Final Report

For the Project Entitled:
Research, Commercialization, & Workforce Development in the Polymer/Electronics Recycling Industry

(Grant Number: DE-FC26-00FT40598)

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Project start date: November 22, 1999
Project end date: March 31, 2005

February 2006

Disclaimer

Abstract

The Mid-Atlantic Recycling Center for End-of-Life Electronics (MARCEE) was set up in 1999 in response to a call from Congressman Alan Mollohan, who had a strong interest in this subject. A consortium was put together which included the Polymer Alliance Zone (PAZ) of West Virginia, West Virginia University (WVU), DN American and Ecolibrium.

The consortium developed a set of objectives and task plans, which included both the research issues of setting up facilities to demanufacture End-of-Life Electronics (EoLE), the economics of the demanufacturing process, and the infrastructure development necessary for a sustainable recycling industry to be established in West Virginia.

This report discusses the work of the MARCEE Project Consortium from November 1999 through March 2005. While the body of the report is distributed in hard-copy form the Appendices are being distributed on CD's.

This work has been carried out under DOE Grant Number DE-FC26-00FT40598.

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A. Introduction

Every year it is estimated that more than 1.5B lbs of waste from end-of-life electronic devices is disposed of in the U.S. each year. Much of this obsolete equipment is stored by consumers and organizations, but a significant amount of it finds its way into landfills either in this country or overseas. It is estimated that only about 10% of e-waste is recycled and it comprises between 2-4% of municipal solid waste. However, the e-waste stream is growing three times faster than conventional waste streams in landfill sites.

In an effort to solve this problem, the MARCEE Project was formed in 1999 at the request of Congressman Alan Mollohan, who had an awareness and interest in this subject. A consortium of research and business groups was assembled, which included West Virginia University (WVU), the Polymer Alliance Zone (PAZ) of West Virginia, DN American and Ecolibrium, in order to build an electronics recycling business based in Wood County, West Virginia. This report details the progress that has been made towards achieving that vision.

B. Project Goals

The overall goal of the project was to develop a multi-faceted approach to the disposition of end-of-life electronics (EoLE). This would be achieved by:

- Identifying the various input streams for processing EoLE.
- Evaluating existing technologies for processing (EoLE).
- Characterize/identify the recycled plastics in the laboratory – test the recycled/virgin materials for strength, durability, and temperature integrity
- Develop a business model
- Identify the infrastructure requirements and understand the economic questions associated with an electronics/polymer recycling facility in Wood County, WV
- Coordinate the development and implementation of a curricula designed for the polymer/electronics recycling industry workforce development

C. Project Highlights

- PAZ purchased and is currently developing a one-hundred and fifty-six acre industrial park which will be the home of the Mid-Atlantic Recycling Center for End-of-life Electronics (MARCEE Project). The site will house a cluster of facilities that are dedicated to recycling, re-engineering and remanufacturing projects from end-of-life electronics. The brick and mortar portion of the project will not utilize any DOE or EPA funds. It will be entirely financed by lease income from the existing 313,500 square foot building as well as other public ($4.3 million grant from the State of WV for purchase) and private financial sources.
- The long term financial success of the Polymer Technology Park and the "MARCEE Project" will be accomplished by the Polymer Alliance Zone's continued reinvestment of its' lease income from the existing 315,500 square foot building and by matching the public sectors financing programs with private sectors

entrepreneurial capabilities and industry's technology. Once this is accomplished PAZ will step out of the project and will only be involved as requested.

- PAZ successfully completed the development of a business plan and a simulation tool for establishing the business of end-of-life electronics within the PAZ region. The plan and simulation tool allowed PAZ to leave the conceptual planning stage and enter into the implementation phase of the MARCEE project.
- The simulation tool was widely sought and is still used throughout the U.S. by public and private agencies to identify the real costs of recycling EOLE. This tool has opened many doors and has positioned PAZ as the expert in developing a regional recycling facility to recycle EOLE.
- MARCEE was officially recognized by the US DOE and US EPA as the prototype regional facility to be replicated nationwide. The program continues to receive data from national and international sources.
- The PAZ Simulation Tool" has been validated by industry members and was adopted by the National Electronics Product Stewardship Initiative (NEPSI) as the vehicle to identify the real costs of recycling EOLE.
- The Polymer Alliance Zone has established the National Center for Electronic Recycling (NCER). Working with OEM's, NCER has formed an "Industry Coalition" that will assist in making the recycling of EOLE economically feasible. This is a result of many discussions with industry, government and non-government agencies
- PAZ worked with Region III's five states and Washington D.C. to facilitate a pilot Project, eCycling. The Electronics Industry Alliance, the US EPA and the States Solid Waste Authorities funded the project.
- PAZ received a $50 million, private-sector contribution (in-kind) of an Internet-based trading network (GreenOnline) for the rapidly growing field of environmental commerce. This technology is undergoing further enhancements and will be activated upon completion.
- PAZ, along with subcontractor DN American, has collected data from worldwide sources through industry surveys and interviews with research companies in order to identify the best available technology on separating end-of-life electronics. Visits by PAZ and PAZ's industry advisory committee members to Germany, Spain, Switzerland, England, Canada, and other countries has yielded information regarding the "best practices" being used elsewhere. We intend to use this information in developing an EOLE recycling industry in West Virginia.
- PAZ has initiated, led and hosted national programs examining the recycling industry, identifying solutions to related issues, and creating a dialogue among government and industry leaders. Examples include the National Electronics Stewardship Workshop, held in partnership with West Virginia University, and the Stakeholder Dialogues which were held in conjunction with the Gordon Institute at Tuft's University.

- PAZ garnered a great deal of project publicity through articles published in trade and academic journals including Plastics News, Plastics from Electronics (an American Plastic Council publication), The Solid Waste Report, E-Scrap News, Business and the Environment, and Chem-Line. In addition, PAZ and WVU have made numerous presentations throughout the world on the MARCEE Project.
- A spreadsheet model of the demanufacturing process has been developed to assess the process economics. It indicates that in order to be viable, a recycling center requires a minimum of 30M lbs of input material per year. This suggests that the idea of regional recycling centers, such as MARCEE, may be the correct model.
- It has been shown that commingled plastics, which typically show poor mechanical properties, can be reinforced with materials such as glass fibers to yield polymer composites with excellent mechanical properties. Prototype construction materials have been made from these EoLE plastics, and are presently being tested under real world conditions.
- Extensive experimental studies have been carried out using froth flotation to separate plastics into their various polymer classes. While separation of two polymers can be carried out fairly efficiently, separating three or more polymers is time consuming, making it economically unattractive.

D. Task by Task Breakdown of Activities

Phase I – Business and Technology Assessments, Supporting Research, Master Plan Development, Information Exchange, and Workforce Programs

Task 1.0 Phase I Program Plan

The Recipient shall develop and submit a program plan detailing planned Phase I activities to the COR within 45 days following award. The program plan shall contain items such as detailed descriptions of planned activities, their schedule, a plan for obtaining and evaluating recycled plastics, details of quality assurance/control procedures to be adopted for the project, and such other information as might be needed for orderly conduct of the project. The program plan shall include detailed specifications as to who does what on the project.

Project activities shall be compared to the program plan. Deviations to the program plan shall be documented and corrected as needed. Identified changes to the program plan (as needed) will be coordinated and conveyed to the COR for mutual agreement.

Task 1.1 Economic Feasibility Assessments, Industry Structure and Business Plan (Logar)

The Recipient shall provide an assessment of the economic feasibility of the essential aspects of a regional center to dispose of EOL electronics. The assessment shall be conducted sequentially with progress dependent upon preceding results. Essential aspects of a regional center include the logistics and transportation system, the supply stream of obsolete electronics, and the separation unit.

Based on the economic feasibility of the issues previously described, the Recipient shall recommend the most likely commercially successful structure and business units that would be included in a regional EOL electronics-processing center.

Depending on the results of previous tasks, the Recipient shall develop a business plan for a regional center. The business plan shall contain the following components for the targeted commercialization venture: a comprehensive study of the supply side cost centers, and a comprehensive analysis of the demand side cost centers including an assessment of potential products, services, and other sources of revenue for the proposed regional center.

Description of work performed, accomplishments and results:

During Phase I, the business plan group determined that identification of the potential supply stream of EOL electronics for the recycling center is of critical importance. The supply stream of EOL electronics is not, as originally thought, readily available from existing warehouses and storerooms. Rather, significant quantities of EOL electronics are refurbished and sold or passed down to other users.

Identification of the supply stream entailed 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 WVU business plan group developed a transportation model for the proposed regional center in Wood County. The group suggested that all aspects from air to rail to water to highway transportation need to be investigated thoroughly in order to determine the final site and locate the supply stream for MARCEE.

The business plan group determined that the DOE and DOD donate a majority of their usable surplus computers to public school systems as mandated by a presidential directive. They recommended that new residential, industrial, and commercial sources be investigated as potential suppliers.

The business plan group completed its feasibility analysis of demanufacturing separation processes. Their findings and recommendations were issued as a report.

The results of the Phase I study showed that for the MARCEE project to be economically viable:

1) a secure and steady supply stream at a reasonable cost must be identified;
2) a demanufacturing facility with the necessary space and equipment to store, process and produce marketable products is necessary;
3) end products must be produced at a cost that is competitive.

The business group's final report analyzed 19 breakeven scenarios representing various economic conditions under which the facility would be able to make a profit. Five of the 19 breakeven scenarios are in Appendix A, the additional 14 are included in the December 2000 Final Report for the Business Plan Group. Copies of the Business Plan Group's final report can be obtained by contacting Dr. Carl Irwin at (304) 293-2867 ext. 5403 or by email at cirwin2@wvu.edu.

The business plan group's final report includes an alternative for consideration focusing on low-value, high-volume products. For example, the off-set blocs and the transportation infrastructure products being developed by Dr. GangaRao Hota's group should have ready markets.

Other selected results from the business plan group are included in Appendix A.

Task 1.2 Best Available Technologies and Practices (BAT&P) (Turton)

The Recipient shall assess the BAT&P for demanufacturing EOL electronics and making initial material separations, separating and using plastics derived from EOL electronics, processing and using glass recovered from EOL electronics, and processing and using metals recovered from EOL electronics. The Recipient shall also produce a flexible process / spreadsheet model that can be used in predicting the potential for commercial success of an overall recycling facility. This spreadsheet will predict the economics of building a facility based on number of computers, number of refurbished units, operator requirements, capital investment for building facility, utilities for running facility, and product revenues and feed prices (if any).

Description of work performed, accomplishments and results:

During Phase I, the technology assessment group and the business plan group visited several companies that are involved in separating and processing materials from EOL electronics to investigate the technologies and methods that already exist for recycling EOL electronics. Companies visited include MBA Polymers in Richmond CA, DMC Recyclers in Hagerstown MD, SDR Plastics in Ripley, WV, Butler-McDonald in Indianapolis, IN, and Envirocycle in Hallstead, PA. Results of the Phase I visits indicated that 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's, but is also growing its business by refurbishing post-industrial computers for resale.

The technology assessment group's Phase I activities included the development of a spreadsheet model of the demanufacturing process which provides, for various capacity inputs, 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.

Results of Phase I indicate that 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.

Other selected results from the best available technologies group are included in Appendix B.

Task 1.3 Polymer Characterization, Research and Testing (Gupta)

The Recipient shall analyze the rheological, thermal, and mechanical properties of various blends of recycled and virgin polymers, for example, using a range of blends of recycled PC and Virgin ABS, and a range of blends of recycled ABS and Virgin PC. Analysis is to be done on the effects of reinforcement additives such as rubber, mica, and glass fiber on the properties of various blends of recycled and virgin polymers, for example, a range of recycled PC blends toughened with rubber, a range recycled PC blends filled with mica or other filler, and a range of blends of recycled PC reinforced with glass fibers.

Samples are to be provided for testing and fabricating one component part for electronics application using various blends of recycled/virgin polymers both with and without reinforcements and additives, and include results of tests conducted on sample products. This activity will be facilitated by establishing working relationships with existing polymer companies and product manufacturers to develop processes that yield consistent quality resin blends acceptable for commercial use.

<u>Description of work performed, accomplishments and results:</u>

The polymer characterization and research group developed compounding processes during Phase I that enable the maximum amount of separated recycled polymers to be used in the fabrication of new products. The goal was to minimize material processing costs while targeting high-value applications and products. In order for fabricators, 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 virgin polymers.

Since properties of recycled polymers vary significantly from batch to batch, compounding processes were developed to control the properties of recycled polymers. The research team investigated 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.

Results in Phase I 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. The goal now is to substantially increase the recycle content through combinations of techniques (1) – (5) above. Results also indicated that properties of recycled polymers depend not only on the amount of impurity present but also on the nature of impurities and contaminants that are present. At a given purity level, the mechanical properties of recycled material:

1) will be negatively affected if the impurity is not compatible or processable at the extrusion temperature
2) will not be negatively affected if the impurity is both compatible and processable at the extrusion temperature.

The polymer research team utilized the knowledge of researchers outside of WVU during Phase I. Some examples of this are the formation of a collaborative effort with Ohio State University and with the Product Safety Corporation of West Virginia.

Results obtained by the polymer research team were presented at the May 2000 Society of Plastics Engineers meeting in Orlando, the August 2000 International Congress on Rheology in Cambridge UK, the June 2000 meeting of the SE Ohio Section meeting of the Society of Plastics Engineers, the January 2001 meeting of the 32nd International Conference on Fire Safety, and the January 2001 meeting of the Recycling Engineering Thermoplastics from Used Electronic Equipment Stakeholder Dialogue.

Other selected results from the polymer characterization, research, and testing group are included in Appendix C.

Task 1.4 Applications and Product Development (Hota)

The Recipient shall determine mechanical, thermal, and aging properties of virgin/recycled polymer blends to be used in automotive and infrastructure applications.

The usage of recycled polymers are to be promoted in transportation vehicles through establishing working relationships with automotive component manufacturers and by developing sample automotive products such as prototype headlight housings, bumper shapes, vehicle cross-beams, reinforced door/window frames.

Promote the use of highway and transportation infrastructure products through establishing working relationships with manufacturers of highway and transportation infrastructure products, and by developing sample infrastructure products, such as prototype guardrails, and guardrail parts.

Description of work performed, accomplishments and results:

During Phase I, the application and product development group worked closely with the polymer characterization and research group on the development of 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 were 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.

The bond strength between FRP fabric with recycled polymers and discarded tires was established with and without primer application and analyzed during Phase I. Results indicated that the minimum bond strength increased over 100% with the use of primers.

Guardrails and guardrail post coupons made of polypropylene were also tested during Phase I at coupon level under bending and tension. Results showed the potential of using recycled thermoplastic polymers for infrastructure applications. Preliminary tests on recycled polymer shells with discarded tire cores were conducted and results indicated that high-energy absorption was present.

The results of the application and product development group are discussed in greater detail in the appendix in a paper by Vijay P.V., Hota V.S. GangaRao, and John M. Bargo entitled

"Mechanical Characterization of Recycled Thermoplastic Polymers for Infrastructure Applications" presented at the August 2000 conference on Advanced Composite Materials for Bridges and Structures (ACMBS-3), Ottawa, Canada.

