Cradle to cradle: Reverse logistics strategies and opportunities across three industry sectors

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Abstract
Manufacturers have experienced institutional pressures in the form of market and regulatory demands to conform to the standards dictated by environmental regulations. The primary forces are studied for three industry sectors (automotive, consumer appliances and electronic) to close the supply chain loop in the product lifecycle. The first deals with identifying the drivers of a growing market for recycled and remanufactured products. The second relates to the creation of economically efficient end-of-life product returns and reuse/recycling practices. The third deals with enabling supply chain coordination for redesign of products, disassembly methods and practices, and services.

1. Introduction

Most developed countries have environmental regulations prescribing the responsibilities of manufacturers, generators and users of chemicals to properly dispose of chemical wastes. In the mid-1980s this was commonly known as “cradle-to-grave” resource management. Today, modern environmental management prescribes sustainable manufacturing practices that focus on prevention of waste and responsible care of the earth’s natural resources. The focus on recovery of resources, recycling and reuse can be described as “cradle-to-cradle” resource management.

Regulatory drivers exist in Europe, the US and Japan, dictating the prevention of waste and to promote the recovery of waste for reuse, remanufacturing or recycling of materials including electronic equipment and batteries, chemical products, glass, paper, plastics, and heavy metals. Europe in particular is leading the way in its drive to reduce automotive end-of-life, electronic and packaging waste in its landfills by requiring manufacturers and distributors to “take-back” the environmentally hazardous products and packaging for recycling or reuse. This producer responsibility is driving companies to put plans in place for product returns, recycling and for redesigning their products and packaging to meet these requirements in order to participate in the European marketplace. It is interesting to note that the institutional pressures play a vital role in the compliance of the manufacturer to the regulations through market and regulatory pressures, which is complemented by the competitive constraints existing in the market. These powerful forces constrain the market to move in the same direction to become more similar to one another (DiMaggio and Powell, 1983). Moreover, as these constraints push forward the knowledge of the environmental impact of the manufacturers, it boosts further competition within the institution to provide the best products with maximum conformity to the regulations laid out in the market (Darnall et al., 2008). Additionally, as third world countries develop and consumption increases, raw materials will be in short supply (steel, aluminum, copper and oil). New commodity markets will develop to extract these commodities from end-of-service life products.
The objective of this paper is to identify the primary forces for three industry sectors (automotive, consumer appliances and electronics) to close the supply chain loop in the product lifecycle including:

- Identifying the drivers of a growing market for recycled and remanufactured products (i.e., market competition, regulations and globalizing growth).
- Creation of economically efficient end-of-life product returns and reuse/recycling practices.
- Supply chain coordination for redesign of products, disassembly methods and practices, and services.
- Identify lessons that can be learned when designing a closed-loop supply chain.

In order to examine the above objective the format for this paper follows:

- A literature review.
- Industry response to product end-of-life issues.
- Considerations in designing reverse logistics.
- Advantages of remanufacturing.
- Closed-loop supply chains and competition.
- Additional reverse logistic opportunities revealed.
- Future research needs and conclusions.

2. Literature review

A literature review is summarized below. The primary purpose of the review was to identify (1) What are the primary global drivers of cradle to cradle supply chains? (2) In general, how do producer responsibilities defined by EU law influence closed-loop supply chains? (3) Is recycling and reuse market driven or regulation driven? The review of the literature focused on the automotive, consumer appliance and electronics industry segments.

Most developed countries have regulations focused on preventing and managing waste streams such as municipal waste, industrial and hazardous waste. These regulations are the result of societal, consumer and environmental values spurred by a variety of interests such as population density, land limitation for landfills, sustainable resources for natural resources, clean water and air (van den Bergh and van Veen-Groot, 2001). Additionally, the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal (1992) prohibits the international shipment and trade of hazardous wastes—particularly to protect developing countries from polluting their own environments due to undeveloped environmental protection measures.

The European Union has been a leader in developing regulations such as End-of-life Vehicles Directive (ELV), Waste Electrical and Electronic Equipment Directive (WEEE), Restriction of Use of certain Hazardous Substances Directive (RoHS), and the Packaging and Packaging Waste Directive. For purposes of limiting the scope of this paper, the Packaging Directive will not be examined. This project seeks to understand some of the “macro” forces that drive hazardous material recycling, reuse and remanufacturing and to evaluate selected industry segments’ (automotive, consumer appliances and electronics) capacity to deal with the existing European regulations.

