Group on Industrial Ecology. 1998. *Material and Energy Flows*. Available on-line: http://www.oit.doe.gov/mining/materials/.

Lund, R.T. 1996. *The Remanufacturing Industry: Hidden Giant*. Boston, Mass.: Boston University.

Navin-Chandra, D. 1993. "ReStar: A Design Tool for Environmental Recovery Analysis." In *Ninth International Conference on Engineering Design, The Hague*. Zurich: Heurista.

Steinhilper, Rolf. 1998. *Remanufacturing*. p. 103. D-70569. Fraunhofer IRB Verlag: Stuttgart.

United Nations Environment Programme. 1999. *Global Environment Outlook 2000*. Available on-line: http://www.grida.no/geo2000/ov-e.pdf.

U.S. Environmental Protection Agency. 2000. *Linking Energy and Climate Change*. Available on-line: http://www.epa.gov/appdstar/linking.html.

World Resources Institute. 2001. *Earth Trends: The Environmental Information Portal*. Available on-line: http://earthtrends.wri.org/.