Demanufacturing: Redefining Solid Waste and Product Management

In "demanufacturing," the usual production cycle is reversed: Obsolete products are used to create components for the manufacture of new products. A demanufacturing program now being developed in New Jersey involves the collection and processing of consumer electronics and appliances (CEA) that are obsolete, unrepairable, or otherwise nonfunctioning. These materials are source-separated from the solid waste disposal stream at the point of generation and directed to a facility where they can be disassembled and processed into usable components. The recovered components are then available for reuse.

This sounds like recycling. However, the ultimate goal of a demanufacturing system is to maintain the "product definition" throughout the process. This can be accomplished by preserving ownership and responsibility for the product throughout the entire demanufacturing process. This "product definition approach" has been adopted for the CEA stream that is the subject of the New Jersey program. The New Jersey Department of Environmental Protection (NJDEP) has determined that the segment of the stream of obsolete products that remains in the manufacturer's warehouse or storage, and in which the manufacturer does not relinquish ownership or responsibility throughout the demanufacturing process, is not a waste, but can be managed as a product. This same determination can be expanded to other segments of the management system for CEA.

Developing a Demanufacturing Process

The development and implementation of a fully utilized demanufacturing process require an established framework for the collection of the material that is to be reclaimed; in the case of the New Jersey program, this material is CEA. Obsolete CEA is generated primarily by three sources: consumers (including households, small businesses, and institutional sources); direct retail sources (such as electronic and appliance repair shops); and industrial sources, particularly the electronics industry. Consumer electronics and appliances may be owned outright or leased. The collection system needs to be able to recover CEA from these various sources, then consolidate, store, and transport it to a disassembly/demanufacturing facility.

Most assume that a demanufacturing system must operate as a "take-back" or reverse distribution system. Under such a system, a manufacturer remains financially responsible for collecting and processing its products after they have been discarded by the consumer. These systems can work in some cases, as they have with rechargeable batteries. New Jersey, as well as many other states, requires manufacturers to take back vehicle lead acid wet cell batteries and rechargeable nickel-cadmium and sealed lead acid dry cell batteries. Manufac-

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turers of these batteries generally rely on recycling or household hazardous waste collection programs to gather at least some of the batteries they take back.

The take-back system for rechargeable dry ceil batteries works in part because these batteries are relatively small. They can fit into mailer boxes for easy transport to consolidation/recycling facilities. Other items of relatively small size, such as thermostats or mercury switches, may also be good candidates for a reverse distribution system. Similarly, the take-back system for vehicle lead acid batteries works because of the value of the lead. Lead acid battery manufacturers need recycled lead from secondary lead smelters in order to produce new vehicle batteries.

By contrast, the collection model that New Jersey is evaluating for CEA is patterned after that established for white goods. "White goods" is a municipal solid waste classification for large discarded appliances such as water heaters, stoves, refrigerators, freezers, or dishwashers. White goods are collected from households and appliance stores, consolidated by dismantlers, and transported to metal processing facilities.

A similar system probably would work for CEA. To distinguish the two systems, CEA could be classified as "brown goods." Thus, a CEA demanufacturing system does not have to be managed as a take-back system.

While a demanufacturing system need not be a take-back program, it does need a commitment by CEA manufacturers to reuse and/or assist in market development for the recovered components. It is recognized that, initially, the recovered components and materials from demanufactured CEA may not be available or readily usable by CEA manufacturers. As it becomes more developed, however, demanufacturing will allow manufacturers to design specifically for reusability and recyclability. Establishing a system which insures that such products will be collected, consolidated, and processed so that their components can be utilized again will encourage manufacturers to design for reusability/recyclability.

In New Jersey, the CEA demanufacturing system will be implemented in phases, with initial emphasis on components that are available in relatively large quantities from single generator sources. The system may be phased in by first collecting from industrial sources, then from direct sources such as repair shops, and finally from all other municipal sources.

Environmental Reasons for Demanufacturing

An overriding issue in establishing a demanufacturing system involves the guiding principle behind the Resource Conservation and Recovery Act (RCRA). RCRA requires that, to the maximum extent achievable, solid waste be reused as a resource. In New Jersey, this mandate is also emphasized in the state's Solid Waste Management Act.

Solid waste, simply defined, is an accumulation of discarded products and packaging. It is made up of municipal solid waste (MSW), which includes household, commercial, and institutional waste; bulky wastes (including construction and demolition waste); and industrial waste. Clearly, some discarded products can be diverted from the disposal stream for reuse through a demanufacturing program.

Why CEA?

