Research, Commercialization and Workforce Development in the Polymer/Electronics Recycling Industry

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1.0 Introduction

In today's world where computers are essential, the question needs to be addressed, "What do we do with the computers when they become obsolete?" According to National Safety Council estimates, approximately 24 million personal computers became obsolete in 1999, but only fourteen percent were recycled or donated, [5]. By 2004, as many as 315 million personal computers could become obsolete.

The project entitled "Research, Commercialization, and Workforce Development in the Polymer/Electronics Recycling Industry," is a multi-year project that seeks to develop, integrate, and apply technologies for recycling end-of-life (EOL) electronics. The project is supported by the U.S. Department of Energy through the National Energy Technology Laboratory. The research team consists of three research groups at West Virginia University (WVU), the Polymer Alliance Zone (PAZ) of West Virginia, DN American, Inc. of Fairmont, West Virginia, Ecolobrium, Inc. of Austin, Texas, and other subcontractors. PAZ leads the project and the WVU Research Office jointly coordinates the project with PAZ.

2.0 Challenge

A challenge facing today's society is to develop strategies and infrastructure for recovering maximum value from materials and components from EOL electronics equipment. The goal is to avoid landfilling and incineration of EOL electronics. This project has multiple objectives that seek to find acceptable solutions to this challenge. The main objectives of the project are to:

1. develop business plans and technology assessment models to assist establishment of a regional EOL electronics processing center,

2. identify, develop, and demonstrate economically viable techniques for recovery of value from plastic, metal, and glass components from EOL electronic equipment;

3. develop economically feasible and environmentally acceptable high-value uses for EOL electronics equipment;

4. promote private sector involvement, [1], [4], in developing a recycling infrastructure that attracts new businesses and investment opportunities for the polymer and related industries and builds on the existing polymer industry;

5. develop an Internet portal to support information exchange, e-commerce, and clearinghouse functions for the electronics recycling industry,

6. adapt workforce training programs to provide the human resource needs for this new industry.

3.0 Approach

The project consists of three phases that seek to evaluate and establish a program for the management and processing of recycled plastics and other materials from EOL electronics equipment.

The first phase of the project includes an assessment of the potential supply stream of EOL electronics and an evaluation of the best available technologies and practices for processing EOL electronics. These assessments include identification of equipment, manufacturers, an evaluation of minimum capital costs for equipment and facilities, and material throughput requirements for break-even operations.

Blends of virgin and recycled plastics will be tested to determine the ratios necessary to meet manufacturing and safety requirements. These materials will be characterized by rheological, thermal, and mechanical properties. The effects of reinforcement additives on the properties of the bends of virgin and recycled polymers will also be studied. Recycled plastics will be evaluated for application in the electronics, automotive, highway, and infrastructure markets, [6].

A business plan for the Mid-Atlantic Recycling Center for End-of-Life Electronics (MARCEE) will be initiated during phase one. This includes studies of the logistics and transportation system, the supply stream of EOL electronics, and the demand potential for recycled materials from EOL electronics. The business plan includes site selection criteria for MARCEE, analysis of the potential supply stream, and identification of near and long-term funding sources for the venture.

An information exchange website for the electronics recycling industry is being built to facilitate communications within the industry and to provide a platform for advancing the industry through e-commerce. Curriculum and workforce training programs will address the human resource needs within the emerging electronics recycling industry.

The second phase of the project will further develop and expand the work conducted in phase one. The demanufacturing spreadsheet model will be expanded to include assessment of economic impacts of policy alternatives. The research emphasis will be on issues that support commercialization and product development.

Business model development will emphasize establishment of a regional EOL electronics processing center, and securing public and private sector funding sources. The electronics recycling web site will be updated and expanded.

During the third phase, the electronics recycling facility will be in operation, a supply chain management and logistics system addressing requirements of the industry will be in place, and training and curriculum programs will continue. An Internet trading platform that facilitates value-based transactions for suppliers, recyclers and buyers will be fully functional.

4.0 Project Description

4.1 Economic feasibility assessments, industry structure and business plan

Economic feasibility assessments of the electronics/polymer recycling industry are essential for such a venture to be successful. The analysis includes a comprehensive study of the supply side cost centers, a comprehensive analysis of the demand side cost centers, an assessment of potential products, services, and other sources of revenue, [7]. Once the study is completed, the most likely commercially successful structure and business plan for a regional EOL electronics-processing center in Wood County, West Virginia will be recommended.