The EU’s End-of-Life directive requires car manufacturers who import or sell cars in Europe to take producer responsibility to arrange for disposal and/or recycling of the vehicle. The directive sets targets by 2006 for reuse and recovery to be 85%, disposal of 15% and energy recovery of 5%, by weight per vehicle. Targets for 2015 are 95% of a vehicle’s weight must be reused or recycled; 10% energy recovery and a maximum of 5% disposal by vehicle weight. The directive also requires the OEMs to produce dismantling manuals and reports that identify components for disassembly with a view toward recoverability and recyclability (Directive 2000/53/EC; Kumar and Fullenkamp, 2005).

The WEEE directive essentially applies to all equipment that can be plugged into an electrical circuit or that operates on batteries. It includes large and small household appliances, information technology and telecommunications equipment, lighting equipment, electronic tools, toys and sports equipment, some medical devices, monitoring and control instruments. The WEEE Directive’s purpose is the prevention of waste equipment and it seeks to improve the environmental performance of all those involved in the lifecycle including producers, distributors, consumers and especially the operations directly involved in the treatment of waste electrical and electronic equipment. China and Korea have followed the EU in promulgating regulations to manage electronic equipment wastes, in order to ensure its electronic exports can compete globally and to mitigate electronics waste issues. Statistics released by the China Electronics Import & Export Corporation estimate that 70% of China’s electronics exports will be impacted by WEEE and RoHS requirements (Hicks et al., 2005).

RoHS (EU Directive 2002/95/EC) was published as a companion to the WEEE directive and they are applied together. The RoHS bans the use and placing on the market of certain hazardous heavy metal including lead, mercury, cadmium, chromium and brominated flame-retardants in new electrical and electronic equipment after 1 July 2006 (US Commercial Service, 2005).

Additionally, the REACH Regulation, which deals with the Registration, Evaluation, Authorization and restriction of Chemical substances, was formally adopted on 18 December 2006 by the EU Council of Environment Ministers. The goal of the proposed regulation is to provide sufficient information on chemicals that are used, and to phase out those chemicals that pose unmanageable and unacceptable risks. A centralized database is proposed for the documentation and dissemination of chemical information. Companies that manufacture, import and use chemicals will be responsible of assessing the safety of chemicals and managing the risks. REACH was launched on 1 June 2007.

In addition to the regulatory forces, there have been societal and resource drivers that have required industry and consumers to focus on ecological sustainability. Following is a brief discussion of some of these basic market forces.
One critical factor is the supply and demand of limited resources such as steel, copper, aluminum and petroleum as a source of energy (Prospect, 2005). Each of the three sectors (automotive, consumer appliances and electronics), which are reviewed in this paper, rely on supplies of these natural resources to manufacture their products. There has been a long history of steel, aluminum and copper recycling in the US and around the world. Recycling of these materials is market driven due to their value. Global prices of steel have risen sharply in the past several years as China’s economic growth has surged. Iron ore prices have risen significantly in past years (19% in 2004, 71% in 2005 and 19% in 2006, respectively) (Glader and Barta, 2006) and the availability of steel scrap is in short supply (Steel Recycling Institute, 2006a; Engineering News Record, 22 March 2004). Steel is the world’s most recycled material and it is cheaper to recycle steel scrap than to mine virgin ore. Approximately half of the steel produced is recycled through the steel-making process. In the US, the Steel Recycling Institute (2006a) reported steel recycling rates of nearly 76% in 2005. According to the US EPA, steel recycling contributes 74% in energy savings in the production process, 90% in virgin materials use, 97% reduction in mining wastes, 88% reduction in air emissions and 76% water reduction. Steel recycling is a well-established supply chain of collection programs, ferrous scrap processors, mini-mills and fabricators and there are more than 70 end markets for recycled steel (Steel Recycling Institute, 2006a). The automotive and appliance industry substantially drive and rely on recycled steel. These two segments report nearly 100% recycling rates. Steel can be recycled and reused over and over again (American Iron and Steel Institute, 2007).