Meetings and cooperative programs on product development for recycled polymers were conducted during Phase I with PPG Industries, Owens Corning, IBM, SDR Plastics, and other specialty manufacturers.

The critical importance of positively identifying the potential supply stream available to the regional EOL electronics recycling center was again confirmed by a product development team at Owens Corning. They were reluctant to go forward with a demonstration project for high-volume applications such as vehicle bumpers, because they did not believe that once the demonstration model was completed, that there would be a 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 was delivered and installation is proceeding.

Other selected results from the application and product development group are included in Appendix D.

Task 1.5 Project Master Plan: Site Selection, Financial Plan, Construction and Training Programs (PAZ)

Develop the 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 Recipient will conduct market studies to determine project acceptability to the community, and develop financial plans for short and long-term funding to assure long-term sustainability of the recycling center. The Recipient shall validate the economic viability of locating end-of-life electronics recycling companies, as well as other related businesses in the local region.

In addition, the Recipient shall organize a workshop on the disposition of EOL electronics by federal government agencies, and develop curricula and training programs needed in the electronics reuse/recycling industry.

Description of work performed, accomplishments and results:

During Phase I, the Polymer Alliance Zone of West Virginia established plans for MARCEE including the development of 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 were visited and evaluated. A photo of the future site of MARCEE and the survey used to choose the site are included in Appendix E.

PAZ has developed financial plans for short and long-term financing for the continued success of MARCEE. 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 first class of the curricula/training development programs graduated in July 2000.

PAZ and Ecolibrium coordinated the National Electronics Stewardship Conference that happened in February 2001 on the disposition of EOL electronics. The conference agenda and other documents pertaining to the conference appear in Appendix E.

Task 1.6 Industrial Information Exchange, Virtual Eco-park, and Internet Trading Tools (DN American)

The Recipient shall develop a web-based interactive industrial information exchange that provides 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 Recipient shall develop a web-based "virtual eco-park" that encompasses all operations involved in disposition of end of life electronics; further enhance an electronics platform to create a national communications hub for coordination, disposition, and deployment of end of life electronics; develop an electronics interface to and content data for an international clearinghouse of information on best available technologies and practices, environmental regulations, and reuse/recycling strategies related to end-of-life electronics, and; develop a requirements and design document relating to the usage of electronic commerce for successful operation of an electronics reuse/recycling businesses in the local region.

Description of work performed, accomplishments and results:

During Phase I, DN American established the industrial information exchange: http//www.electronicsrecycling.net. There are various components to the site that provide information on:

1) The electronics recycling industry, the various electronics recycling projects, industry events, industry resources, and a stakeholder dialogue;
2) Recycling plastic, metal, and glass;
3) Environmental news, industry news, and a forum that allows any interested party to post a question or comment on a posted question;
4) Search mechanism which allows a search of collection organizations in all 50 states or to search the industry directory;
5) Household electronics;
6) Federal and state programs, reports, and legislation;
7) Companies that collect equipment for electronics recycling;
8) Companies that deal in demanufacturing;
9) Companies that refurbish computers

The virtual "eco-park" and the storehouse of information on best available technologies and practices, environmental regulations, and reuse/recycling of end-of-life electronics was investigated to determine if it was user-friendly. As a result of these findings, the site was improved and upgraded to increase its usability.

The DN American team conducted site visits during Phase I to PAZ member companies to study how the use of the Internet could improve communications between industry partners.

The DN American team formed an industry alliance with the Electronics Industry Alliance to help support and provide content material for the website. The http//www.electronicsrecycling.net site was launched at the National Electronics Stewardship Conference held in Shepardstown, WV in February 2001.

Samples of the www.electronicsrecycling.net website and the website DN American developed for the National Electronics Stewardship Conference appear in Appendix F.

Task 1.7 Project Support, Business Plan, Environmental Impacts, Site Development, and Conferences (PAZ)

The Recipient shall arrange meetings and plant visits with key industry, government, and other contacts that can help further the goals of the project, including computer/electronics OEMs, electronics recycling companies, relevant state or federal organizations, foundations, etc. This task includes providing a list of names of potential contacts and coordinating a schedule of meetings and plant visits.

The Recipient will support development of business/industry/marketing plans by (1) 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 in an electronics recycling/disposition center, (2) providing sound estimates of the projected quantity and quality of the supply stream over a 5-year time horizon, and (3) provide inputs on other aspects of the business plan development as requested by project team members.

The Recipient shall assess the environmental, health, and safety concerns most relevant to establishing and operating a regional electronics recycling/disposition center. The results of this task, specifically, an assessment of the impacts on recycling operations of the use of toxic materials and/or their alternatives, will be provided in the Topical Report submitted under Task 1.8.

The Recipient shall assess the state, federal, and international environmental, regulatory, and other policy issues that are most relevant to establishing and operating a regional electronics recycling/disposition center. The results of this task, specifically, an evaluation of proposed legislation and directives that will directly affect the regional center will be provided in the Topical Report.

The Recipient shall organize a workshop for assessing national electronics recycling policies. The interactive workshop format will engage state and federal agencies, private industry, recyclers, and related non-governmental organizations in identifying the elements needed for coordinated policies and programs related to electronics disposition. The Recipient will develop a follow-up plan of action to benefit the regional center.

Description of work performed, accomplishments and results:

The Texas Team lead by Greg Pitts of Ecolibrium Inc., conducted information searches on the hazardous materials contained in computer and electronic equipment during Phase I. The study included heavy metals and plastic contaminants and fillers.

The Texas Team assisted with initial site development. During Phase I, 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.

During Phase I, the Texas Team conducted an informal survey of electronics recyclers on environmental, health, and safety regulations.

During Phase 1, the Texas team assisted PAZ with coordination and planning of the National Electronics Stewardship Workshop, which occurred in February 2001. The agenda and other sample information are included in Appendix F.

Task 1.8 Topical Reports (Irwin)

The Recipient shall prepare and submit a draft topical report that covers the efforts under Tasks 1.1 – 1.7 in accordance with the Reporting Requirements Checklist after completion of Phase I. This report shall provide a comprehensive description of the results achieved and shall include tabulations of data, figures, photographs, and other bibliographic citations to support the investigations undertaken. It shall summarize all technical reports where applicable. Within thirty (30) days after submittal, the COR will accept the draft topical report or recommend changes and the Recipient shall revise the topical report and submit the final topical report with 30 days after receipt of review comments. If the Government elects not to continue with the remaining effort, the Topical Report will become the Final Report.

Description of work performed, accomplishments and results:

The Topical Report for Phase I was submitted in August 2001.

Phase II -Business Model Completion, Design of a Commercialization Project, and Integration of Recycling Technologies and Products

Task 2.1 Project Design and Business Model Development (PAZ)

The Recipient will continue to refine the business plan developed under Task 1.1 for establishing the business of recycling end-of-life electronics within the local region, and develop and evaluate possible business models using a combination of qualitative, quantitative and simulation techniques. The Recipient will use these models to evaluate business variants, and develop a more detailed business plan for the most attractive business variant(s).

<u>Description of work performed, accomplishments and results:</u>

The Polymer Alliance Zone in coordination with subcontractor SAIC completed a business plan. The simulation tool information is constantly updated and is used to validate business assumptions. (See Appendix G)

SAIC

PAZ Simulation Tool Development

Beginning in earnest during the summer of 2001, SAIC developed a system dynamics model as an analytical tool for MARCEE business planning and industry analysis. Under the direction of the PAZ Industry Steering Committee, the SAIC Team assembled available data and developed a complex model involving the operational and financial relationships of more than 90 variables across 4 discrete electronics recycling activities (demanufacturing /refurbishment; processing of metals, glass, and plastics). This simulation was developed using a commercial software product called iThink™ and a final version of the simulation a run-time copy of iThink™ was delivered to PAZ on a CD ROM in February, 2002.

The PAZ Simulation Tool has been very well received and used as an analysis tool for MARCEE business planning (see below) and for target company recruitment. A summary of the Simulation and baseline data inputs is included in the Business Plan.

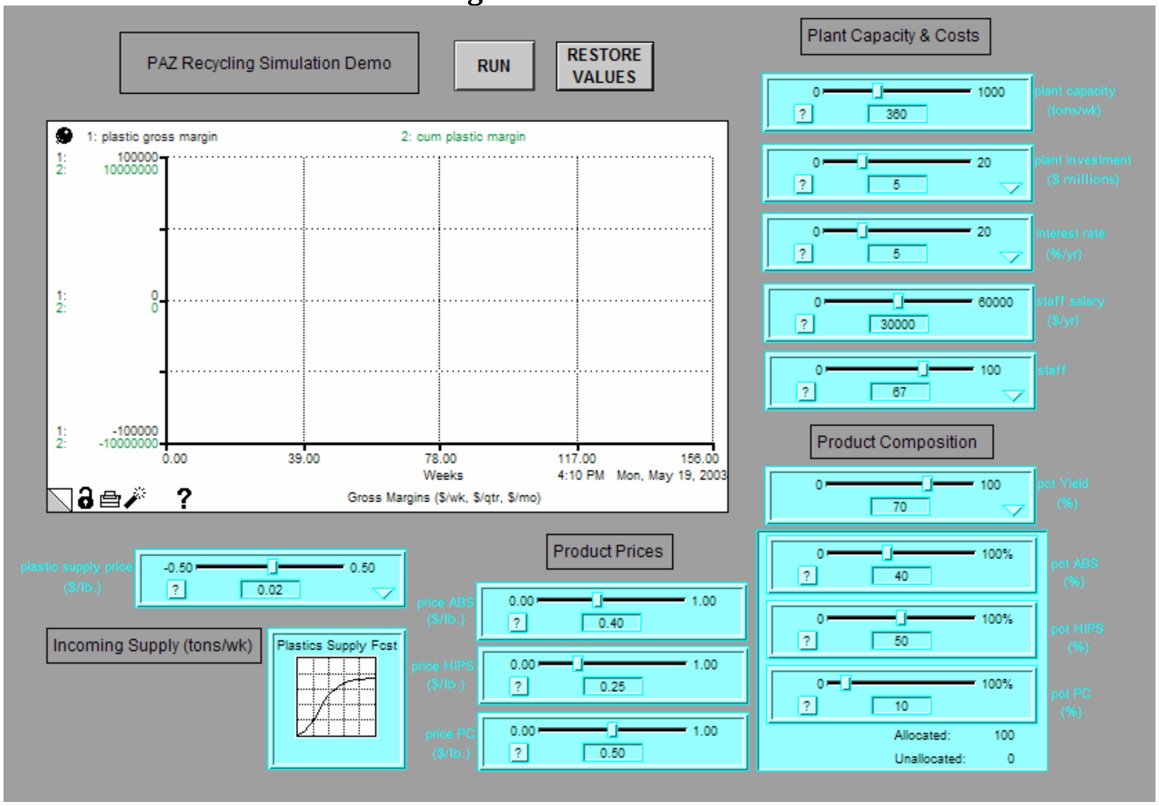
MARCEE Business Plan

Following development of a functioning version of the PAZ Simulation Tool, the SAIC Team assembled simulation results, available data, and market insights into a draft MARCEE Business Plan. This plan also includes analysis of the industry (including status and a critique of industry-led systems around the world), critical steps for making large-scale electronics and plastics recycling economically viable, and 6 action items for business plan implementation. The basic structure of this plan, finalized in January, 2002, remains essentially unchanged as PAZ charts the course for large-scale recycling of electronics and plastics. An Adobe Acrobat™ (*.pdf) file of this business plan is included in Appendix G.

The Paz Simulation Tool, May 2003 Demo Version

In order to craft a viable regional model and Business Plan in early 2002, PAZ developed a simulation model to explore numerous industry scenarios and to test various regional model configurations for the recycling of end of life electronics and associated materials. The simulation was developed with a baseline set of relationships among the stocks and flows that typically make up the electronics recycling industry. In April 2003, in order to distribute the Simulation more widely, PAZ created a Demo version of the Simulation Tool focusing on plastics recycling operations. Although the other model operations are still embedded in this Demo tool, only the plastics recycling operation is adjustable through the Graphic User Interface (GUI), a picture of which is provided in Figure 1.

Figure 1: Demo GUI



The PAZ Simulation is a system dynamics model using software called iThink™, Version 7.0. The Demo can also be run using a demo version of iThink™ available at http://www.hps-inc.com/.

Assumed Available Plastic Scrap Volume

As a starting point, and based on suggestions from various industry sources, the simulation works up to a weekly input volume of 300 tons per week of scrap plastic for processing. This is a starting point for simulation purposes and is a reasonable estimate based on the best data available to PAZ and the simulation team. This supply volume is expected to be within an order of magnitude and generally consistent with threshold supply requirement estimates by published studies, plastics recyclers, earlier studies by PAZ, and other published documents. The unit of time used in the simulation is per week for up to three years.

The simulation is a mathematical representation of the recycling facilities, so every element requires a number, formula, or graphical value. In developing the simulation, the technical team received substantial information from a variety of sources, but in some cases considered assumptions were used. The overall set of simulation relationships and input data were reviewed with several experts in the industry as a “reality check” and modifications made accordingly. Figure 1 above contains a list of the most important values used in the simulation. These values can be easily changed and the resultant impact of new values on industry breakeven evaluated.

Other plastics recycling input values are presented below in Table 1. Although important in combinations, these values were determined to be generally less sensitive and/or changeable than the values provided on the GUI and shown in Figure 1.

Table 1: Other Plastics Recycling Variables

VARIABLE	QUANTITY	NOTES
landfill_cost	$0.03 per pound	Landfill cost
loan_length	10 years	For capital equipment purchase. Note that loan length exceed term of simulation.
pct_ABS	40%	Typical characterization of ABS plastics from end of life electronics
pct_HIPS	50%	Typical characterization of HIPS plastics from end of life electronics
pct_PC	10%	Typical characterization of PC plastics from end of life electronics
plant_rent	$10/sf	Conservative, usually will exceed actual cost
plant_space	100,000 sf	
plastic_ship_dist	100 miles	Both for incoming supply and outgoing product
Burden	1.3	Multiplier on salary to estimate benefits cost

Although the larger simulation assumes four different operating units (demanufacturing/refurbishment, glass, metals, plastics), the Demo focuses only on plastics.

Plastics Process Assumptions

Scrap plastic input is assumed to be output from the demanufacturing of end of life electronics. In some facilities the plastics material is separated manually at the demanufacturing step in order to achieve increased purity. Others shred everything and separate the various polymers at the particle level.

For the demo simulation, input plastic scrap supply is assumed to be in mixed regrind form similar to output from typical shredding/grinding operations like those conducted by MicroMetallics Corporation. Mixed plastic is separated using an automated process engineered with a $7 million capital equipment investment, producing a capacity of 360 tons per week. Output is projected as compounder-ready flakes that command a price consistent with post-industrial recycled flake.

Operating Reports from the Simulation

Although the simulation software provides two methods of presenting reports – tables of data and graphs – data from the Demo Simulation are presented only in graphic form. Because this is a mathematical model, any variable or combination thereof can be presented in report form. Through use of a toggle at the lower left corner of the main graph on the GUI, the demo provides output of the following four reports:

- Gross margins
- Revenue by resin (ABS, HIPS, PC)
- Capacity utilization
- Shipping costs in, out, and disposal costs

The Demo defaults to the gross margins chart; the other reports can be viewed by clicking on the lower left portion of the graph.