4.2 Best available technologies and practices (BAT&P)

The goal of this task is to assess which available technologies are the most appropriate for the needs of the EOL electronics/polymer recycling facility in Wood County, West Virginia. Available technologies and practices for initial material separations, separating and using plastics derived from EOL electronics, and processing and using metals and glass recovered from EOL electronics will be assessed.

Another goal of this task is to produce a flexible/spreadsheet model that can be used to predict the potential for commercial success of an overall demanufacturing/recycling facility. It will predict the economics of building a demanufacturing facility based on the number of computers, the number of refurbished unites, operator requirements, capital investment for building the facility, utilities for running the facility, and product revenues and feed prices.

4.3 Polymer characterization, research, and testing

This task is to analyze the rheological, thermal, and mechanical properties of various blends of recycled and virgin polymers, and to evaluate the effects of reinforcement additives, e.g. rubber, mica, and glass fiber on the properties of various blends of recycled and virgin polymers.

Another part of this task is to provide various blends of recycled/virgin polymers, both with and without reinforcement additives, that can be used for fabricating and testing component parts in electronics equipment.

4.4 Application and product development

The purpose of this task is to find high-value and high-volume applications for recycled polymers. This will be accomplished through analyzing the mechanical, thermal, and aging properties of various virgin and recycled polymer blends for use in automotive and infrastructure applications.

The researchers will work toward development of sample automotive products, e.g. prototype headlight housings, bumper shapes, vehicle crossbeams, and reinforced door/window frames produced from recycled polymers. Sample infrastructure products such as offset blocks, prototype guardrails and guardrail posts will also be assessed.

4.5 Project master plan: site selection, financial plan, construction and training programs

The research team involved in this task will develop site identification/selection information, including cost projections, access to transportation, availability of utilities and public services, engineering site assessments (mineral rights, drainage, soil conditions, etc.), environmental impact statements, and archeological finds. The research team will also access public opinion for the project through holding public hearings to learn the acceptability of the project to the local community.

In order for this venture to be successful, financing must be in place. The researchers in this task will develop short and long-term financial plans by working with both government agencies and the private sector to ensure financial feasibility of MARCEE.

The availability of a qualified and reliable workforce is a critical issue for the manufacturing industry. One of the goals of this task is to develop curricula and training programs needed by the electronics reuse/recycling industry. The training programs will provide a reliable source of employees for the industry.

4.6 Industrial information exchange, virtual eco-industrial park, and Internet trading tools

The goal of this task is to develop a web-based interactive industrial information exchange to provide a unified directory of sources, a match-making capability between customers and suppliers, a forum for dialog and public relations, and access to trading platforms for materials derived from recycled electronics. The research team involved in this task will develop a virtual “eco-industrial park” that encompasses all infrastructure, technical, and commercial aspects of electronics recycling.

This website will evolve into a communications hub for the industry that provides access to an international clearinghouse of information on best available technologies and practices, environmental regulations, and reuse/recycling strategies related to end-of-life electronics.

4.7 Project support, business plan, environmental impacts, site development, and conferences

The main focus of this task is to provide support as needed on the project. This includes arranging meetings and plant visits for the project team with key industrial and governmental contacts, supporting the development of the business, industry, and marketing plans by providing: primary data on the supply stream (amount, location, and composition) of actual EOL electronics equipment that would be available within the next year for processing at the Wood County, West Virginia site; providing sound estimates of the quantity and quality of the supply stream over a five year period, and providing information to the teams involved in the business plan development.

An additional purpose of this task is to provide reports on environmental, health, and safety concerns, and an assessment of the impacts on recycling operations of toxic materials and their alternatives. A series of reports will be provided to the research team that detail state, federal, and international policies and legislation related to electronics recycling, [5].

5.0 Accomplishments and Results

5.1 Economic feasibility assessments, industry structure and business plan

This business plan group has determined that identification of the potential supply stream of EOL electronics for the recycling center is of primary importance. The supply stream of EOL electronics is not, as originally thought, readily available from existing warehouses and storerooms. Significant quantities of EOL computers are refurbished and sold or passed down to other users, [2].