Which discarded products should become the initial focus of a demanufacturing program? The limiting factor in the reuse of solid waste is the presence of heavy metals. Reusing solid waste in processes such as composting or energy recovery reduces the weight and volume of the solid waste and increases the concentration of heavy metals in solid waste-derived end products. Hence, one goal of a demanufacturing program should be to divert heavy metal-containing products from the disposal stream.

Which heavy metals are of concern? This depends on the environmental media standards against which any solid waste facility and any solid waste-derived product will be judged. One important standard is that set by the Toxicity Characteristic Leaching Procedure (TCLP). Any heavy metal in the solid waste stream, or any solid waste-derived product, in which the total metal concentration greatly exceeds the TCLP threshold should be a metal of concern.

Based on information available about the heavy metal concentration in New Jersey solid waste, it appears that metals of concern include cadmium, lead, and mercury. **Exhibit 1** documents the total metals concentration in milligrams per kilogram (mg/kg) and parts per million for cadmium, lead, and mercury in the state's municipal solid waste incinerator bottom and combined residual ash. Bottom ash is the residue that remains on the grate after incineration. Combined ash encompasses both bottom ash and fly ash. Fly ash is the residue or particulates extracted from the flue gas stream of the incinerator through air quality control systems. Bottom ash accounts for approximately 90 percent of the volume of combined ash, while fly ash makes up the remaining 10 percent.

With information on (1) the concentrations of heavy metals in the combined ash stream, (2) the volume reduction efficiency of municipal solid waste incinerators, and (3) the efficiencies of incinerator air quality control systems, it is possible to calculate the concentrations of heavy metals in MSW using a mass balance methodology.

Using the ash concentration levels shown in Exhibit 1, the cadmium, lead, and mercury concentrations in the state's municipal solid waste have been calculated as:

Cadmium: 15.25 mg/kg
Lead: 543.25 mg/kg
Mercury: 3.25 mg/kg

The TCLP regulatory threshold for cadmium, lead, and mercury are as follows:

Cadmium: 1 mg/l
Lead: 5 mg/l
Mercury: 0.2 mg/l

Thus, the cadmium, lead, and mercury concentrations in both the residual ash and the MSW stream are above background levels for these constituents.

In addition, the concentrations of these metals in incinerator ash and MSW exceed the cadmium, lead, and mercury levels that the state has set for site-specific cleanup and remediation with regard to groundwater, surface and drinking water, sludge, and soils. Moreover, weighing and composition analyses of municipal solid waste undertaken by three New Jersey county utility authorities (the Bergen County Utilities Authority, the Cape May County Municipal Utilities Authority, and the Union County Utilities Authority) confirm that cadmium, lead, and mercury are of concern. Clearly, cadmium, lead, and mercury should be heavy metals of focus in a source separation and demanufacturing system.

A review of the total cadmium, lead, and mercury in discarded products found in the New Jersey MSW disposal stream reveals that consumer electronics and appliances (and the thermoplastics that house them) are a major source of these

Exhibit 1. Concentrations of Cadmium, Lead, and Mercury in Bottom and Combined Ash from New Jersey MSW Incinerators

	Cadmium mg/kg (ppm)	Lead mg/kg (ppm)	Mercury mg/kg (ppm)
Bottom Ash	21.2 (12.9-34.0)	1566 (990-1976)	0.275 (0.00-1.0)
Combined Ash	61.0 (39.0-82.0)	2173 (1338-3500)	6.5 (4.0-8.4)

Based on a joint research project performed in 1991-92 by NJDEP on the total metals contents of bottom and combined ash for the Warren County incinerator, a 400-ton per day capacity, mass burn facility in Oxford, New Jersey.

metals. Other sources include batteries (rechargeable and mercury oxide); mercury-containing lamps; and mercury switches, including thermostats. Evidence indicates that source separation programs for these few categories of discarded products can remove greater than 90 percent of the cadmium, lead, and mercury from New Jersey's municipal solid waste stream.

Some of these non-CEA wastes are already being addressed. New Jersey currently has a statewide source separation program for rechargeable dry cell batteries and vehicle wet cell batteries. In addition, two pilot programs are underway to manage source-separated mercury-containing lamps and thermostats (mercury switches). Based on the success of these pilot programs, NJDEP will expand the availability of these programs to all the counties with municipal solid waste incinerators. The demanufacturing program for CEA will help "close the loop" for source separation programs that are seeking to improve the environmental performance of solid waste facilities.

It should be noted here that the goal in the source reduction/source separation programs is *not* zero metals concentration. Cadmium, lead, and mercury, as well as other heavy metals (and some organics, for that matter), exist in the natural environment. These materials cannot be totally eliminated, but implementing an effective source separation system can significantly reduce them to below levels of regulatory—and, more importantly, environmental—concern.