Task 2.2 Continuation of Modeling Effort and Product Feasibility Study (Turton)

Modify as necessary and use a spreadsheet model to facilitate application of research results to new product development and the evaluation of best available technologies; to evaluate the material flows from a demanufacturing facility; compare empirical results with actual material streams from EOL electronics and plastics separation lines; and; to assess the manufacturing cost and market potential for transportation infrastructure products that incorporate at least 25% low-grade mixed fines of recycled plastics from EOL electronics.

<u>Description of work performed, accomplishments and results:</u>

2.2.1: Economic Evaluation and Characterization of Plastics Stream

In order to evaluate accurately the product stream flows from an EOL electronics recycling facility, detailed material characteristics and flow rates of the raw material streams were evaluated.

2.2.1.1 Analysis of Content of EOL Electronic Equipment

A series of tests were performed to evaluate the composition of EOL electronic equipment. In general, the separation of metals and glass from e-waste is well established. Therefore, the main focus of this part of the work was to evaluate the properties of the plastic content of the e-waste and to determine both the quantity and make-up of the plastic component of the recycled material.

Keyboards: An ASTM ash test (ASTM "Ash Content in Thermoplastics" - D-5630) was carried out on the plastics obtained from the keyboards and keys of 3 EOL computers, namely a Dell QuietKey™, a Gateway Anykey™, and a generic IBM. The results are shown in Tables 2-4. The ash content varied from about 0.3 to 1.1 wt%. These data are an indication of the inorganic (filler) content used in the various plastic components in the keyboards. In Table 5, the composition of the keyboards is given in terms of the metal, plastics, and circuit board and wiring content. The plastic content of the keyboards ranged from 57–64 wt%, which corresponds to weights of 670 – 1330 g per keyboard.

CPUs: The overall compositions of 5 EOL CPUs were evaluated by separating the parts by hand and then weighing the respective pieces. These results are shown in Tables 6-10. The amount of plastic in the CPUs varies between 3.8 and 7.9 wt% of the CPU, which corresponds to 300 to 1180 g of plastic per CPU.

Table 2: Ash composition of Dell QuietKey™

Keyboard Casing

Crucible Weight (gm)			
Empty	With sample	With ash	Weight % ash
17.0824	20.1675	17.0935	0.3598
17.0821	22.117	17.1082	0.5184
17.0808	23.0318	17.1142	0.5613
17.0821	22.0591	17.108	0.5204

Keys

Crucible Weight (gm)			
Empty	With sample	With ash	Weight % ash
18.7193	21.9708	18.7422	0.7043
18.7199	23.8749	18.758	0.7391
18.7204	24.4762	18.7641	0.7592
18.7213	23.4271	18.7561	0.7395

Table 3: Ash composition of Gateway Anykey™ 2000

Keyboard Casing

Crucible Weight (gm)			
Empty	With sample	With ash	Weight % ash
16.8858	20.3567	16.9092	0.6742
16.8860	21.2730	16.9157	0.6770
16.8851	22.8328	16.9264	0.6944
16.8865	22.8745	16.9267	0.6713

Keys

Crucible Weight (gm)			
Empty	With sample	With ash	Weight % ash
17.133	20.5001	17.1642	0.9266
17.1338	21.8554	17.1775	0.9255
17.1339	21.6711	17.1769	0.9477
17.134	23.6689	17.1949	0.9319

Table 4: Ash composition of IBM

Keyboard Casing

Crucible Weight (gm)			
Empty	With sample	With ash	Weight % ash
18.9379	24.6726	19.1854	4.316
18.9404	23.4034	19.1337	4.331

Keys

Crucible Weight (gm)			
Empty	With sample	With ash	Weight % ash
18.6851	24.7953	18.7519	1.093
18.6855	23.3439	18.7364	1.093

Table 5: Composition of Keyboards (in weight %):

Keyboard	Metal	Plastic	Circuit Board + Wiring	Misc (Plastic film, rubber cushions, etc)	Weight of Keyboard kg
Dell QuietKey	31.3	56.84	8.79	3.07	1.172
Gateway Anykey 2000	24.79	64.02	8.57	2.62	1.412
IBM	27.66	60.76	8.97	2.6	2.229

Table 6: Plastic Content of CCS 386

Plastic Type	Weight (gms)	% Weight		Weight (gms)	% Weight
Green	206	2.649	Plastic	302	3.883
Gray	70	0.9001			
Misc	26	0.3343			
Rem weight	7475	96.12			
Net	7777	100			

Table 7: Plastic Content of Gateway 2000 New Tower

Plastic Type	Weight (gms)	% Weight		Weight (gms)	% Weight
White	1012	6.4090	Plastic	1181	7.4793
Creamish	32	0.2027			
Black	37	0.2343			
Floppy Drive	100	0.6333			
Rem weight	14609	92.521			
Net	15790	100			

Table 8: Plastic Content of GIC 486

Plastic Type	Weight (gms)	% Weight		Weight (gms)	% Weight
Muddy White	288	3.541	Plastic	318	3.910
Yellow	30	0.3689			
Rem weight	7814	96.09			
Net	8132	100			

Table 9: Plastic Content of - PC Importers

Plastic Type	Weight (gms)	% Weight		Weight (gms)	% Weight
Front Panel	280	4.341	Plastic	335	5.1934
Yellow	55	0.8526			
Rem weight	6116	94.81			
Net	6451	100			

Table 10: Plastic Content of Professional Computer Systems

Plastic Type	Weight (gms)	% Weight		Weight (gms)	% Weight
Greyish	28	0.307	Plastic	394	4.3229
Creamish	290	3.182			
Floppy Drive	30	0.329			
Black	46	0.505			
Rem weight	8720.25	95.677			
Net	9114.25	100			

Polymer Content and Density of Plastics from Keyboards and CPUs

A breakdown of the types of plastic found in the CPUs and keyboards and their respective densities is shown in Table 10. In this table, the identification of the polymers was achieved using a Spectrum One FTIR from Perkin-Elmer Instruments. The identification of small quantities of butadiene rubber is difficult due to the overlapping of spectra and it is most probable that SAN (styrene-acrylonitrile) is equivalent to ABS (acrylobutadiene styrene) and the identification of polystyrene and styrene/butadiene mixtures is equivalent to HIPS (high impact polystyrene). The results from Table 11 show that the majority of the plastics in this EOL equipment are ABS and HIPS, which is consistent with manufacturers' information. However, there are a significant number of other polymers present in the EOL material and this additional material impacts the overall separation efficiencies and yields that are obtainable in the physical and chemical separations.

It should also be noted that all the polymer samples derived from EOL electronic equipment had densities greater than 1 g/cm^3 (greater than water). This rather surprising result is probably due to the fact that all of these polymers have some amount of filler material that is generally inorganic in nature and this tends to increase significantly the density of the polymers.

Table 11: Plastics composition and density for various EOL Electronic Equipment

Polymer	Density	Source	% Ash
SAN (20% A)	1.0582	PCS - Grey (CPU)	0.8825
	1.0583	PCS - Creamish (CPU)	0.8726
	1.0857	PCS - Black (CPU)	0.8913
	1.0577	Dell QuietKey Keys (Keyboard)	0.7355
	1.0561	Gateway Anykey Keyboard (Keyboard)	0.9329
	1.1299	CCS 386 - Grey (CPU)	2.2387
	1.0456	GIC 486 - Yellow (CPU)	0.1809
	1.0515	PC Importers - Yellow (CPU)	0.0836
	1.0755	PC Importers - Front Panel (CPU)	3.5237
	1.0795	HP DJ 870C - Blue (Printer)	2.2298
	1.1095	HP DJ 680C - Blue (Printer)	5.0127
	1.0588	Apple Design - Keys (Keyboard)	0.8219
	1.0653	Micron Keytronic - Keys (Keyboard)	2.4339
	1.0543	Microsoft Monoblock - Keys (Keyboard)	1.7503
	1.0608	Mitsumi - Keys (Keyboard)	1.6011
	1.0499	PC Concepts - Keys (Keyboard)	0.9451
Polystyrene	1.0345	Dell QuietKey Keyboard (Keyboard)	0.4900
	1.0345	Gateway Anykey Keyboard (Keyboard)	0.6792
	1.0344	CCS 386 - Green (CPU)	0.5679
	1.0405	GIC 486 - Muddy White (CPU)	0.4133
	1.1173	HP DJ 870C - Grey (Printer)	1.8076
	1.0425	HP DJ 680C - Creamish (Printer)	2.0870
	1.0579	Apple Design - Keyboard (Keyboard)	3.3165
	1.0418	Fujitsu Ltd - Keyboard (Keyboard)	0.9566
	1.0336	Fujitsu Ltd - Black (Keyboard)	0.5768
	1.0461	Micron Keytronic - Keyboard (Keyboard)	1.4550
	1.0386	Micron Keytronic - Keybase (Keyboard)	0.0446
	1.0438	Microsoft Monoblock - Keyboard (Keyboard)	0.8075
	1.0517	Mitsumi - Keyboard (Keyboard)	1.6736
VA / VC / V-OH	1.3607	IBM (2235) Keyboard (Keyboard)	4.3090
PBT	1.5312	Gateway 2K - Black (CPU)	23.7269
	1.3231	IBM (2235) Keys (Keyboard)	1.0960
	1.3025	Fujitsu Ltd. - Keys (Keyboard)	2.0583
PPO	1.3292	Gateway 2K - Greenish White (CPU)	31.2259

Styrene - Butadiene (85% S)	1.1624	Gateway 2K - CD - Floppy (CPU)	2.1030
	1.1734	Gateway 2K - White (CPU)	1.9740
	1.1843	PCS - Floppy (CPU)	2.2460
	1.0384	PC Concepts - Keyboard (Keyboard)	0.9356
Polycarbonate	1.3925	HP DJ 870C - Dark Grey (Printer)	25.5822
	1.3156	HP DJ 870C - Black (Printer)	14.4103
	1.3839	HP DJ 680C - Rough Grey (Printer)	25.2895
	1.2458	HP DJ 680C - Black (Printer)	5.4185
	1.2607	HP DJ 680C - Smooth Grey (Printer)	4.0992
Polyacetal	1.4209	Apple Design - Key Supports (Keyboard)	-
	1.4142	Fujitsu Ltd - Key Supports (Keyboard)	-

2.2.2 Product Feasibility

This research effort assessed the opportunity for a guardrail spacer block made from recycled plastic, which could be produced and marketed successfully as part of the Polymer Alliance Zone's (PAZ) economic development efforts. The spacer block is part of the guardrail system, which also includes the post as well as the guardrail itself. Data was collected from a number of sources including state officials responsible for highway guardrail installation and maintenance, contractors who subcontract this installation and maintenance with the states and manufacturers currently producing plastic spacer blocks.

Results are presented using a SWOT (strengths, weaknesses, opportunities and threats/challenges) analysis format. The SWOT analysis addresses both state and contractor markets as well as competitive products that can be substituted for the proposed plastic spacer block. General findings indicate that a both opportunities and challenges are present with this product.

It is recommended that the recycled plastic spacer block assessed here, successfully meet all product specifications as well as all crash test requirements. The organization manufacturing this spacer block should consider producing the entire appears the strategy of working with an entire guardrail system made of recycled plastic versus working with only one component of that system (spacer block) that is made from recycled plastic is more attractive to state officials. It is further recommended, that this plastic guardrail system and each component of the guardrail system be developed, produced and sold at the cost or below the cost of those products currently available on the market. Finally, it is recommended that an aggressive lobbying effort be undertaken to facilitate the adoption of this product’s acceptance and use by states and the contractors who work for those states.

2.2.2.1 Introduction

The purpose of this research effort was to assess the opportunity for a guardrail spacer block made from recycled plastic, which could be produced and marketed successfully as part of the Polymer Alliance Zone's (PAZ) economic development efforts. The spacer block is part of the guardrail system, which also includes the post as well as the guardrail itself. The role of spacer block is to provide space to keep vehicle tires from becoming wedged within the guardrail system. It should be noted that guardrails are not required on all highway systems and some systems that require guardrails do not require spacer blocks; specifically, those highway systems with lower speeds and less traffic. In addition, the number of spacer blocks will vary (as measured by distance between the blocks) by highway system with the interstate highways requiring the most blocks per mile.

This report presents the findings of this assessment and is presented in several topical areas. First a discussion of the methodology used to gather the information pertinent to the use of plastic spacer blocks on guardrail systems is presented followed by the limitations of this research. A SWOT (strengths, weaknesses, opportunities and threats/challenges) analysis of the plastic spacer block follows. The SWOT analysis addresses both state and contractor markets as well as competitive plastic spacer blocks that can be substituted for the proposed plastic spacer block. The SWOT analysis also assesses the proposed plastic spacer block from both a components and aesthetics appeal aspect. The report concludes by offering recommendations gleaned from the information assessed and presented in this report.

2.2.2.2 Methodology

To get information on the demand for the guardrail replacements, the researchers gathered information from a number of different sources. First, a series of telephone and personal interviews were conducted with representatives of both the federal department of transportation (DOT) and the West Virginia department of transportation (DOT). These representatives were responsible for either highway construction and maintenance or product and contractor acceptance for building and maintaining highways. Next websites of the state DOTs for the states contiguous to West Virginia (and PAZ) were analyzed. From these websites background information on the number of miles of roadways in each state and contact information for the maintenance departments were obtained.

Using the telephone and electronic mail additional information was received from the contiguous states (other than Maryland) as well as those states that based on initial research appeared to offer an opportunity for adoption of the plastic spacer block. Maryland did not to respond to any inquiries. The states either using or have used plastic spacer blocks and offering a potential opportunity included North Carolina, South Carolina, Georgia and Connecticut.

Some states did not keep records on guardrail installment and/or replacement while others could only provide estimates. Still, others would not even estimate the number of guardrails installed or replaced annually in their state. In sum, this is not an area readily tracked by either the federal or state transportation officials.

Contractors approved to do business with state DOTs and potential spacer block competitors were also interviewed. Information on how one goes about doing business with the states and selecting highway material such as the spacer block was gathered from the contractors. Manufacturers of plastic spacer blocks provided information on the industry in general and the plastic spacer block in particular. Both contractors and these potential competitors identified problems and challenges associated with the acceptance of the plastic spacer block.

2.2.2.3 Limitations

One of the limitations of the research was the inability to get consistent data from the different states. Each state places responsibility for managing their highway systems under different department heads. Some are centralized in the state capital while others are decentralized into regions and/or counties. These centers of responsibility also have different components of the highway system for which they are responsible. For example, some states have departments that are responsible for interstates and turnpikes, only. Other states have different departments that are responsible for each of the different types of roadways. These roadway classifications include but are not limited to interstate, state routes, county and city roads. Each roadway not only has a different classification but different criteria for the use of guardrails. This made it difficult to obtain consistent information about the miles of different roadways within the differing states. Many of the departments did not track any of this information and did not have accurate data regarding this information.

One of the biggest problems getting information from contractors was their unwillingness to share information about their business. Some of the contractors would not give specific information about their installation costs and what they pay for materials. They believed they would be giving away a competitive advantage if they provided any specifics regarding their guardrail business. A couple of the contractors would not provide any information at all unless we were offering a guardrail replacement or installation job to them. Due to the fact that the research team was not affiliated with a DOT some of the contractors would not share any information.