Aluminum is also a market-driven recycled metal. In the case of aluminum, remelting requires only 5% of the energy required to make aluminum from ore (Millbank, 2004) and the recovered metal accounts for about one-third of the total aluminum consumption world-wide. The value of scrap metal ensures that commercial recycling occurs in developed countries, and Brazil and India are also leading recyclers of aluminum because of the endemic poverty. The automotive sector, i.e., cast parts for engine blocks and heads with average product lifecycles of 12 years), beverage can and construction industries are major consumers of aluminum. Ford Motor Company and Alcan launched North America’s first closed-loop recycling program for automotive aluminum sheet scrap in 2002 (Millbank, 2004).

Future trends and economic pressure include the flow of large amounts of aluminum scrap being shipped from Europe and North America to China and India, making the material scarcer (Platts Commodity News, 2005a,b). This material flow and the ELV directive have impacted Europe’s secondary aluminum smelting industry and market consolidation is occurring (Karpel, 2002). The EU is in danger of losing significant parts of the aluminum-processing industry (Millbank, 2004).

Copper prices have been very volatile over the last several years; annual averages ranged from $3679/metric ton in 2005, 6722/metric ton in 2006 and 6391 in the first quarter of 2007 (World Bank, 2007). However, the growth of the Chinese economy is expected to keep world demand for copper on the rise (Gross, 2005).

2.1. Economic efficiency

There is a fundamental difference in the EU regulatory system and the Environmental Protection regulations of the US in terms of economic practices. Considering the EU has advanced these regulations first, they have placed the financial costs on either the product users (i.e. first owner or last owner) or on the manufacturer. The monetary funds in effect subsidize the disassembly, recycling or reuse programs. When the funds are managed by governments there is less market competition to improve environmental management by the producer. More EU countries have realized that extended producer responsibilities drive improved environmental and economic efficiency. When producers are made responsible for the extended end-of-life phase of products, they have more motivation to facilitate other members of the supply chain, the users, and the stakeholders of end-of-life processing. They have the opportunity to make the process more effective and cost efficient. The regulated/socialist waste management approach to paying for recycling is very different from the recycling for profit point of view.

3. Industry response to product end-of-life issues

This section presents qualitative analysis of a few consumer goods industries that have been actively incorporating reverse logistics as part of their business operations. The industries analyzed for recycling and reuse include automobile, electronics and appliance.

3.1. Automobile

Automobile recycling has long been a profitable business in the United States. The Steel Recycling Institute reported the 2003 recycling rates to be 103%. The automobile recycling rate is calculated by comparing the total steel used to produce new cars versus the total steel recovered from old cars (Steel Recycling Institute, 2006b). There are over 10,000 dismantlers in the US and the infrastructures of dismantlers and shredders are strongly intertwined in the US (Johnson and Wang, 2002). In the European Union, it is estimated that 8–9 million vehicles are discarded annually, which result in recycling of approximately 75% by weight of the vehicle and 9 million ton of waste created per year. (Note the US and EU use different measures of recycling.) The ELV directive is aimed at preventing and managing these wastes. Within Europe, Japan and Asia there are similar regulatory goals, but the mechanisms for accomplishing these objectives vary. (These differences will not be examined in this paper. The reader is referred to an excellent overview, “Exploring the Determinant Factors for Effective End-Of Life Vehicle Policy” by Nawon Kim (2002) for an examination of national policy differences.)
Due to the value of steel and other components of automobiles, recycling practices are more advanced than the other sectors examined in this paper. ELVs contain hazardous substances such as spent oils, solvents, heavy metals, organic toxics and ozone-depleting substances. Contaminated shredder residues are a significant issue around the world. See Fig. 1 for an example of a materials flow for an ELV treatment system (Kim et al., 2004).

A Strengths, Weaknesses, Opportunity and Threat (SWOT) analysis (see Table 1) has been selected to summarize the issues the automobile manufacturers face in taking on producer responsibility for their product’s ELV regulatory drivers. This SWOT analysis is based on a review of the literature and may be limited by availability of information and is likely biased toward published successes (there are few companies who publish their management failures). Additionally, the literature primarily represents EU university research or US trade organizations.