Identification of the supply stream entails five steps: (1) define the scope of EOL electronics equipment to be processed, i.e., PCs, monitors, mainframes, pagers, telephones, computer mice, etc., (2) characterize the material compositions of the EOL electronics to be accepted, (3) determine the quantity of EOL electronics available to be processed, (4) determine the transportation costs associated with obtaining the supply, and, of great importance, (5) identify the suppliers who are willing to work with the regional center in Wood County.

The business plan group has developed a transportation model for the proposed regional center in Wood County. They have been told that, by presidential directive, the DOE gives the majority of its EOL computers to public school systems. Efforts are underway to identify individuals within the DOD and the GSA who are knowledgeable about disposition of EOL electronics, [8], [10].

5.2 Best available technologies and practices (BAT&P)

The technology assessment group and the business plan group have visited several companies that are involved in separating and processing materials from EOL electronics. Companies visited include MBA Polymers in Richmond CA, DMC Recyclers in Hagerstown MD, SDR Plastics in Ripley West Virginia, Butler-McDonald in Indianapolis IN, and Envirocycle in Hallstead PA. These companies have evolved their own supply streams, specialized services, and customers over years of operations, for example, Envirocycle processes high lead-content glass from CRT, but also is growing its business of refurbishing post-industrial computers for resale.

A spreadsheet model has been developed to evaluate the economics of building and operating a demanufacturing facility. This model will be used to simulate a number of case studies to investigate the response of economic parameters to a variety of inputs. The economic parameters evaluated by the spreadsheet include, net present value, capital cost of warehouse, capital cost of equipment, revenues, and operating costs. The spreadsheet model predicts the economic feasibility of operating a demanufacturing center based on the number of incoming computers, number of refurbished units, operator requirements, capital investment for buildings, utilities for running the facility, and product revenues and feed prices, [8].

An EOL electronics recycling center requires at least 30 to 60 million pounds of input material per year. If the supply is only computers, then one to two million computers per year, i.e., four to eight thousand computers per day, must be available for processing. The implication is that the supply of EOL electronics must include a broad array of electronic equipment, not just computers. Secondly, because it provides a high-value use of the resources, refurbishing EOL computers for reuse should most likely be part of the regional center business plan.

5.3 Polymer characterization, research, and testing

The polymer characterization and research group is developing compounding processes that enable the maximum amount of separated recycled polymers to be used in the fabrication of new products. The goal is to minimize material processing costs while targeting high-value applications and products. In order for fabricators, Original Equipment Manufacturers (OEMs), and polymer supply companies to accept recycled polymers, it is essential that mechanical, thermal, and rheological properties of recycled materials closely approximate those of the virgin polymers.

Since properties of recycled polymers vary significantly from batch to batch, compounding processes must be developed to control the properties of recycled polymers. The research team is investigating control techniques such as (1) blending recycled polymers with similar and/or dissimilar chemical type polymers, (2) adding fillers such as mica and talc, (3) adding reinforcements such as glass and/or carbon fibers, (4) adding toughening agents such as rubber, and (5) heat treating to adjust the average

molecular weight distribution. Preliminary results indicate that approximately 15% recycled material of 99% purity can safely be added to chemically similar virgin material without significantly altering rheological, thermal, and mechanical properties, [9]. The goal now is to substantially increase the recycle content through combinations of techniques (1) – (5) above, [8].

Results obtained by the polymer research team on this project have been presented at the May 2000 Society of Plastics Engineers meeting in Orlando, the August 2000 International Congress on Rheology in Cambridge UK, and at the June 2000 meeting of the SE Ohio Section meeting of the Society of Plastics Engineers.

5.4 Polymer Application and Product Development

The application and product development group works closely with the polymer characterization and research group on developing uses for recycle polymers. This work, of necessity, proceeds in close cooperation with a variety of fabricators, OEMs, and other intermediate and finished product manufacturers. Three categories of applications and products are being investigated: (1) high-volume, somewhat lower value applications such as highway guardrail posts and offset blocks, (2) medium-value applications such as headlight housings and bumpers for automotive vehicles, and (3) high-value, possibly lower volume applications such as computer housings and monitors.

Based on mechanical and thermal results using test coupons, 50% to 100% recycle content is feasible for category 1 applications. Creep and water/salt aging tests are currently under way. Meetings and cooperative programs on product development for recycled polymers are underway with PPG Industries, Owens Corning, IBM, SDR Plastics, and other specialty manufacturers, [8].