Finally, potential competitors (those currently manufacturing plastic spacer blocks) were willing to share some information but rejected any questions related to the marketing of their product. This refusal was based on the competitive nature of this business and their perception that revealing this information could jeopardize their competitive advantage--real or perceived. Therefore, one must be cognizant of these limitations and the affect they have on the assessment provided below.

2.2.2.4 Analysis of Strengths, Weaknesses, Opportunities, and Threats (SWOT Analysis)

The following section provides results of a SWOT analysis conducted for this plastic spacer block being assessed here. The SWOT provides a structure for assessing the fit between what an organization producing the proposed plastic spacer block can (strength) and cannot do (weakness) and what the marketplace environment is moving in favor of (opportunities) and against (threats/challenges). The SWOT allows the user to integrate and synthesize diverse information such as that being analyzed here. Therefore, the following SWOT analysis offers the reader an opportunity to assess this diverse information in a meaningful framework.

Strengths

The life expectancy of the plastic spacer block is longer than that of the wood spacer block. The plastic spacer block will last up to 30 years barring any accidents. The wood spacer block will last 15 to 20 years barring any accidents. Those plastic spacer blocks currently in existence have met crash test performance standards and unlike the wood spacer blocks, the integrity of the plastic spacer block is easily noticeable if it is compromised.

The plastic spacer blocks are easier to install than the wood counterparts. The plastic spacer blocks offer a smooth thru-hole for faster installation than wood. Often the holes in the wood will need to be re-drilled or made oblong in order to be installed. There is also a problem with the wood arriving at the job site cracked and therefore cannot be installed. The plastic spacer block will come from the manufacturer ready to be installed with no defects. With the ease of installation combined with the longevity of plastic versus wood the overall long-run cost of the plastic spacer blocks will be lower.

After mounting the plastic spacer block (unlike the wood spacer block) will not rotate on the post. The molding of the plastic spacer block will keep the block in place for the life of the spacer block on the guardrail. This not only addresses performance issues but visual issues as well. Moreover, unlike wood spacer blocks, the plastic spacer block can be reused after impact and if the integrity is not compromised.

Another strength would be the value of the plastic spacer block after the useful lifespan. Currently, the used plastic spacer block is valued at approximately $1.00 per block. One manufacturer is buying back the blocks at that price but you must stockpile approximately 300 before the manufacturer will transport them back in the empty trucks from which they just delivered new plastic spacer blocks. This reinsures the continued use and purchase of their product.

The plastic spacer block is environmentally friendly. The plastic spacer block is made from recycled plastics and can be recycled again after its' lifespan. If required, the core of the plastic spacer block can be filled with other waste materials. For example used tires can be shredded and inserted in the plastic spacer block as a core filler. The plastic spacer block can also be filled with other materials such as sawdust.

Weaknesses

The supply of plastics to be recycled in the manufacturing of the plastic spacer blocks can be a problem. To make a plastic spacer block it takes 95% polyethylene. Manufacturers expressed a concern that it may be difficult to keep a large enough recycled supply to produce large amounts of plastic spacer block if the demand were to increase.

Another weakness is with integrating the plastic spacer block with wooden blocks in the same stretch of guardrails along a given highway system. Several states surveyed indicated they do not want to intermix plastic and wood spacer blocks. They want consistency in the materials being used. This is a problem since most of the guardrail work being done is the replacement of guardrails after accidents. Aesthetics are an important consideration.

The cost of the plastic spacer block is also an obstacle. The cost of plastic spacer blocks has been reported to be higher than wood spacer blocks. This cost is reported to be as high as $3.00 per block more than wood. This higher cost could be accounted for in both production and transportation costs. It has been reported that the labor costs to produce plastic spacer blocks currently on the market are much higher than the labor costs to produce the wood spacer block. As for transportation, the wood spacer blocks are manufactured at regional sawmills. Plastic spacer blocks are only produced in a few geographical areas and will need to be transported to the states' or contractors' warehousing facilities.

There is also inconsistency in the information on the weight and size of the block. Some reports say that the plastic spacer block is lighter while others say it is heavier. This may be explained by reports by some who indicate you can use smaller dimensional plastic spacer blocks than those of the standard wood spacer block. Research at West Virginia University indicates the block being assessed here would be lighter than the wood spacer block even if both had the same dimensions.

There was no standardized information on state highway systems let alone guardrail systems from the different states. Some of the states had information on the different types of roadways in their state while other states did not have this information. Pennsylvania for example had limited information on the number of miles of roadways in their state. Some states broke the roadways down into interstate, county, and municipal while others just called them principal roadways with no breakdowns. It was, therefore, difficult to discern how different roadways were classified. Some of the state departments only had information on the roadways that they were responsible for and did not consider county and municipal roads. Other states had information on all roadways. This will help to explain the discrepancies in the mileages from state to state and makes it difficult to determine the spacing of the spacer blocks by type of highway and thus the potential demand. The different states also had different departments within the Department of Transportation that managed the roadways. Some states had different departments for the turnpikes while some took care of everything except for city roads and county roads. It was difficult to find some of the departments that were in charge of the repairs and maintenance. Some left this decision-making to regional or county officials while others kept the focus at the state level. All of this made it difficult to assess the demand for the plastic spacer block.

When considering the costs associated with the installation and replacement of guardrail systems, the decision makers appeared to be more concerned with costs in today's budget rather than savings that could be generated with a product that enjoyed a longer lifespan (30 years versus 15 years). The higher up front cost is more important than the fact that plastic spacer block will last longer and require less up keep. Therefore, although long-run costs savings are a strength of the plastic spacer block, it is the short-run up front costs that seem to matter most to these decision-makers.

Contractors install and/or replace most of the guardrail systems in the states analyzed. Not only does each state have several contractors working for them each year but the contractors used may vary from one year to the next based on the bidding process. In addition, it was discovered contractors have the flexibility in the materials they use -- including wood or plastic spacer blocks. The materials, however, must come from an approved list of items that is put out by the state

Contractors also do not want to commingle wood and plastic spacer blocks on a job. If wooden blocks are being used, contractors tend to stay with wooden blocks. Both contractors and state highway departments want consistency in the materials and the look of the guardrails on their roadways.

Contractors are interested in working on jobs today. They bid on projects looking at short-term costs of material with the bid specifications (i.e. spacer blocks) not the longevity of this material. Products that last longer could also affect the opportunity for future work within a short timeframe.

Another problem facing contractors is the variation in the construction/materials of the plastic spacer blocks currently on the market. There is no uniformity between the spacer blocks of one manufacturer versus another manufacturer. In addition, with low production levels it is difficult for contractors to obtain enough spacer blocks from one manufacturer to complete a project. These contractors also believe that if they were to order a large amount of the plastic spacer block the cost would increase due to what they believe to be a limited production capacity. It was also suggested that it would be difficult to introduce a total plastic guardrail due to the current stronghold the steel industry has on producing guardrails. There are three (3) producers of guardrail in Ohio alone. These producers do supply states other than Ohio and have a lot of lobbying power with the decision makers in government. The zinc oxide coating that is on the guardrails is also mass-produced in Ohio. This would make breaking into the industry a difficult task.

Finally, states and contractors alike are not convinced that plastic is the way to go. Presently, they are not required to use plastic and there is little incentive or few directives to move toward plastic. Therefore, they are taking a wait-and-see attitude toward the adoption and use of plastic spacer blocks.

Opportunities

The next section analyzed is that of opportunities for successfully marketing the plastic spacer block to potential customers. Two sections of potential customers are analyzed. These are the states, which would ultimately buy and pay for the plastic spacer block to be installed on their highway systems and the contractors who actually purchase and install the blocks on the states' highway systems. The first market opportunity to be analyzed is that of the individual states included in this assessment. This is followed by an assessment of the opportunities with contractors.

Opportunities by State

Thirteen states have approved the use of plastic spacer blocks for guardrail systems. There are only two states, Connecticut and Georgia, solely using the plastic spacer block at this time.

Ohio

The State of Ohio indicated that there was approximately 11,036 miles of priority lanes and 27,978 general lanes or a total of 39,014 miles total that is maintained by the Ohio State DOT. The State DOT does not take care of county or turnpike roads and did not have any information on these roads.

Unlike most of the states Ohio is currently in the process of tracking the numbers of miles of guardrails in their state. Most states are not currently tracking their guardrail systems while some states have not tracked the mileage of roadways within their states. Ohio estimated that they have 1500 miles of guardrails on their priority lanes and 1800 miles on their general lanes, for a total of 3300 miles of guardrail total. Ohio replaces approximately 250,000 feet of guardrail on a yearly average due to age. This is representative of approximately 2 % of their guardrail system. Due to accidents they replace approximately 200,000 feet of guardrail, which is slightly less than 2 % of their system. The state replaces approximately 60-70 % of the guardrail when they do any resurfacing of the road. Ohio spends approximately $3.5 million a year on contractors who replace guardrail and approximately $2 million replacing guardrail by the DOT crews for a total of $5.5 million. The work is split approximately 60% contractor and 40% state. Many contractors are approved to do guardrail work in Ohio, however only a few receive the majority part of the business.

Pennsylvania

Pennsylvania would only provide total highway miles with no breakdown based on type of highway. Pennsylvania has approximately 40,000 highway miles. Moreover, Pennsylvania creates approximately 10 new miles of roadway each year. The Pennsylvania DOT does not maintain the county and turnpike highways.

Through secondary data, however, we were able to determine that Pennsylvania has approximately 991 miles of guardrail on their interstates and 542 miles of median barrier on their interstates. They have approximately 7138 miles of guardrail on their state highway system and 534 miles of median barrier on their state highway system.

Pennsylvania does not replace guardrails due to age. The state only replaces guardrails due to accidents and when upgrades are needed. Thus, any work done is based on the money budgeted for those projects. Pennsylvania does not keep statistics on the number of miles replaced due to accidents. The state replaces approximately 10-15% of the guardrail system when the roadways are resurfaced. The state does the replacements on a limited basis and contractors do all of the new construction and any major replacements. Pennsylvania does not have any information on the costs to replace guardrail systems on a yearly basis.

The department that handles the contractors is PENNDOT's Bureau of Construction and Materials. PENNDOT did not provide any information when requested on the contractors doing business with the state.

Kentucky

Kentucky has 762 interstate miles, 26,017 miles of state highways, approximately 40,000 miles of county roads, 648 miles of turnpike roads, and 649 miles of parkway roads. The state officials did not know the average number of new miles of roads created in the state on a yearly basis. Kentucky follows the American Association of State Highway and Transportation Officials (AASHTO) guidelines on whether or not the guardrails are needed. Kentucky has approximately 697 miles of guardrails on their interstates. The state has approximately 1979 miles on their state highway systems and 549 miles on their turnpikes. Kentucky does not have the information on the county and parkway road systems. The state does not have any information on who would have this information. Kentucky does not keep statistics on how many miles of guardrails were replaced yearly due to accidents. The state does not replace the guardrails when highways are resurfaced.

Kentucky officials said that contractors and the state DOT do the guardrail replacement. They could not provide any percentage of guardrail work done by each group. The officials did provide a list of nine different contractors approved to do business with the state of Kentucky.

Virginia & Maryland & South Carolina

Information relevant to this assessment was not obtained from these three states. Virginia officials stated that they do not keep any of statistics regarding highway guardrail mileage. Maryland could only be contacted by electronic mail and when notified via electronic mail, the Maryland state DOT did not respond. The only information found regarding Maryland was that this state had a total of 17,000 lane miles. South Carolina was contacted due to the conversation with the one of the manufacturers of plastic spacer blocks. According to this manufacturer, South Carolina was using the plastic spacer block. However, after contacting South Carolina's DOT, the research team was informed that the state of South Carolina does not use the plastic spacer block and at this time the state is not planning on using plastic spacer blocks. There are approximately 852 miles of interstate in South Carolina. Contractors install all guardrails in South Carolina.

West Virginia

West Virginia has 549 interstate miles, 34,610 state highway miles, 37,370 county roads, 88 turnpike roads, and 1736 National Highway system miles. The State of West Virginia does not keep any information on guardrails. Officials indicated that in order to obtain this information we would have to contact each district. When contacting several districts, we were informed that the districts did not have that information. The districts did tell us that they do replace the guardrails due to age after 20 years. One district manager estimated that $200,000 was spent on guardrails in his five county district. Currently Hota Gangarao of West Virginia University is installing plastic spacer block on a test basis in West Virginia. West Virginia also stated that contractors did all of the guardrail replacement.

Georgia

Georgia was contacted as a result of a conversation with the one of the manufacturers of plastic spacer blocks. Georgia is one of the states that is using plastic spacer block. Georgia provided limited information via the telephone interview. An electronic mail message was sent asking more in-depth the questions as per their request, but was never responded to by the Georgia state DOT. Through secondary research, it was learned that the State of Georgia has approximately 17,990 state highway miles and approximately 81,227 county roads. The number of miles of interstate, turnpike or other roads was not available. State officials estimated that Georgia has approximately 1600 miles of guardrails on their highways. Georgia officials estimated they replace approximately 25-30 miles of guardrails yearly due to accidents. The state does all maintenance to the guardrails and contractors do all new guardrails. Georgia is replacing all of their wood spacer blocks with plastic spacer blocks. Replacement occurs when guardrails are changed due to either age, accident or highway maintenance.

North Carolina

It was also learned from a manufacturer of plastic spacer blocks that the state of North Carolina currently uses some plastic spacer blocks. North Carolina representatives indicated that this state has approximately 1023 interstate miles, and 78,245 state highway miles. The officials estimated that approximately 10% of their highway system was covered by guardrail. The guardrails are repaired by the state DOT and the contractors do all new guardrail installations. When inquiring as to why North Carolina was using the plastic spacer blocks, the officials informed the research team that the plastic spacer blocks were used on a trial project and the state had not yet decided whether or not to use the plastic spacer block in the future.

Connecticut

A manufacturer of plastic spacer blocks informed the research team that Connecticut was using plastic spacer blocks. When interviewing representatives of the state of Connecticut, it was learned that the state has 5200 total highway miles. However, officials did not have the breakdown per type of roadway. State officials did not have specific information on the guardrails and were not willing to respond to electronic mail with the questions. Connecticut, however, now uses only the plastic spacer block. The decision to move in this direction was based on the long-term stability of plastic spacer blocks and pressure from the environmentalists. Replacement occurs when guardrails are changed due to either age, accident or highway maintenance. Officials estimated that in a 3-year period that the state has spent over 1 million dollars in guardrail replacements.

Contractor Opportunity Assessment

A number of contractors involved with installation of guardrail systems in the states here were contacted. Some were less than forthcoming, since they considered the information being assessed as part of their competitive advantage in the bidding process. Others did offer insight into the opportunities for using plastic spacer blocks in their contracted work.

The contractors doing most of the guardrail installation work that agreed to be interviewed indicated they did between 80 to 90 percent of their business with state, county or city governments. The other 10 to 20 percent of their business tended to come from private sector contracts.