In summary, the automotive industry appears to be prepared to meet the 2006 requirements for ELV recycling. As the EU has evolved its policies toward producer responsibilities, the manufacturers have stepped forward to accept the responsibilities and better performance has resulted:

- Producers are aligning with dismantlers and recyclers. Producers are demanding improved disassembly and recycling starting at the design phase and moving forward through the supply chain. Manufacturers expect to be able to gain economic efficiency and to see reductions in cost of recycling fees.
- Used parts and recycled materials, especially metals, are reintroduced into their supply chain.
- Sharing information on components and disassembly procedures is beginning to occur.

### 3.2. Electronics

There are several examples of electronics distributors and manufacturers who are very interested in take-back programs with an eye toward recycling and reuse programs (Cottrill, 2003; Jung and Bartel, 1999; Zhou et al., 1999). Some of the best examples are Xerox copiers that are leased, refurbished and go through multiple lifecycles, single-use cameras that may actually be reused up to 10 times by unsuspecting consumers; and cell phones that are collected and resold in secondary markets. These examples are famous because their reuse or service is value-added and make the economic case for tying reuse or recycling to corporate profit. However, not all consumer electronic take-back or recycling programs are profitable when additional regulatory drivers are applied. Dell’s reverse supply chain and consumer take-back program was not designed to provide profit (Cottrill, 2003).

In the US alone, only a portion of the ewaste issue is illustrated by the following estimates. The US National Safety Council estimates that by 2007 more than 500 million computers will be discarded, which will

![Fig. 1. An example of materials flow of the end-of-life vehicle treatment system.](image-url)
A SWOT analysis (see Table 2) has been selected to summarize the issues the electronic manufacturers face as they focus on meeting the EU regulatory drivers. This SWOT analysis is based on a review of the literature and may be limited by availability of information and is likely biased toward published successes. This directive has not been fully implemented at the time of this writing so fewer examples are available. Additionally, the literature primarily represents EU university research or US trade organizations.

In the electronics industry, there is a challenge to be successful in both ecology objectives and economic objectives. Electronic production processes are designed to build electronic products from scratch. So the greater the level of aggregation of a product to be recycled, or when the product still resembles the original product, the more the input and expense are needed to move it back into the market. Manufacturers can be profitable by including recycled materials in production and they likely have the logistics to support this process already. Additionally, the “green” label attracts customers; the reuse of highly aggregated products is better for the

Table 1
SWOT analysis—automobile manufacturer’s ability to meet the EU producer responsibility requirements of ELV

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<thead>
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<th>Opportunities</th>
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<tr>
<td>● There is a successful and strong reverse supply chain in existence for automotive recovery. Recovery, recycling and reuse technology and markets exist</td>
<td>● Each EU country has a slightly different structure for their ELV program (i.e., producer responsibility, first/last owner pays portion of scrapping fee, etc.)</td>
<td>● Investment in R&amp;D re-engineering could improve component design and design for disassembly. Others in the industry have already reduced their recycling fees by 35–40%</td>
<td>● Abandoned vehicles are a problem in countries that place some responsibility on the end user of the vehicle (i.e., Germany and the Netherlands). End users abandon cars in order to avoid paying waste disposal fees. More EU countries are reorganizing their programs to place the responsibility fully on manufacturers. This will ultimately require R&amp;D on redesign</td>
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<tr>
<td>● There is market competition for significant wastes streams, particularly the metals, tires and recyclable solvents</td>
<td>● Dismantlers are not always incentivized to remove all hazardous materials before metal recovery occurs. Contamination of shredder material and landfills is a significant liability</td>
<td>● Remanufacturing of some components could create profit growth in reuse markets or services. (This segment probably does not need to search for new market segments for remanufactured goods)</td>
<td>● Foreign producers who do not have disassembly information or reverse supply chain networks may have to transport vehicles back to the country of origin or pay higher fees</td>
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<tr>
<td>● Some manufacturers successfully remanufacture or reuse parts. They have integrated these materials back into their supply chain</td>
<td>● In the EU, approximately 25% of vehicle weight is not recycled today. Eight to 10% of the vehicle consists of plastic (polyvinyl chlorides which are difficult to recycle). Improved technology and markets are needed for glass and plastic waste streams</td>
<td>● Spare parts are a profitable business</td>
<td>● Johnson and Wang’s research found that plastics, polymers and glass materials cannot be economically recovered and are expected to drain the recycling infrastructure unless markets for these materials are developed. These researchers did not believe the 2015 recovery rates were feasible within the industry</td>
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<td>● Volvo, Saab and BMW appear to have taken their producer responsibilities more seriously. They have redesigned their cars so that components can be dismantled more efficiently. Consequently, they have lowered their producer allocation fees by 35–40% to ELV programs. Design paybacks have been demonstrated</td>
<td></td>
<td>● Sustainable financial mechanisms have not been developed for all waste materials to enter into a perfectly competitive market place</td>
<td>● EU monitoring programs are expected to increase to ensure compliance; noncompliant manufacturers will be fined</td>
</tr>
<tr>
<td>● Half of the recyclable materials are recovered</td>
<td></td>
<td>● Information systems and monitoring systems are not in place</td>
<td>● US and Asian vehicle producers may be at a disadvantage compared to Volvo, Saab and BMW for efficient dismantling designs. Their EU monitoring programs are expected to increase to ensure compliance; noncompliant manufacturers will be fined</td>
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<td>● Effective recycling systems and existing infrastructure for metal scrap</td>
<td></td>
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contribute 6.3 billion pounds of plastic and 1.6 billion pounds of lead to the waste stream. By 2010 the International Association of Electronics recyclers estimates that one billion computers will be scrapped. They also claim that 1.5 billion pounds of electronic equipment is recycled annually, which includes 40 million units of computer equipment including processors, monitors and printers. Half of the recyclable materials are recovered metals (Reverse Logistics Trends, 2005). The drivers of electronic recycling and reuse include:

- Current and anticipated environmental legislation in the global market place.
- Consumer preferences for “green” products.
- Corporate image and “sustainability”.
- Increasing waste disposal and landfill costs.

Fig. 2 illustrates a simplistic lifecycle flow with environmental aspects. EU directives will direct more emphasis into the recycling and reuse loop (Electronic Consumer Goods Case Report, Kleijn, 1999).
environment but opposes many technological and consumer-desired technological upgrades. People are fascinated by changing technology (Wenzek, 2003). Manufacturers while considering future uncertainty can also design products for which their functionality can be upgraded in order to extend product’s life span (Umemori et al., 2001). The WEEE directives require OEMs to do more and this will force more dynamic relationships within an already complex supply chain. WEEE will drive OEMs to establish closed-loop product lifecycle management, OEMs will design and engineer products for reusability and sustainability. An additional challenge will be that supply networks will have to look forward and backward for resource planning and advanced planning. The return flow of products will have to be efficiently managed and the information flow will be critical. It should be anticipated that OEMs will require very sophisticated information and network systems for a closed-loop lifecycle (Wenzek, 2003). Wenzek also believes that a holistic view of the entire business ecosystem and closed-loop mentality is essential in creating a competitive advantage. He also recommends that business will have to change their mindsets to view products as vehicles for other business models, especially unique services (such as leasing or renting equipment). (Zhou et al., 1999) in an article entitled "Multi-lifecycle Product Recovery for Electronic Products", advances the very interesting concept of design for multi-lifecycles. Researchers have known that 70% of the cost of a product is set during the design phase and this is also the phase where commitment to reducing the product environmental impact is made (Zhou et al., 1999). Zhou recommends the use of multi-lifecycle engineering approaches which could save manufacturers much of the cost of waste disposal and disassembly and could provide them profits from efficient product recovery (Zhou et al., 1999).

3.3. Appliance

The SWOT analysis (see Table 3) of appliance manufacturer's ability to meet the requirements of WEEE and RoHS is very similar to the electronics industry except that appliances have long been recycled and there are established infrastructures for the collection and recycling of appliances. The appliance recycling process is more similar to vehicle recycling because of the metal, CFC refrigerant (in cooling appliances) and motor recovery. Polychlorinated biphenyls can be found in appliance motors and compressors that were made before 1979. Mercury is another hazardous metal found in some gas pilot-light ranges, in freezer doors with lid lights and in small fluorescent lights of control panels on ranges and clothes dryers. These hazardous substances are being
Table 2
SWOT analysis—electronic manufacturer’s ability to meet the requirements of WEEE