Economic Reasons for Demanufacturing

Based on a general impact analysis, it makes environmental sense to establish a system that source-separates those discarded products which contribute significant quantities of cadmium, lead, and mercury to the emissions and discharges of solid waste facilities. But does it make economic sense? What does it cost, and are these costs justified by the benefits derived?

For some municipalities in New Jersey, solid waste management has become one of the highest line-item budget costs. Over the past ten years, most municipal budget items, such as police protection, fire protection, general administration, and pensions, have doubled. In that same period of time, the cost of solid waste management has increased by a much greater margin—in some cases, by a factor of five.

One reason these costs have risen so quickly is the expense of managing heavy metals found in the waste stream. Clearly, then, diverting products that contain these metals from the waste stream by source separation and demanufacturing could significantly reduce solid waste management costs. The discussion below outlines current costs and suggests how much they could be decreased.

Cost of Complying with Incinerator and Solid Waste Regulations

New Jersey requires that municipal solid waste incinerator ash be sampled and tested using the TCLP analysis. The data compiled under this testing requirement, which has been in place since the first district municipal solid waste incinerator was started up in 1986, serve as the basis for environmental and economic analysis. (Because of a 1994 U.S. Supreme Court decision denying municipal solid waste incinerator ash an exemption from the hazardous waste provisions of RCRA, all municipal solid waste incinerators throughout the country are now subject to requirements similar to those that have been in place in New Jersey since the mid-1980s.)

A number of regulatory requirements aimed at reducing the solubility and mobility of heavy metals in municipal solid waste incinerator residual ash (particularly meeting TCLP regulatory thresholds) drive up the cost of combusting heavy metal-laden waste.

First, excess lime from the incinerators' air quality control spray dryers must be injected into the system to stabilize the residual ash. While the stabilized ash can be classified as a nonhazardous residual ash, injection of lime increases the ash's pH. The increase in pH may cause the lead in the ash to become more soluble in acid rainwater. Lead is an amphoteric metal that is soluble (as are most metals) at low pHs. However, unlike most other metals, lead remains soluble at the high pH range. In order to control this condition, a phosphoric acid immobilizer[1] is added to the residual ash stream.

In addition to the costs to stabilize the residual ash, New Jersey has recently adopted stringent mercury emission standards for municipal solid waste incinerators. These standards were based on the recommendations of a public/private partnership task force established to evaluate all sources of mercury emissions in New Jersey. The task force recommendations were published in a final report in 1993. The task force study showed increased levels of mercury in the ambient environment and identified municipal solid waste incinerators as the newest and largest source of mercury emissions into New Jersey's environment. The study also demonstrated that existing controls on municipal solid waste incinerators did not adequately capture mercury emissions. The task force recognized that municipal solid waste incinerator mercury emissions needed to be significantly reduced in order to lower the additions to ambient mercury levels.

To accomplish this reduction, NJDEP has adopted mercury emission standards for municipal solid waste incinerators of 65 micrograms per dry standard cubic meter (μ/dscm) by 1996 and 28 μg/dscm by the year 2000. To achieve this standard—which, by the year 2000, will represent a 96-percent reduction over 1992 mercury emission levels—municipal solid waste incinerators are required to install and operate mercury control equipment that adds activated carbon to the incinerator's flue gas stream to absorb mercury. In addition, programs are being put in place to source-separate and remove mercury-containing items before they are processed by the incinerators.

Preliminary data from the Union County Utilities Authority's municipal solid waste incinerator indicate that with both source reduction and mercury control equipment, the mandated mercury levels can be achieved. In addition, a reduction in mercury emissions to meet the standards on the inlet side of the air quality control equipment could be achieved through a source separation program, of which demanufacturing is an important component.

Exhibit 2 shows how much the procedures for managing heavy metals add to the cost of processing each incoming ton of municipal solid waste that goes to an incinerator. Based on these costs, and the quantity of municipal solid waste managed by municipal solid waste incinerators in New Jersey, it is estimated that the users and rate payers of these facilities incur approximately $17 million annually in operations and maintenance costs to control cadmium, lead, and mercury in the municipal solid waste incineration system from discarded products.

Moreover, because of the total cadmium, lead, and mercury concentrations in residual ash, the only currently available option for managing the ash is disposal at municipal solid waste landfills that have double composite liners. Constructing such a landfill currently costs approximately $500,000 per acre. Tipping fees at these landfills range from about $55 to $75 per ton. As a result, rate payers and users of municipal solid waste incinerators in New Jersey pay approximately $30 to $45 million annually to dispose of residual ash.