These government bids are done annually. The criterion for each job bid is mandated by the state. In Kentucky, the state even goes as far as to recommend the supplier of the materials to keep the continuity of the aesthetics of the guardrails. The other states leave the decision of which guardrail components to use to the contractor as long as the components are on the approved list. In summary, contractors will use those components of a guardrail system that are the least expensive yet meeting specifications and those they are most familiar with. There is a reluctance to change on the part of the contractors.

Threats/Challenges

The plastic spacer block is not a new concept. There are nine different companies approved to make plastic spacer blocks. However, our research shows that only three of these firms are playing a significant role in the production and marketing of plastic spacer blocks. Trinity Industries, which is number one in sales in the market, makes both the solid plastic spacer block and the filled plastic spacer block. Bryson Industries is second largest in sales in the market and produces a solid plastic spacer block. Mondo, which is third in sales, produces a solid plastic spacer block. Mondo Polymer is a sister company of Mondo Building and Excavating. Bryson Industries and Trinity Industries do not only manufacture plastic spacer blocks but they also both manufacture all components of the guardrail system.

This includes wood spacer blocks as well as steel guardrails and posts. Mondo Polymer produces only the solid plastic spacer block but is also involved with plastic tire chucks for larger trucks. These three major competitors have the use of an existing logistical system and the capacity to compete on price. The other six companies manufacturing plastic spacer blocks only manufacture plastic spacer blocks and are not major players in the guardrail manufacturing industry.

There presently are two types of plastic spacer block on the market--the solid plastic spacer block and the plastic spacer block with filler. The solid block is more valuable because it contains more plastic and will be easier to recycle. While the plastic spacer block with filler block, although initially less expensive is more costly to recycle and has less plastic value. The filler blocks are filled with a variety of non-recyclable materials such as shredded tires, carpets, peanut shells etc.

One of the manufacturers of plastic spacer blocks that was interviewed indicated that they were approved to do business in 13 states most of which were in the southeast region of the United States. Although, approved in 13 states, only Connecticut and Georgia are using the plastic spacer blocks. North Carolina and South Carolina are pegging projects with the plastic spacer block. However, it was learned that although approved for pegging projects, South Carolina is not using the plastic spacer block at this time and North Carolina is halted further installation at this time. Florida also approved the use of the recycled plastic spacer block but placed a limitation on the plastics that were to be used in the recycled block. The state of Florida mandates that the plastics used in the recycled block come from Florida plastics. The research seems to indicate that many of these states have approved the use of the plastic spacer block so as to appear to be more environmentally conscientious. Nevertheless, according to the manufacturers, the only way to get plastic spacer blocks used by contractors in those states is for the state to mandate the use of the plastic spacer block.

The cost of the plastic spacer block over the wooden block will keep the contractors from using it. For example, the cost of plastic spacer blocks from one manufacturer is $4.60 plus transportation. The cost of a second manufacturer's plastic spacer block varied by volume but blocks were found to range from $5.95 to $6.05 per unit including transportation. Meanwhile, wood spacer blocks were found to have a delivered price ranging from $2.94 to $3.75. Due to the bidding process, contractors are price sensitive. Unless mandated to do so the contractor will continue to use the wood spacer block.

One cost savings possibility does favor the plastic spacer block. That savings comes from the installation time saved with the predrilled holes in the plastic spacer block. Some of the wooden blocks need to have the pre-drilled holes reamed out to align with the guardrail holes when installing. A cost-benefit analysis of the two products (wood versus plastic) should be conducted in order to sell the contractors in order to sell them on this advantage. However, according to one report, a contractor can install more meters of guardrail per day when using plastic but overall plastic still costs more to install than wood.

Not only is cost a major threat but also so is the contractors’ opinion of the plastic spacer block. The contractors are responsible for most of the guardrail construction. Of the states contacted guardrail replacement was primarily done by contractors. In most states the contractor has a choice of what type of spacer block to use. If the contractor does not want to use the plastic spacer block it will not be used. That is unless states mandate the use of the plastic spacer block.

Another threat is the hardwood industry. Current producers of hardwood spacer blocks will not want to relinquish the market share to plastic spacer block manufacturers. The lobbying that they have done in the federal system will make it difficult to break into the industry. Similar, the steel industry and the zinc oxide industry (such as that found in Ohio) will make it difficult to break into the total plastic guardrail system.

The longevity of the plastic spacer block is also a deterrent. If the contractors use the plastic spacer block they are not going to have to replace those blocks for 30 years. The wood spacer block has a built in obsolescence with a limited number of years (approximately 15) that it will last. Some contractors see the use of the plastic spacer block as reducing their potential work in the future.

Local and regional production is also a challenge. The wooden spacer blocks are obtained from local or regional sawmills. The plastic spacer blocks are only manufactured in a few locations throughout the United States. Transportation costs, therefore become a major factor in the decision to use plastic versus wood.

Finally, many states do not see a need to change from the wooden spacer block. States like Kentucky will use only wooden spacer blocks. If other states continue to operate like Kentucky and do not see the need to switch from the wooden spacer blocks there will be little immediate demand for the plastic spacer block.

2.2.2.5 General Findings

The data collected for this study to identify the potential for plastic spacer blocks for highway guardrail system as a substitute for wood spacer blocks presents both opportunities and challenges. Outlined below are highlighted some of the opportunities as well as the challenges.

Thirteen states have approved the plastic spacer block as meeting state specifications for highway guardrail systems. Of those thirteen states two: Connecticut and Georgia have adopted the plastic spacer block for use on all of their highway guardrail systems. In addition, two other states: North Carolina and South Carolina have identified specific highway projects where the plastic spacer block has been used. The exact reasons for the projects being selected is not known by the respective state representatives the research team spoke with. It is also not known why there is no other highway guardrail projects designated for using the plastic spacer block in the future.

On average guardrail systems are on approximately 10 percent of the states' highway systems that were contacted for purposes of this analysis. Each state contacted also replaces approximately 2 percent of their total guardrail system on a yearly basis due to accidents, age, and highway resurfacing. Those states spend approximately $1 million per one percent of their guardrail system that is replaced each year.

The durability of the plastic spacer block is an asset. The cost savings with the reuse of the plastic spacer block after accidents and the ability to recycle the plastic spacer block after its' lifespan is also a cost opportunity.

Recycling plastic and using plastic over wood has gotten the attention and support of environmentalists. Their efforts as lobbyists can be beneficial toward encouraging states to adopt the recycled plastic spacer block over the wood spacer block.

There appears to be a greater interest in having the entire highway guardrail system constructed of recycled plastic rather than only focusing in on the spacer block. Moving in this direction would require the entire plastic guardrail system to pass crash tests similar to that of the steel guardrail systems currently being used.

It has been reported that the use of pressure treated wood like that used in wood spacer blocks may no longer be manufactured. If this moratorium does go into effect the life expectancy of the wood spacer block would decrease significantly, thus making the plastic more attractive as a substitute.

There exist, however, challenges to the successful integration of the plastic spacer block into state highway guardrail systems. For companies currently producing plastic spacer block this effort represents a secondary component of their business. The attitude appears to be a wait-and-see approach to this product with little significant effort being put forth to market the product.

The wood spacer blocks are presently less expensive than the plastic spacer block. They cost less to produce and less to transport. The wood spacer block is produced locally and regionally where the plastic spacer blocks are manufactured in only a few locations. The two largest manufacturers of plastic spacer blocks are located in Texas (Trinity Industries) and Mississippi (Bryson Industries). The third is located in Ohio (Mondo Polymer).

It is reported by contractors who install guardrail systems and manufacturers who produce highway guardrail systems that presently there is not enough demand for plastic spacer blocks to make it feasible for the manufacturers to produce the block in large quantities. The contractors have experienced a difficult time acquiring enough plastic spacer blocks for their highway projects. Contractors have also found that the cost for the spacer blocks versus the wood are higher priced and there is no consistency in the components used to produce the plastic spacer block from a manufacturer versus another manufacturer. The contractors also believe that should the demand increase for plastic spacer blocks there is some question as to whether there is a sufficient supply of plastic to produce enough spacer blocks to meet that demand.

At this time there exists no incentive on a national level for contractors or states to use the plastic spacer block versus the wood spacer block. It will take some external directive or change in requirements for highway guardrail systems to insure a much quicker adoption of this new technology.

2.2.2.6 Recommendations

The successful production and marketing of the spacer block made from recycled plastic is dependent on a number of issues. The first issue is the successful completion of crash tests performed by an entity certified to perform such test for the federal government for the product proposed here. At this time crash tests have not been performed on this particular recycled plastic spacer block. It is assumed that the recycled plastic spacer block assessed here will indeed meet both crash tests and product specification requirements. Therefore, this assessment is based on the assumption that the recycled plastic spacer block will indeed successfully pass the required crash tests and meet product specifications for both federal and state highway systems. However, the reader should be cautioned to the fact that all of those interviewed for this assessment indicated that their input was predicated on the assumption the product would successfully meet crash test and product specification standards and urged that the crash test be conducted as soon as possible.

The second issue involved with the successful introduction of this product into the marketplace cost—both fixed and variable. The product must not only be produced (fixed) at a price competitive with those products currently on the market but also must be delivered (variable) at a competitive if not lower cost than those products currently being utilized. The realization here is contractors involved with buying and installing these spacer blocks are *currently* looking at guardrail material from a cost containment perspective. If the delivered cost is higher than that of spacer blocks currently being used, the contractor lacks incentive to purchase the recycled plastic spacer block being analyzed here. Since transportation costs tend to increase as one moves further from the point of production, it is suggested that the producer of the proposed recycled plastic spacer block consider these costs when marketing the product in a market area where variable (transportation) costs can be minimized and the delivered product price competitive.

As one considers the competitive forces affecting the successful production and marketing of the recycled plastic spacer block, buyers of this product become a third issue. As the assessment evolved it became evident that each state offered a unique challenge as well as opportunity for the marketing of this product. Although each state set the specifications for guardrail systems in general and spacer blocks in particular, some states did more of the installation in-house than others. It would seem more opportunistic for the producers of this proposed product to focus on those states in the proposed market area where more of the installation is done in-house (some states do up to 40 percent of their own installation-- e.g. Ohio). This strategy is based on the assumption that the state's goal is cost, product longevity as well as safety; while the contractor would be interested in cost and safety as well as how **soon** the block would need to be replaced (obsolescence). Research into the recycled plastic spacer block indicates it lasts longer than the wooden block substitute, thus a competitive selling point to states interested in purchasing and installing a product that lasts longer and can be recycled.

A fourth issue that arose from the assessment was the fact that most firms currently producing competitive plastic spacer blocks were doing so as a portion of their overall business activity. That is, they were involved in a number of synergistic production efforts, of which the plastic spacer block was only one element. In fact, it seemed as if these competitors treated the plastic spacer block production as almost experimental in nature, and did not have great expectations for adoption or profitability at this point in time. Rather, they wanted to be prepared if and when plastic became a mandated substitute for the current products now being produced and utilized. This would indicate that caution is warranted if a firm planned to enter the market solely on the basis of the production and marketing of spacer blocks from recycled plastic.

A fifth issue involved the area of aesthetics. The visual appearance of the product as it pertained to overall look of the guardrail system was important to the contractors. The point made often was that they did not want a mismatched system. One that had a mixture of wood and plastic spacer blocks in the finished system. Contractors wanted to install a guardrail system that had either all wood or all plastic spacer blocks. Some also voiced concern regarding the inability to get enough of the required recycled plastic spacer blocks to successfully install the number of guardrail systems for which they had been contracted which would give rise for avoiding the plastic since a mixture of wood and plastic would be required and thus the issue with aesthetics.

To overcome the problem with aesthetics, support for an entire guardrail system made from recycled plastic material seemed to gain acceptance from those being assessed. This system would include not only the spacer block but also the post and the guardrail itself, all of which would be made from recycled plastic. Of course, successful completion of the crash test requirements would have to be made and the cost of the overall recycled plastic guardrail system would have to be competitive. But the concept was well received and seem to offer a unique opportunity with those involved in this assessment and a sixth issue to be considered for those considering producing and marketing this product.

The successful introduction of this innovative product is going to require some unique marketing techniques to be instituted. The results of this assessment indicate a wait-and-see approach toward acceptance of this product by those charged with the purchase and installation of spacer blocks on state highways. This wait-and-see attitude seems to be the case for those currently producing competitive plastic spacer blocks as well. This based on the finding that most states, contractors and even manufacturers are treating the plastic spacer block as an experimental item rather than a part of their mainstream business. With this wait-and-see attitude currently in place, it is recommended that those with a vested interest in the proposed recycled plastic spacer block assessed here institute a push rather than pull marketing approach. Utilizing a traditional pull strategy, the manufacturer would attempt to stimulate demand by directing their marketing activities toward the buyer, in this case the contractors charged with installing the spacer block. However, since the attitude toward the proposed spacer block made from recycled plastic was assessed to be one of a wait-and-see interest level, a push approach is recommended. The push approach would drive the product through the system causing the contractor to buy and use the product out of necessity in order to successfully meet the contract specifications. This push approach would require a heavy emphasis on personally selling the attributes of this product to the state governments charged with setting the specifications for successfully completing guardrail installations in each of their respective states. This personal selling effort would also require effective lobbying at both the federal and state levels and possible inclusion of government policy changes and incentives to use recycled plastic material as part of the respective states highway construction and maintenance programs. This push approach would thus be a method for improving the current wait-and-see atmosphere of acceptance of the recycled plastic spacer blocks among those charged with buying and installing these products on state highways. It is further recommended that this push strategy be initially targeted to those states within the targeted marketplace outlined earlier in this report.

In summary, it is recommended that the recycled plastic spacer block assessed here, successfully meet all product specifications as well as all crash test requirements. The organization manufacturing this spacer block should consider producing the entire guardrail system (guardrail, post, and spacer block) out of recycled plastic. It appears the strategy of working with an entire guardrail system made of recycled plastic versus working with only one component of that system (spacer block) that is made from recycled plastic is more attractive to state officials. It is further recommended, that this plastic guardrail system and each component of the guardrail system be developed, produced and sold at the cost or below the cost of those products currently available on the market. It is also recommended that this product be marketed using an aggressive push strategy toward the marketplace. Finally, it is recommended that an aggressive lobbying effort be undertaken to facilitate the adoption of this product's acceptance and use by states and the contractors who work for those states.

Additional information on the work performed under Task 2.2 can be found in Appendix H.

2.2.2.7 References

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Task 2.3 Polymer Characterization, Research, and Testing (Gupta)

The Recipient shall analyze the effects of reinforcement additives such as rubber, mica, and glass fiber on the properties of various blends of recycled and virgin polymers, for example, a range of recycled PC blends toughened with rubber, a range recycled PC blends filled with mica or other filler, and a range of blends of recycled PC reinforced with glass fibers. The Recipient shall provide sample products for testing and fabricate component parts for electronics application using various blends of recycled/virgin polymers both with and without reinforcements and additives, and document results of tests conducted on sample products. Also, the Recipient will maintain and continue working relationships with existing polymer companies and product manufacturers to develop processes that yield consistent quality resin blends acceptable for commercial use.