<table>
<thead>
<tr>
<th>Strengths</th>
<th>Weaknesses</th>
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<tbody>
<tr>
<td>• Take-back programs are viewed by customers to be a service if it is easy to do or if it is tied to consumer trade or purchase</td>
<td>• Manufacturers have less control of consumer’s disposal practices. Large electronic components will need to be managed by municipality or special home pickup. (Too heavy to carry to a store)</td>
</tr>
<tr>
<td>• Precious metal recycling is already an economic driver. There are existing profit markets for aluminum, copper, wire and unpopulated circuit boards</td>
<td>• Electronics products can have a field life in the decades, so predicting the rate of return and end-of-life value is not easily predictable</td>
</tr>
<tr>
<td>• The technology for recycling plastics is improving</td>
<td>• Few manufacturers have a robust reverse supply chain</td>
</tr>
<tr>
<td>• In comparison to automotive and appliance industry, electronic waste volume is much smaller</td>
<td>• There appears to be a shortage of profitable recycling outlets</td>
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<td>• New market segments may be identified for remanufactured goods. Environmentally conscious design may improve the ease of disassembly and refabrication into new products. Designs which optimize these processes will likely be more profitable</td>
<td>• OEMs will put pressure on their materials supply chain to accurately identify and remove hazardous substances. Some components may not have viable materials alternatives. Supply chains may become disrupted</td>
</tr>
<tr>
<td>• Suppliers who can provide acceptable materials have market and profit growth opportunities</td>
<td>• OEMs that cannot control or eliminate the hazardous materials in their products face fines and potential loss of markets in regulated countries</td>
</tr>
<tr>
<td>• The less effort needed to conduct end-of-life processing, the lower the cost of processing. Recyclability or remanufacture of components or products can be a key competitive advantage if disassembly can be optimized</td>
<td>• OEMs who cannot adequately take responsibility for their WEEE and RoHS will not be profitable and may go out of business</td>
</tr>
<tr>
<td>• Companies such as Xerox, Kodak, Volvo and Electrolux have instilled an environmental consciousness into their corporate culture and product design (in some product business units), which can provide models of success and failure for benchmarking</td>
<td>• Most do not have the information systems to support take-back and dismantling processes</td>
</tr>
<tr>
<td>• New customer service offerings throughout a product’s lifecycles or multiple life cycles could be differentiating and more profitable</td>
<td>• Few manufacturers have perfect visibility of their components chemical make-up</td>
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Table 3
SWOT Analysis—appliance manufacturer’s ability to meet the requirements of WEEE

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<td>• Take-back programs are viewed by customers to be a service if its easy to do or if its tied to consumer trade, purchase or part of municipal waste pickup service</td>
<td>• Appliance products can have a field life of 7–16 years, so predicting the rate of return and end-of-life value is not easily predictable</td>
</tr>
<tr>
<td>• Metal recycling is already an economic driver. There are existing profit markets for aluminum, steel, motors and compressors as well as used appliances</td>
<td>• Few manufacturers have a robust reverse supply chain or information needed by dismantlers for efficient disassembly</td>
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New customer service offerings throughout a product’s lifecycles or multiple life cycles could be differentiating and more profitable

phased-out in the US and Europe. Styrofoam insulation is also a waste stream that can be recovered for energy or reprocessed for injection molded parts. In the US, there are over 11,000 locations that accept appliances for recycling, and the US steel industry estimates that nearly 90% of the appliances are recycled for their spare parts and metal content (Appliance Recycling Information Center, 2005; Sundin, 2001).

In summary, the appliance industry has the opportunity to leverage existing collection and recovery processes and coordinate improved economic savings in the disassembly and recycling process. Additional capacity needs to be added to recover and reuse non-metal wastes and reduce land filling wastes. This industry traditionally has not taken a systems approach in integrating environmental management with metals recycling. Cianter provides an example of weak systems thinking for environmental management regarding the phase out of chlorofluorocarbons (CFCs) refrigerants in domestic refrigerators. In a detailed lifecycle assessment on the replacement refrigerant HFC-134a, research illustrated that the CFC substitute increases the friction and wear of aluminum components, which increased electrical energy consumption of the compressors. Additional research was identified to evaluate new compressor designs aimed at serviceability and extending the life of the compressor (Cianter, 2000).