Potential Savings from Shifting to Source Separation and Demanufacturing

One way of controlling—and perhaps significantly reducing—municipal solid waste management costs is to develop a demanufacturing system. It is estimated that each New Jersey house-

Exhibit 2. Costs To Control and Manage Heavy Metals at New Jersey MSW Incinerators

Component/Additive	Cost Per Ton of MSW Processed
Lime Addition	$0.60-1.20
Immobilizer	$1.20-2.10
Activated Carbon	$3.00-5.00
Additional Cost of Solid Waste Disposal	$0.34
Capital Cost	$300,000-750,000

Data developed from engineering and environmental reports submitted to the NJDEP's Bureau of Resource Recovery Engineering.

hold in counties with municipal solid waste incinerators could potentially save $40 to $60 per year with a source separation and demanufacturing program focused on products that contain heavy metals of concern. The discussion below suggests how a source separation and demanufacturing system could operate.

Impact of the Universal Waste Rule

The development of source separation and demanufacturing programs for heavy metal-containing products will likely be helped along by EPA's recent issuance of the "Universal Waste Rule." Under this rule, certain types of wastes that are produced in relatively small quantities by a wide variety of generators (including households, small businesses, institutions, and manufacturers) can be exempted from the hazardous waste regulations of RCRA Subtitle C if properly managed. Households and other small quantity generators of these types of waste are currently exempted from hazardous waste regulations.

The Universal Waste Rule allows some wastes which might otherwise be classified as hazardous, such as rechargeable nickel-cadmium batteries and mercury-containing thermostats, to be collected, consolidated, stored, and transported to appropriate facilities without having to be managed as hazardous waste. For the most part, these types of wastes have traditionally been disposed of as household trash because they look like and are indistinguishable from currently exempted sources. These wastes from all generators have ultimately wound up in municipal solid waste facilities. The problem occurs when programs are developed to manage these types of waste source-separated from the disposal stream. The intent of the new Universal Waste Rule is to encourage the creation of recycling and reclamation programs for these wastes.

In the initial phases of demanufacturing, the system may need to be managed as a recycling process. Thus, it will be beneficial to classify some of the materials to be handled by the system as "universal waste"—even though the ultimate goal is to prevent such material from becoming "waste" at all. CEA likely would qualify to be classified as a universal waste.

Universal Waste Consolidation Facilities

Currently, New Jersey counties operate programs that handle household and conditionally exempt small quantity generator hazardous waste (HHW/CESQG). Several counties are in the planning process to develop permanent programs, and two counties (Burlington and Monmouth) currently operate permanent facilities. Households and small generators usually take this waste to drop-off points around the state on designated "collection days," and it is then transported to facilities for processing. These programs can now operate to consolidate waste classified as "universal waste."

In order to manage obsolete consumer electronics and appliances, universal waste consolidation facilities could be created that would qualify as permanent HHW/CESQG facilities. Unlike current HHW/CESQG facilities, however, these universal waste consolidation facilities would include a source separation and demanufacturing component from all generators.

Such a system could manage a range of household, small business, institutional, and large industry wastes, including not only CEA (with its plastic housing), but also items such as batteries, fluorescent lightbulbs, oil-base paint residues, mercury switches (including thermostats), and other such wastes. Collectively, these items now account for more than 90 percent of the cadmium, lead, and mercury in New Jersey's municipal solid waste stream.

The money to operate universal waste consolidation facilities would not need to be generated by product taxes or additional user fees on MSW facilities. Preliminary economic analysis indicates that the cost could be fully covered by the savings in operational costs that would be realized if products containing heavy metals of concern were diverted away from MSW incinerators. Keeping such items out of incinerators would significantly reduce the very high costs that such facilities now incur for managing heavy metals in the waste stream, and for residual ash disposal.

Continuing Challenges

NJDEP is continuing to analyze the economics and environmental impact of demanufacturing. Two issues need to be evaluated in greater detail:

- Will municipal solid waste incinerators still need to maintain some degree of "back-end" control over heavy metal- containing items?
- How will the source separation program be phased in, and how will it work in conjunction with current municipal solid waste incinerator control systems?

These two issues will of course affect the cost of the source separation and demanufacturing system. In the initial years of the program, a key challenge will be to phase in the system in a way that minimizes—and eventually eliminates—these additional costs.

Note

1. This is a patented system developed by Wheelabrator Environmental Systems called WESfix®.

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While the Demanufacturing Project is a collaborative effort, NJDEP's Division of Solid and Hazardous Waste Bureau of Recycling Planning and Market Development remains solely responsible for the ideas and opinions expressed in this column.