Description of work performed, accomplishments and results:

Using a rubber compound to improve the properties of blends of recycled PC and ABS

Accomplishments and Results

- One of the most desirable properties of PC is its high impact strength. However, recycled PC shows very low impact strength due to the presence of impurities. Even the blends of virgin PC and recycled PC have low impact strength. Thus, it is desirable to improve the impact strength of recycled PC by adding an impact modifier.
- We used a rubber compound known as Blendex 338 as impact modifier for the blends of recycled and virgin PCs.
- It was found that by simply adding Blendex 338 to recycled PC did not result in any improvement in the impact strength.

- However, by blending recycled PC with virgin ABS and Blendex 338 resulted in significant improvement in the impact strengths of the blends.

Details of Experimental Work and Results

Three grades of recycled polycarbonate that were supplied by MBA Polymers have different amounts of impurities. Recycled polycarbonate named as R-PC630 has about 2% impurity level. Impurities are in the form of other plastics such as PMMA, PET, HDPE etc. R-PC 630 has significantly lower impact strength equal to 99.43 J/m (1.86 ft-lb/inch) as compared to 952.21 J/m (17.74 ft-lb/inch) for virgin PC (Lexan 101). Thus, it would be sensible to find ways to improve the impact strength of R-PC630.

In order to modify the mechanical properties of recycled PC, ABS and their blends, a rubber compound known as BLENDEX 338 was obtained from GE Specialty Chemicals. This compound contains 70% polybutadiene rubber and is sold as an impact modifier for PC and PVC. Initially, only BLENDEX 338 was blended with two grades of recycled PC and virgin PC such that the final blend contained 5, 10 or 15% w/w rubber. These results showed that simply blending BLENDEX 338 in polycarbonate did not result in enhancement of impact strength, rather it decreased with increasing concentration of BLENDEX 338.

R-PC630 was blended with virgin ABS and BLENDEX 338. Blends of polycarbonate and ABS are widely used in the plastic industry. These blends provide toughness and heat resistance of PC but easy processability of ABS. Commercially they are available as Cycoloy from GE Plastics and Bayblend from Bayer.

For the blends prepared amount of BLENDEX 338 was kept constant at 10% (w/w), while amounts of virgin ABS and R-PC630 were varied. Virgin ABS used for this work was Cycolac GPM5500 from GE Plastics. Amount of virgin ABS was varied from 18% to 45% (w/w). Blends were prepared in Brabender twin-screw extruder and then pelletized. It was found that in the presence of virgin ABS blending of R-PC630 was much easier and could be carried out at lower temperature. Temperature profile in the extruder, from feed to die was 190, 230, 235 and 225 ^{o}C, and the screw speed was 30 rpm. Specimens for mechanical testing were molded in Battenfeld injection-molding machine with temperature profile of 254, 257, 257 and 249 ^{o}C, from feed to nozzle.

Izod notched impact strength tests were performed according to ASTM D256. Figure 2 shows the impact strength as a function of R-PC630 content. It can be seen that 100% R-PC630 has very low impact strength. However, adding virgin ABS and BLENDEX 338 significantly improves the impact strength of the blends. Interestingly, at 63% and 72% R-PC630, synergistic effect is observed and the resulting impact strength is greater than that one would expect from simple proportional addition. Commercial PC/ABS blends have impact strength in the range of 530-650 J/m (10-12 ft-lb/inch).

Figure 3 shows the yield strength of same blends as a function of R-PC630 content. Tensile strength tests were performed according to ASTM 638 with type I specimen. The stretch rate was 0.8 mm/s (2 in/min). As can be seen, yield strength of the blends is much lower than that of 100% R-PC630 and commercial PC/ABS blends. However it is higher than virgin ABS. BLENDEX 338 also helps in improving the yield strength of PC/ABS blends as evidenced by the fact that the yield strength of a blend containing 50% R-PC630 and 50% v-

ABS is much lower than the blend containing same proportion of R-PC630 and v-ABS but to which 10% BLENDEX 338 has been added.

Therefore, it can be concluded that by blending impact modifier BLENDEX 338 with R-PC630 and virgin ABS, impact strength can be improved. Furthermore, blends must have more than 63% (w/w) R-PC630 content. This suggests that one can use significant recycled polycarbonate content in the PC/ABS blends if an impact modifier is also used.

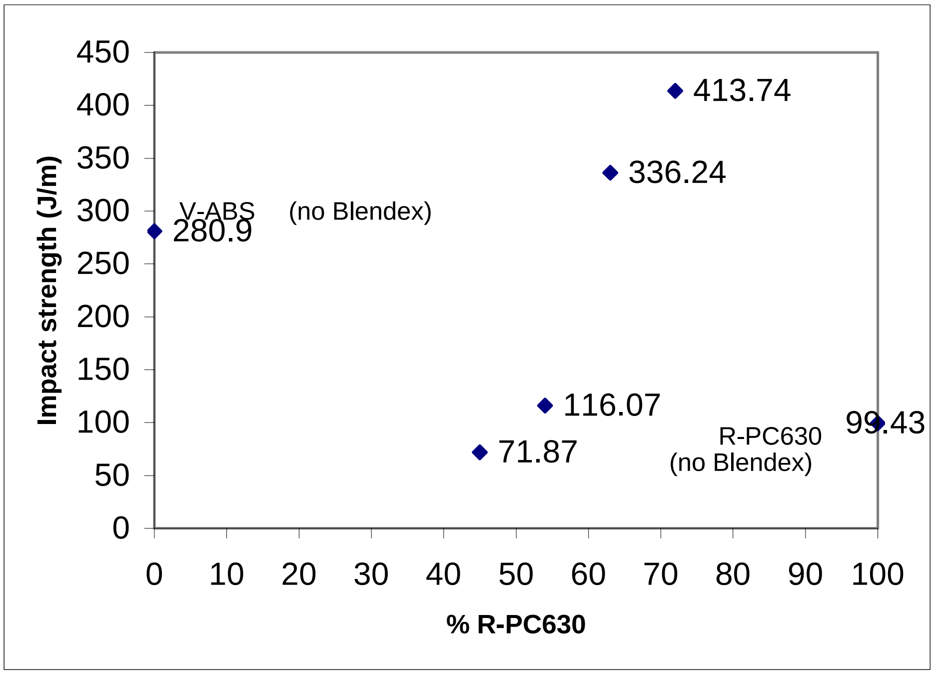

Figure 2: Impact strength versus R-PC630 content for blends of R-PC630, virgin ABS and BLENDEX338. BLENDEX338 concentration is constant at 10% for all the blends, only concentrations of R-PC630 and v-ABS are varied.

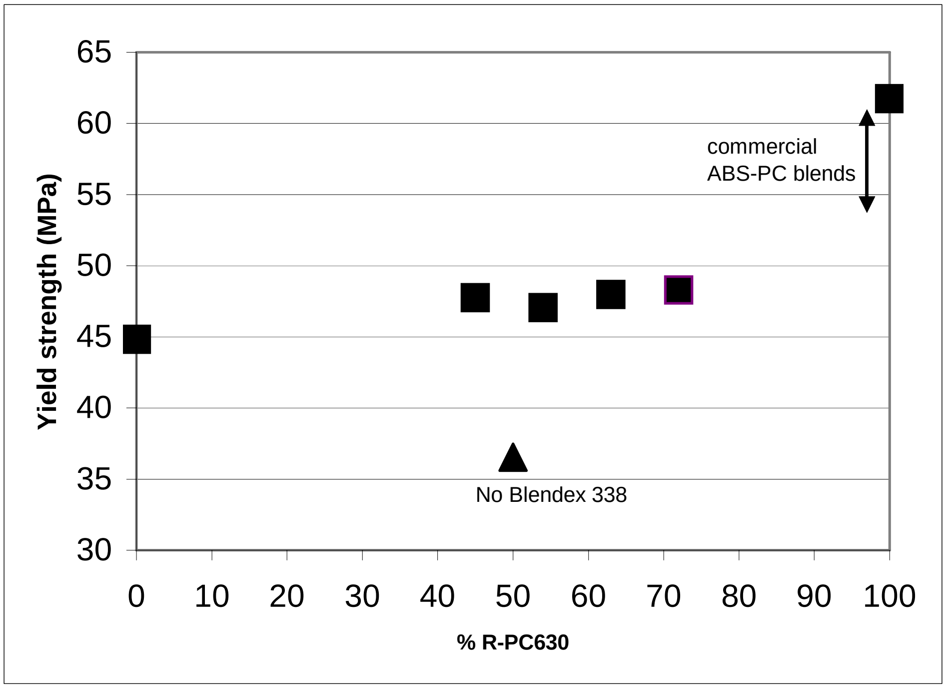

Figure 3: Yield Strength as a function of R-PC630 content. All the blends contain 10% (w/w) BLENDEX 338, only concentrations of R-PC630 and v-ABS are varied. Arrow shows the range of yield strength for commercial PC/ABS blends.

Effect of Impurities on Mechanical Properties of Polycarbonate

<u>Accomplishments and Results</u>

- Recycled PC obtained from various suppliers contains impurities in the form of other polymers such as PMMA, HIPS, PE, ABS etc. Objective of this part of the study was to see the effects of adding different impurities on the mechanical properties of virgin PC so that guidelines can be formulated as to the kind and amount of the impurities that may be acceptable in the recycling stream.
- PMMA, PET, Nylon 6,6, LLDPE and HIPS were blended with Lexan 101 virgin PC at 1, 2 and 4 wt% level. These blends were molded into standard specimen and their mechanical properties were measured.
- Impact strength tests showed that at 1 wt% impurity level there was no significant decrease in the impact strength.
- At 2% impurity level, PET and PMMA do not affect the impact strength, however with LDPE, HIPS and nylon reduction in the impact strength is observed. On further increasing the impurity level to 4%, except PET, all other resins cause a significant decrease in the impact strength of PC. Nylon even at 2% seems to severely affect the impact strength.
- Up to 4% impurity level, there is no significant decline in the yield strength of PC except for LDPE and HIPS.

Details of Experimental Work and Results

To introduce the impurities in PC, following polymers were chosen: PMMA, PET, Nylon 6,6, LLDPE and HIPS. Virgin polycarbonate was Lexan 101 from GE plastics. Blends of polycarbonate with each impurity were prepared at 1,2 and 4% (w/w) impurity level in the twin-screw extruder with temperature profile of 280, 290, 305 and 300°C at 30 rpm. Resulting blends were molded into specimens for mechanical testing in an injection molding machine with temperature profile of 299, 304, 304 and 288°C.

Figure 4 shows the impact strength of polycarbonate at various levels of impurities. It can be seen that for all impurities there is no significant effect at 1% impurity level. At 2% impurity level, PET and PMMA do not affect the impact strength, however with LDPE, HIPS and nylon reduction in the impact strength is observed. On further increasing the impurity level to 4%, except PET, all other resins cause a significant decrease in the impact strength of PC. Nylon even at 2% seems to severely affect the impact strength.

Yield strength of PC containing various impurities is shown in Figure 5. As can be seen up to 4% impurity level, there is no significant decline in the yield strength of PC except for LDPE and HIPS.

These results can be explained in terms of polymer-polymer compatibility and processability. Since polycarbonate is processed at very high temperatures, it is easy to blend other polymer with it hence the processability should not affect the properties of the blends. Therefore, only compatibility of the polymers should affect the properties of the blends. Of the polymers used in this work, only PMMA and PET are compatible with PC and therefore do not affect the mechanical properties of PC at low level of concentration. Whereas, the polymers which are not compatible with PC, have a negative effect on the mechanical properties of PC if present as impurities even at impurity levels of as low as 4%. Thus, this work provides a clear guideline as to which impurities may be acceptable in the recycled polycarbonate.

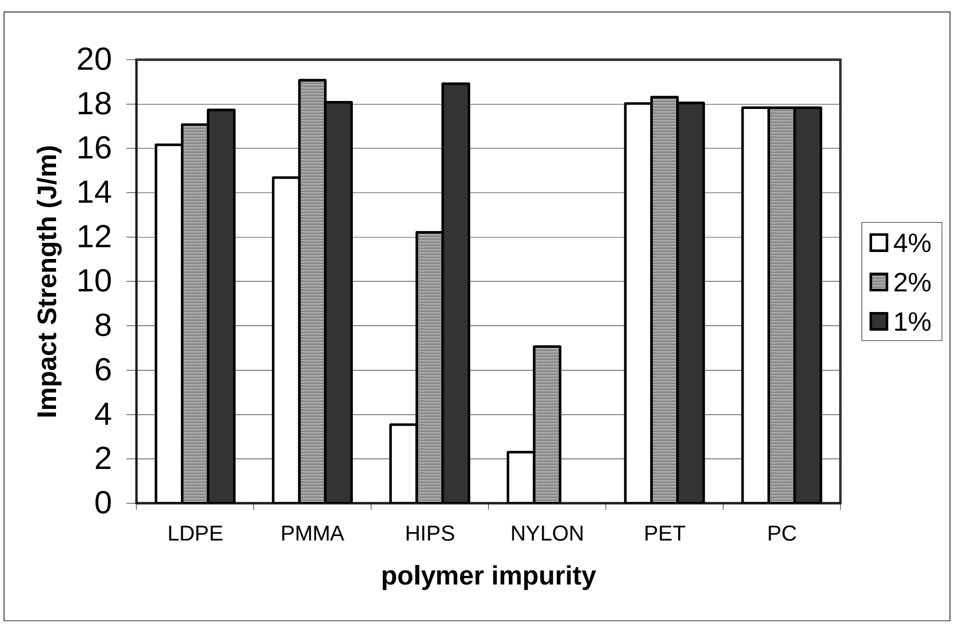

Figure 4. Effect of polymer impurities on the impact strength of virgin polycarbonate.

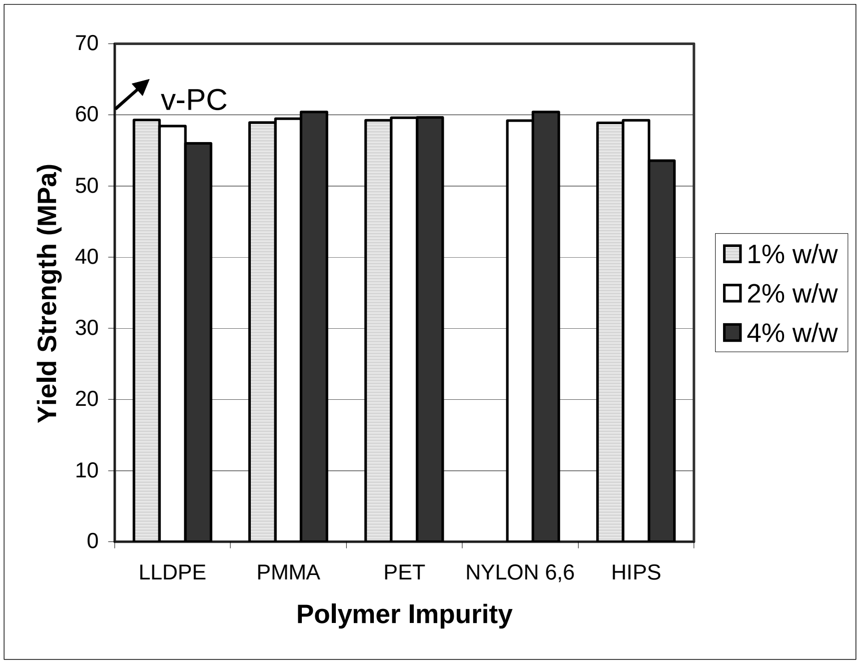

Figure 5. Effect of polymer impurities on the yield strength of virgin PC.