Appliance reuse and remanufacturing is one the most significant opportunities available and will be discussed further in the next section. Additionally, this sector may benefit from creating new customer service offerings.

4. Considerations in designing reverse logistics

The next portion of this paper will summarize some of the strategies manufacturers should consider as they design their reverse logistics systems. In the early phases of compliance with extended producer responsibilities, OEMs will likely rely on third-party take-back services. As OEMs gain better understanding of their responsibility, they are apt to adopt management strategies that help them become economically efficient. Manufacturers are likely to give their designers goals to increase product recovery, recycling and reuse. The following terms will be used:

- Remanufacturing: restoring a product to like-new condition by reusing, reconditioning and replacing parts.
- Reuse: using good components from retired assemblies.
- Recycling: taking component materials and processing them into the same material or other useful material; and
- Repair: bringing damaged components back to a functional condition (Amezquita et al., 1995).

One of the first decisions to be made by manufacturers is a balanced choice about the end-of-life process goals (i.e., recycling by a third-party or take-back channel for remanufacturing). This decision will influence the channel choice for product recovery. This paper assumes that producers will begin to integrate end-of-life processing to a greater degree to ensure that they are meeting and optimizing the costs of end-of-life processing. It is likely that the desire to improve recycling and reuse processes will integrate this into a closed-loop supply chain. Table 4 summarizes some typical collection methods which return the product to the manufacturer (Savaskan et al., 2004).

There are some advantages that will assist the manufacturer in selecting the best return channel method. First overall cost of recovery should be the priority. Third-party collection and processing is an advantage when there are economies of scale from remanufacturing and the third-party can work with a number of manufacturers. When the return value of the end-of-life product is unknown, the collection point closest to the consumer should evaluate the product or assembly and sort valued parts or components—only valued parts or components should be returned to the manufacturer or next user in order to save transportation costs. Manufacturers should do the recovery when the cost of recovery from the customer is significantly lower than transportation costs (Savaskan et al., 2004).

4.1. Advantages of remanufacturing

Earlier in part one of this paper, the WEEE directive’s purpose in preventing waste, promoting recycling and reuse was considered. Additionally, the WEEE and RoHS directives promote product redesign to remove banned substances and to improve labor efficiency for disassembly. According to researchers at Georgia Institute of Technology, remanufacturing is driven by three factors: ecology, legislation and economics (Amezquita et al., 1995).

There are many examples demonstrating that good design can save manufacturing and lifecycle costs (Umeda, 1999, 2001). Today there are also more and more companies that are implementing remanufacturing strategies to retain the accumulated value of products, assemblies or components. The authors of the paper that describe how functional sales have an economic and environmental benefit when used in conjunction with contract on product remanufacturing. This also points to the various strategies that can be employed when the product is designed and adapted to the process of remanufacturing. One of the most crucial steps that the authors describe in the paper relates to the cleaning and repairing steps that needs to be performed before the remanufacturing (Sundin and Bras, 2005). For example, “disposable” cameras, cell phones, printing presses, truck tires, automobile and airplane components and assemblies, copy machines, and toner cartridges are reconditioned or remanufactured and resold (or leased) to end users. Proponents of remanufacturing point out that the product value gained during fabrication is retained and only the worn-out parts are replaced. Remanufactured products incur costs that are 40–60% less than those
incurred in delivery of new products. This is because most of the raw materials already exist in their final form and only a portion goes through material processing and fabrication. In a paper by Giuntini and Gaudette, called “Remanufacturing: The Next Great Opportunity for Boosting US Productivity”, the authors state that remanufacturing saves 85% of the energy needed to start from scratch. Remanufactured goods are rigorously tested to ensure “like-new” operation and often consumers benefit from lower product prices in the order of 30–40%. On the other hand, the recycling process breaks down products to materials that must be reprocessed and refabricated from scratch. From an environmental point of view, remanufacturing has significant advantages including conservation of resources, energy and reduction of waste generation (Lindahl et al., 2006; Ostlin et al., 2005).

In the US, remanufacturing is practiced by the automobile and tire industry, Department of Defense (aerospace), Kodak (cameras) and Xerox (photocopiers and print toner cartridges) to name just a few industries. In the US, remanufactured goods account for $53 billion/year of the GDP (Guide, 2005). The EU packaging and recycling directives are likely to drive more remanufacturing in Europe.