Corporate product development teams have confirmed the critical importance of positively identifying the potential supply stream available to a regional EOL electronics recycling center. They are reluctant to go forward with demonstration projects for high-volume applications until it is confirmed that there would be sufficient supply of recycled polymers to fulfill the projected demand.

The polymer research laboratories developed for the project include mechanical spectrometers, tensile testing machines, differential scanning calorimeters, impact testers, a small extruder for blending, a compression molding machine, and a laboratory pelletizer. An injection molding machine will be delivered within a few weeks.

5.5 Project master plan: site selection, financial plan, construction and training programs

The Polymer Alliance Zone of West Virginia has established plans for the Mid-Atlantic Recycling Center for End-of-Life Electronics (MARCEE) which include a separation and material handling facility, a national communications center, an incubator to develop new businesses, a warehouse, a National Trading Floor for plastic recyclables and a niche

segmentation research and development laboratory co-operated with the private sector/polymer industry and West Virginia University. A number of potential sites for MARCEE have been assessed.

PAZ determined that in order to make the economics' model work, it is necessary to develop clusters of the various segments in the EOL electronics recycling industry. The investigators at PAZ assume that the feedstock produced by recycling EOL electronics will attract plastic, glass, and metals companies to the region, [8].

The first class of the curricula/training development programs graduated in July 2000.

5.6 Industrial information exchange, virtual eco-industrial park, and Internet trading tools

DN American has established the industrial information exchange: http//www.electronicsrecycling.com. The site is broken down into sections containing information and additional resources for the electronics recycling community: 1) summaries of electronics recycling projects that are currently underway, 2) state and local legislative issues and concerns, 3) industry-related links to external sources of information, and 4) an on-line search tool that enables users to search for state and national information on electronics recycling, [8].

Analysis is currently underway to identify all necessary parts of a virtual representation of an eco-industrial park. The concept is to link a number of companies for electronic collaboration thus leading to a physical eco-industrial park.

A user-friendly online system is being investigated to store information on best available technologies and practices, environmental regulations, and reuse/recycling of end-of-life electronics.

5.7 Project support, business plan, environmental impacts, site development, and conferences

An overview was conducted of hazardous materials contained in computer and electronic equipment and materials. The study included heavy metals and plastic contaminants and fillers. Halogenated flame-retardants are used extensively in electronics plastics and are becoming subject to international legislation, [8].

The team has contacted and set-up meetings with electronics and automotive OEM's and electronics recyclers both in the United States and in Europe, [3].

A preliminary site model was completed and sample analysis conducted using Monte Carlo Simulation. Inputs were based upon literature searches, interviews with individuals involved with electronics recycling, and data gathered from site visits to electronics recyclers.

6.0 Application and Benefits

Recycling EOL electronics reduces the amount of post consumer electronic waste that is landfilled, while improving industrial ecology through recovery of material and energy value in EOL electronics. The project is industry-led and thus promotes private sector involvement in solving the problems. The main focus of the project is to develop a regional EOL electronics recycling facility in Wood County, West Virginia, thus another benefit of the project is to increase business development, employment opportunities, and technology transfer for this region of West Virginia.

The concept of a regional center to dispose of EOL electronics is an innovative idea. A goal of the West Virginia regional center is to enhance synergies between various segments of the electronics recycling industry by bringing them together into a single coordinated enterprise.

7.0 Future Activities

Future activities of the project will focus on establishing and operating the polymer/electronics recycling facility in Wood County, West Virginia. This will include ensuring the financial stability of the facility, and validating the economics of locating such a facility in the Wood County region.

Commercial feasibility of recycling EOL electronics will depend upon achieving product volumes material property, consistency, and meeting customer requirements. Therefore, the study should be expanded to analyze the supply and demand of post-consumer sector and post-public education sector EOL electronics by surveying the private and public sector entities to determine their potential as a source of EOL computers.

Further research and demonstration is required to develop processes and partnerships for a commercially successfully electronics recycling industry. Issues surrounding product volumes, consistency of material properties, and high-end applications need to be further explored. The cost drivers must be identified. Full life-cycle costs must be determined. Original Equipment Manufacturers (OEMs) must be involved in product design and industry standards for recycled materials must be established and the whole process made certifiable.

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