Using glass short fiber to improve properties of recycled polycarbonate

- We studied the effect of adding glass short fibers to a mixture of virgin and recycled PC to see if improvements in the mechanical properties can obtained. The objective of this work was to see if by adding glass fibers to polymer matrix its mechanical and flow properties can be made less sensitive to the batch to batch variations in polymer matrix due to the presence of impurities.
- It is shown that impact strength and elongation-to break in a tensile test are the two mechanical properties that are most sensitive to the presence of impurities in PC. On adding short glass fibers, these two properties become almost insensitive to changes in matrix composition provided that the matrix contains at least 75% virgin PC. Thus, a sample containing 15 wt% glass fibers has an impact strength of 1.4 ft-lb/in when the matrix contains recycled PC, and this impact strength goes up to only 1.8 ft-lb/in when the matrix is entirely virgin PC; the increase in strain-at fracture is from 5% to 6.7%. Similarly, the viscosity difference between PC melts with added glass fibers is acceptably small if the matrix contains at least 75% virgin PC.
- For purposes of recycling, separation of commingled plastics is not necessary, and one can formulate a “green” product having 25% recycled polymer (based on resin content) by the addition of an appropriate amount of short glass fibers.

Details of Experimental Work and Results

Figures 6-8 show schematically the experimental design used to study the various PC composites with glass short fibers. Lexan HF 1110 resin was used as virgin PC and RTP 307 containing 40% by weight glass fibers was used for reinforcing. Recycled PC was obtained from MBA polymers.

More details of the study can be found in Ph. D. thesis dissertation of Dr. Adam Al-Mulla entitled “Glass Reinforcement of Recycled Polycarbonate”, WVU, 2002.

Figure 9 shows the stress-strain curves for un-reinforced and glass reinforced 50% recycled PC+ 50% virgin PC. Yield strength and tensile modulus are shown in Figure 10 and Table 12 respectively. Impact strength for the same samples is given in Figure 11.

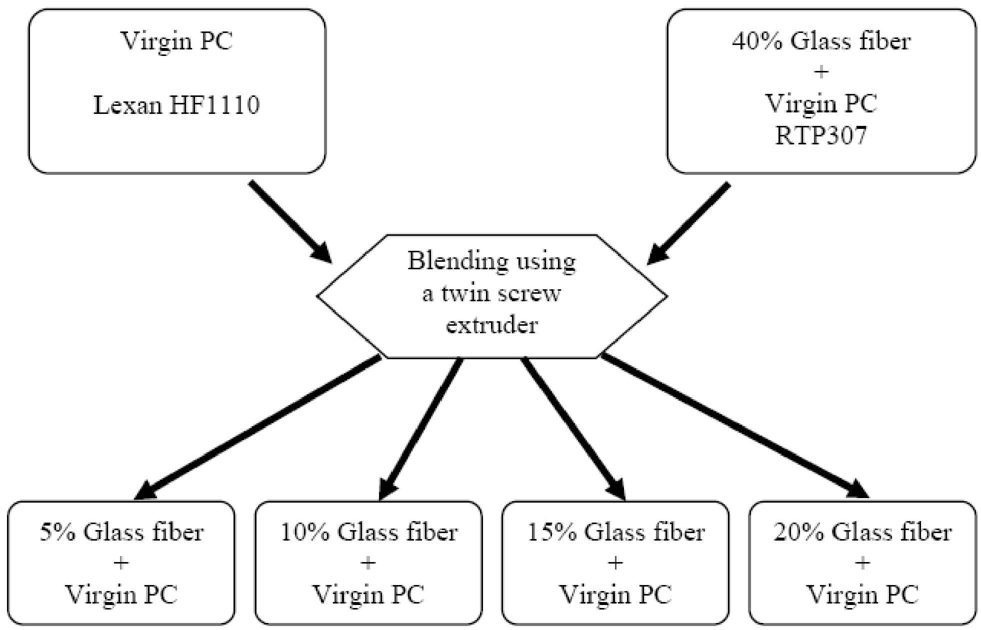

Figure 6. Experimental design for the study of short glass fiber- virgin polycarbonate composites.

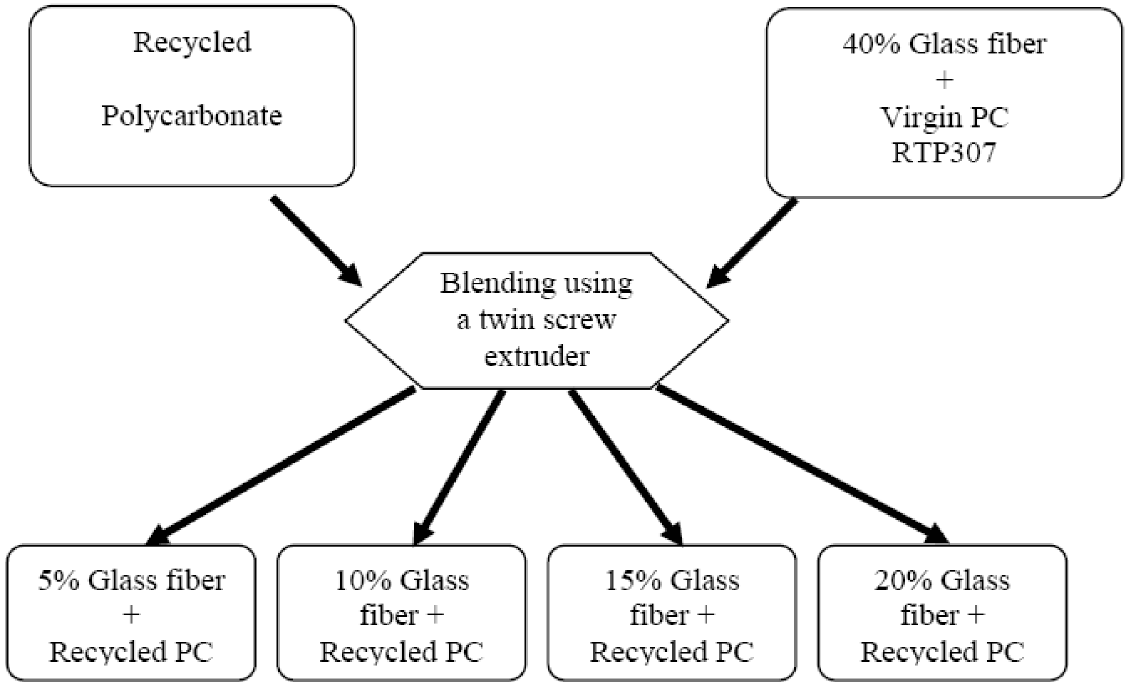

Figure 7. Experimental design for the study of effect of adding short glass fibers to recycled and virgin PC.

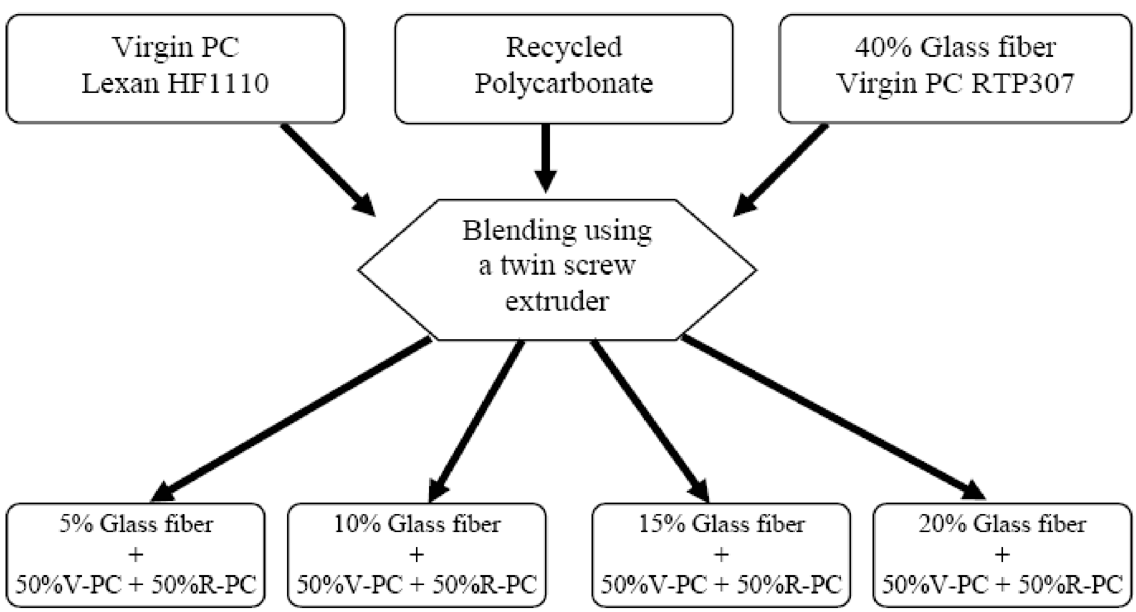

Figure 8. Experimental design to study the effect of glass fibers on a blend of virgin and recycled PC.

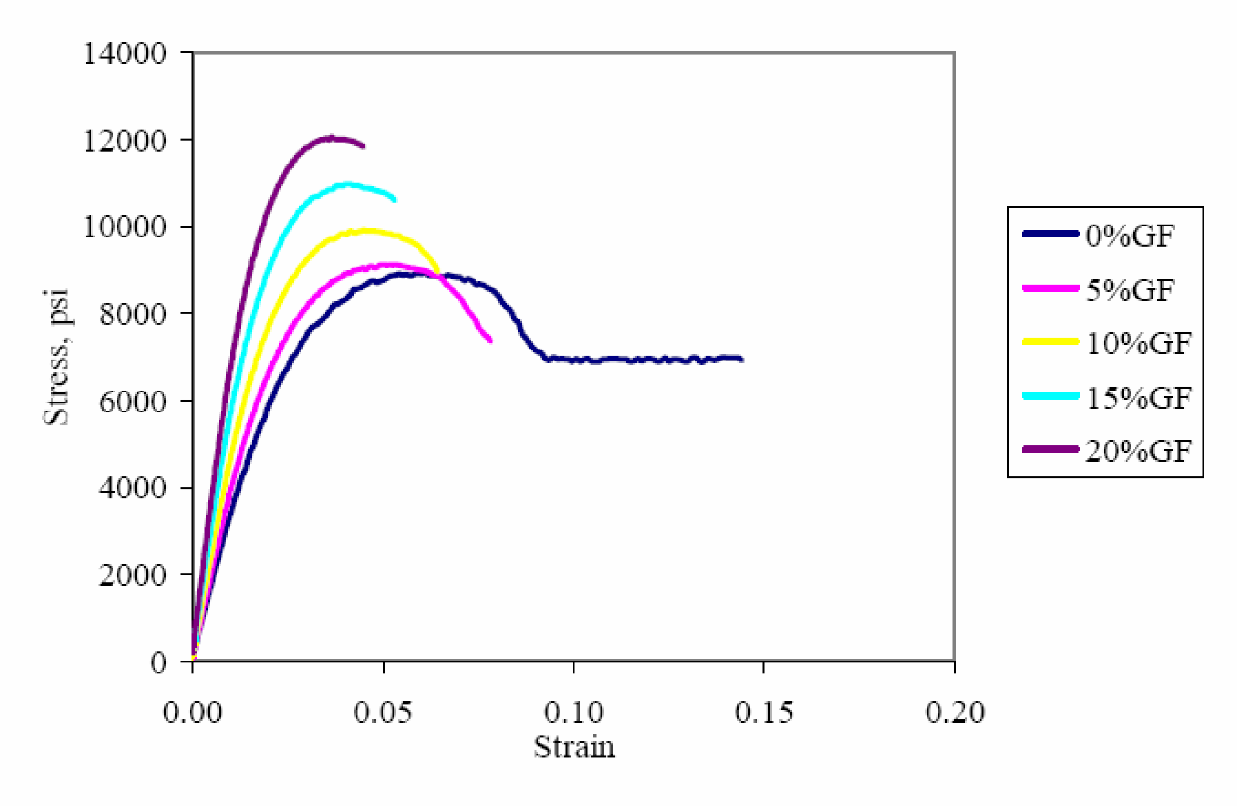

Figure 9. Stress-strain curves for un-reinforced and glass reinforced 50% recycled PC+ 50% virgin PC.

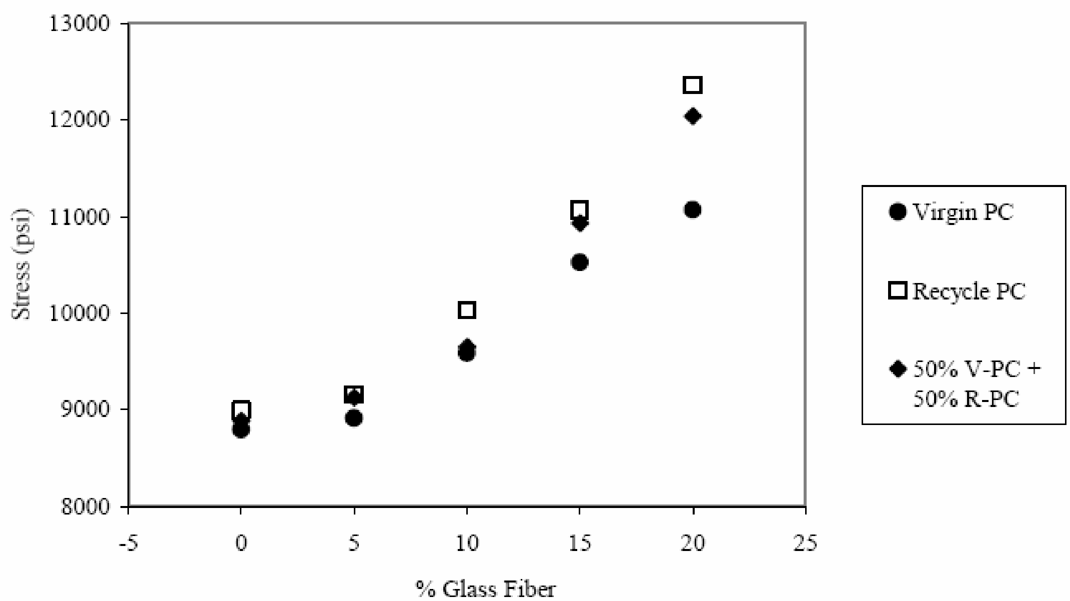

Figure 10. Yield stress for short glass fibers and recycled PC composites showing the effect of glass fiber loading.

Table 12. Elastic modulus of short glass fiber-PC composites.