One management paradigm shift that Giuntini and Gaudette (2003) recommend for remanufactured products and marketing is to recognize that the sale of remanufactured products generates lower revenues, but in absolute terms and as a percentage of sales, profits are often greater. Remanufactured parts also offer the capability to segment the market, meeting diverse customer needs with a broader range of offerings. For remanufactured products to be viable, marketing and sales strategies must shift their focus to solutions that deliver products regardless of whether they are new or not.

4.2. Closed-loop supply chains and competition

Remanufacturing also forms the foundation for closed-loop supply chains (shown in Fig. 3). In some industries, experience has shown that if there is a used item market then that market may compete with the original manufacturer’s market and its supply chain. As OEMs compete for market share they may coordinate their supply chain and reverse logistics to maintain their market share by facilitating the refurbishing, remanufacturing or recycling of the products. This has occurred in the automobile, copy machine and printer toner industries. As the competition increases, the OEM may manufacture less and the OEM is motivated to find ways to increase the competing remanufacturer’s cost of remanufacture. This is often done by increasing the opponent’s costs and by making it more difficult to the competitor to obtain OEM returns and to collect end-of-life product. The OEM begins to compete more on the remanufactured products. Competition may derive additional environmental benefits because the competitors often react by increasing the durability of the product or they may give the product multi-lifecycles in order to increase remanufacturing and associated profits. This impacts the entire OEM supply chain and must be carefully managed (Majumder and Groenevelt, 2001).

5. Additional reverse logistic opportunities revealed

Some of the literature available today has begun to highlight future services associated with reverse logistic needs. It is expected that some companies will outsource reverse logistics in the supply chain. The reverse supply chain is often more complex than the forward supply chain models, so expertise and specialization are
demanded. Often the third-party service provider is selected based on its ability to respond to the complexity and randomness of the reverse supply chain. Information systems and physical infrastructures are also key factors in the success of the reverse supply chain. Several sources identified opportunities for reverse logistic services. Typical service needs of the reverse logistics chain include—customer service, depot repair, end-of-life manufacturing, IT management, recycling, refurbishing/screening, replacement management, returns authorization, spare parts management, transportation, warehousing and warranty management. Of particular note, manufacturers are interested in outsourcing field service support infrastructures such as call center services, field swaps, parts repair and screening for refurbishment/remanufacturing (SalesLink Corporation, 2005; Blumberg and Devine, 2005).

6. Future research needs

Efficient closed-loop supply chains exist today for product rework and customer returns. However, there are few models that are transferable across several industries for reverse logistics of end-of-life returns. There are numerous models available that have been tested for single product lifecycles. Additional research and information are needed for end-of-life reverse logistics systems including:

- Methods of gaining economic efficiency for collection, disassembly, reuse, recycling and remanufacturing.
- Improving recycling technology.
- Developing secondary markets and technology for recycled materials.
- Improved information sharing throughout the closed-loop supply chain for lifecycle cradle-to-cradle management.
- Developing countries need financial and technical support to meet higher environmental standards; and
- Determining whether business eco-efficiency and the internalization of environmental costs is a way of aligning market forces with environmental goals (Silber, 1997).

7. Conclusions and recommendations

In conclusion, this paper has demonstrated that global factors will impact all of our businesses (i.e., market competition, regulations and globalizing growth). There are industry segments that have been successful with end-of-life product management and which have established economically efficient recovery, reuse and recycling systems. The successful, profitable company success stories that are available have changed the way they view sustainable design, manufacturing and waste management. They have been led by champions who valued sustainability and who adopted a systems viewpoint throughout the supply chain.

In the area of marketing, influencing end users to desire “green” products and services is challenging but it is a trend that consumer and investor segments has adopted. The use of remanufacturing is an appealing model that may work in some industry segments, but may not find broad application at this time. Before remanufacturing is universally accepted, economic factors and regulatory pressures are likely to increase and consumer values will have to be changed so that they understand the value of remanufactured goods.

Some research identified in this paper also enumerated significant service opportunities for reverse supply chain management and information systems. Reverse, closed-loop supply chains have not been broadly researched or developed. Supply chain coordination for redesign of products, disassembly methods and practices, and services will be critical for producers of many products in the future.

References