% Glass Fiber	Modulus of elasticity, psi		
	Virgin PC	Recycled PC	50% Virgin + 50% Recycled
0	302938	338237	310945
5	373660	407607	387494
10	448001	480589	475218
15	543597	602599	580264
20	644163	742221	708505

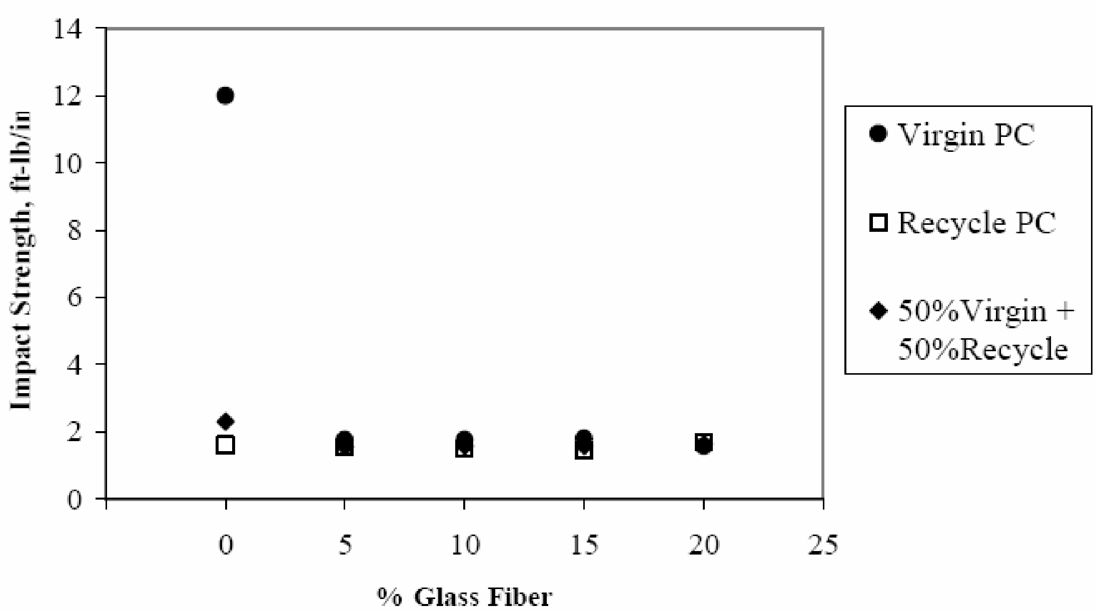

Figure 11. Impact strength of short glass fiber/PC blends as a function of fiber glass loading.

Using Nanoclay to improve mechanical properties of recycled PC

Accomplishments and Results

- Objective of this part of the study was to improve the tensile modulus and strength of recycled PC by adding nanoclays as the reinforcing material.
- Since nanoclay can not be melt blended directly with PC because it causes severe thermal degradation to take place, we first blended nanoclay with polymethyl methacrylate (PMMA) and then blended it with PC.
- It was found that by adding clay up to 4 wt% increase in tensile modulus and strength can be obtained. However, impact strength reduces on the addition of nanoclays.

Details of Experimental Work and Results

Our previous work has shown that the recycled PC has inferior tensile properties, namely tensile modulus and strength, than the virgin resin. By adding reinforcing additives such as clays, glass beads and glass fibers, enhancement in the tensile strength and tensile modulus can be obtained. Montmorillonite clay was obtained from Southern Clay Products. It is not possible to directly blend the clay into the PC. At the high extrusion temperature, PC degrades rapidly in the presence of clay. Therefore, clay was blended with PC in the presence of poly methyl methacrylate (PMMA). Blends of PC/PMMA are widely used in the plastic industry for making equipment housing, panels, truck hoods etc. In addition to providing better tensile properties, introduction of clays also results in higher heat resistance, increased flexural modulus, lower gas permeability, easy flow, dimensional stability, good surface appearance and lower heat release rate.

Before applying this approach to recycled PC, we used virgin PC to test the validity of this approach. Virgin polycarbonate was Lexan 101 obtained from GE Plastics and PMMA was RTP1800 resin obtained from RTP Company. Cloisite 25A nanoclay was obtained from Southern Clay Products. It is a montmorillonite clay which is surface treated to make it compatible with the polymer resin. Blends were prepared in a Brabender twin crew extruder at 20 rpm. In all the blends, ratio of PC to PMMA was kept constant at 5:1 (w/w). Clay loading was 0,1, 2 and 4% (w/w). Though both PC and PMMA are transparent in their virgin forms, their blend is opaque white solid. Resulting blends were molded into specimens for mechanical testing using Battenfeld injection molding machine.

Tensile properties were measured according to ASTM 638 using a Type I specimen. A strain gage extensometer was used to measure the strain on the sample. The stretching rate was 2 inch/min. Figure 12 shows the tensile modulus and Figure 13 shows the yield strength as a function of clay loading. It can be seen that there is a significant increase in the modulus, even at clay loading of as low as 4%. Yield strength also shows an increase in the magnitude as function of clay loading. This shows that reinforcing material such as clays can be used to enhance the tensile properties of PC. Success with virgin resin suggests that same approach should be applied to recycled PC. Figure 14 shows the impact strength as a function of clay loading and as expected, the impact strength decreases with increasing clay content.

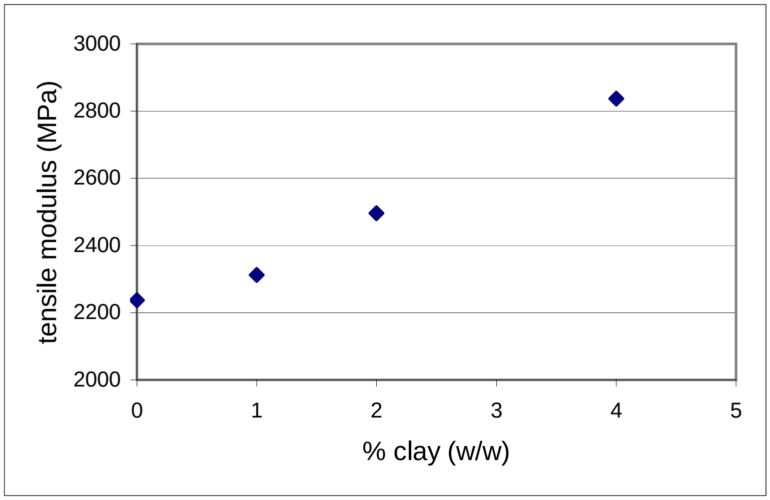

Figure 12: Effect of amount clay on the tensile modulus of PC/PMMA blend. Ratio of PC/PMMA is 5:1 in all samples.

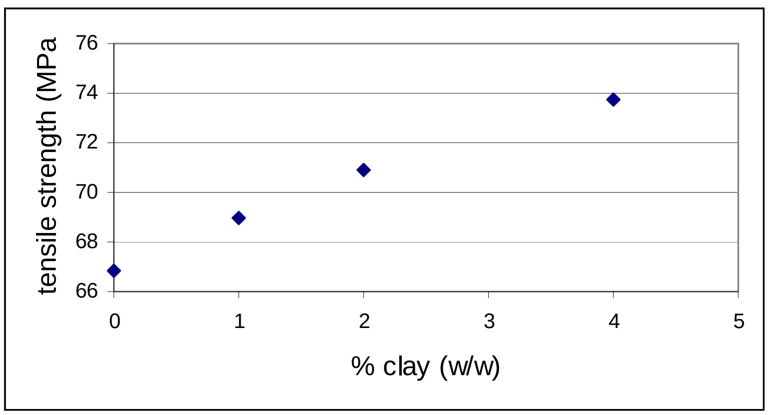

Figure 13: Effect of amount clay on the tensile strength of PC/PMMA blend. Ratio of PC/PMMA is 5:1 in all samples.

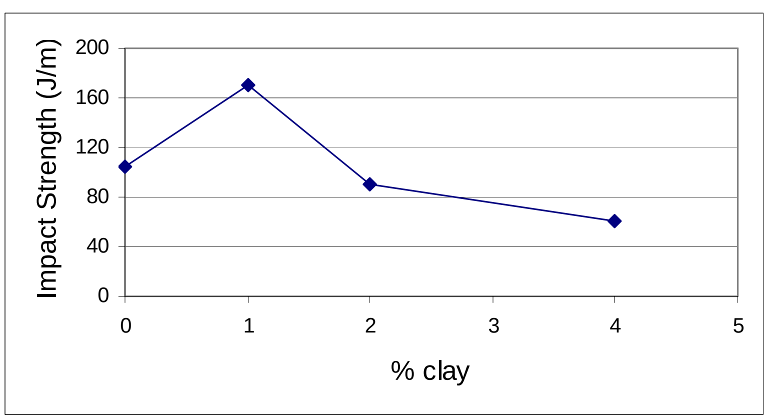

Figure 14: Effect of amount clay on the impact strength of PC/PMMA blend. Ratio of PC/PMMA is 5:1 in all samples.

Using On-line Viscometer to Control the viscosity of the ABS blend

Accomplishments and Results

- It was shown that on-line viscometer can be used to continuously monitor shear viscosity of ABS blends of recycled and virgin polymers as they are compounded in a twin screw extruder.
- Using the real time value of measured shear viscosity, in principle, a feeding system can be designed to control the relative amounts of virgin and recycled feeds to obtain a constant viscosity product.
- A high flow and one low flow virgin ABS resins were melt blended with recycled ABS to obtain a constant viscosity product.
- Mechanical property measurements on these blends showed that unto 25 wt%, recycled ABS can be added to virgin ABS with out causing significant change in the mechanical properties.

In a polymer recycling operation, polymers are obtained from a variety of sources. Consequently they vary greatly in their mechanical and rheological properties. However, when recycled polymers are sold to molders they must be of consistent properties. One of the most important properties of a resin is its shear viscosity. Recycled polymer obtained by blending different feeds must have a constant shear viscosity. One way of achieving a constant viscosity is to blend virgin polymers of different shear viscosities with the recycled polymer in an extruder to obtain a constant shear viscosity end product. Since shear viscosity of the recycled polymer changes with the feed source, the proportions of virgin polymers must be continuously adjusted to obtain a constant viscosity product.

An online viscometer can be attached to the extruder to continuously monitor the shear viscosity of the blend. Depending on the change in the viscosity, the composition of the feed can be adjusted to achieve a constant value of the viscosity. To prove the principle of the method, Dynisco Viscosensor on-line rheometer D9071 was used to measure the melt shear viscosity of the blends. The on-line rheometer is connected through an adapter to the extruder between the tip of the screws and the die section. A small stream of polymer is continuously withdrawn from the process flow stream by a metering pump and then fed through a capillary and finally returning it back to the process flow stream. Pressure drop is measured across the capillary using two pressure transducers. The flow rate across the capillary and hence, the shear rate can be set by controlling the speed of the metering pump. Knowing the shear rate and the pressure drop, the shear viscosity can be easily calculated. An electronic process control unit controls the Viscosensor and on-line data is captured using a computer data acquisition system. The shear viscosity measurements were carried out at 260^{o} C. Capillary diameter was 2mm and length 30mm.

Three kinds of recycled ABS obtained from MBA Polymers Inc. have varying degrees of impurities and consequently different mechanical and rheological properties. Our previous work has indicated that up to 15% recycled ABS can be added to virgin polymer without significantly changing the properties. In this work we increased the level of recycled ABS to 25%. The virgin component of the blend was a mixture of two kinds of virgin ABS resins having different molecular weights or melt flow indexes (MFI). MFIs of recycled and virgin resins are given in Table 13. Virgin ABS resins were obtained from GE Plastics and they are general-purpose Cycolac resins. The melt flow indexes of recycled resins were measured using Dynisco melt flow indexer at 230^o C using 3.8 kg weight. MFIs of virgin resins are from the manufacturer. Of the two virgin resins, one has MFI higher and other lower than the recycled ABS resins. Since resins will be mixed in different proportions their shear viscosity will also be different.

Blends were prepared in a Brabender counter-rotating twin-screw D6/2 extruder. Required amounts of virgin and recycled resin pellets were weighed and then hand mixed together. Table 14 shows the compositions of various blends. They were dried overnight at 90^o C prior to blending. The extrusion temperature conditions, from feed to die, were 220, 240, 240 and 220^{o}C and the extrusion was carried out at 30 rpm. Extrudate comes out in the form of a strand which is quenched in water and then pelletized in a pelletizer.

Table 13: Melt Flow Indexes of ABS resins

Resin	MFI (230^o C, 3.8 kg)
Recycled – ABS	9.5
Recycled – ABS594	7.6
Recycled – ABS612	8.8
Cycolac MG94	11.7
Cycolac MG38	3.7

Table 14: Composition of ABS blends

% Recycled ABS	% Cycolac MG94	%Cycolac MG38
25	75	0
25	56.25	18.75
25	37.5	37.5
25	18.75	56.25
25	0	75

The pellets of polymer blends were dried at 90^o C overnight before molding. Battenfeld BA1000/315 CDC injection molding machine was used to mold specimens for mechanical testing. The temperature profile in the injection molding machine from feed to nozzle was 193.3, 210, 210 and 193.3^o C. The mold temperature was 48.9^o C.

Tensile properties of the polymers were measured using Instron 8501 testing machine according to ASTM 638 using a type 1 specimen. The stretch rate was 5.04 mm/min. Izod impact tests were performed on notched specimens using Satec BLI impact tester according to ASTM 256. The thickness of the samples was 3.1 mm and a notch was cut using Notchvis notch-maker. All measurements were carried out room temperature.

For all the blends prepared recycled ABS content was kept at 25% and remaining 75% was virgin ABS containing a mixture of Cycolac MG38 and Cycolac MG94 in varying proportions. Figure 15 shows the shear viscosity of the blends as measured by the viscosensor as a function of shear rate. As expected shear thinning behavior is observed. It can be seen that by varying the relative amounts of high flow and low flow virgin ABS resins, viscosity of the blends can be changed and that change is measurable by the viscosensor. R-ABS594 has higher viscosity than R-ABS and from Figure 15 it can be seen that by adding low flow MG38 and high flow MG94 the viscosity of R-ABS can be made to approach that of R-ABS594. Thus it would be possible to adjust the viscosity of the blends to a set value by adding a mixture of high flow and low flow virgin resins in order to obtain a consistent quality blend. Relative proportions of virgin resins being added to the recycled stream can be controlled by the on-line viscosensor.

Figure 16 shows the yield strength of the various blends. As can be seen addition of virgin ABS to R-ABS and R-ABS594 improves their yield strength. Furthermore, yield strength remains unchanged even when relative amounts of MG38 and MG94 are varied. Figure 17 shows the tensile modulus which also does not vary with the composition of the blends. Another important parameter of importance is elongation at break and which is shown in Figure 18. Recycled ABS resins have low elongation at break and for a given blend a wide variation is observed from specimen to specimen. The visual observation of the cracked surfaces of the specimens showed the presence of impurities in the form of small particles of unblended plastic causing the sample to fail suddenly. Impact strength of the blends is shown in Figure 19. Here also addition of the virgin ABS results in the improvement in the impact strength of the recycled material and impact strength does not vary significantly with the relative amounts of virgin resins. Therefore, it can be said that varying the relative amounts of virgin material in order to adjust the viscosity does not cause significant variations in mechanical properties.

Thus, it has been shown that an on-line viscometer can be used to measure the shear viscosities of the recycled polymers of different grades. Virgin ABS of two widely different MFIs can be added in different proportions while keeping the recycled ABS content constant in order to obtain a consistent quality blend. Mechanical property measurements in terms of yield strength and impact strength show that these properties do not change significantly on varying the relative amounts of virgin resins. Thus this work shows that a method can be evolved using an on-line viscometer to obtain recycled polymer blends that have consistent shear flow and mechanical properties.

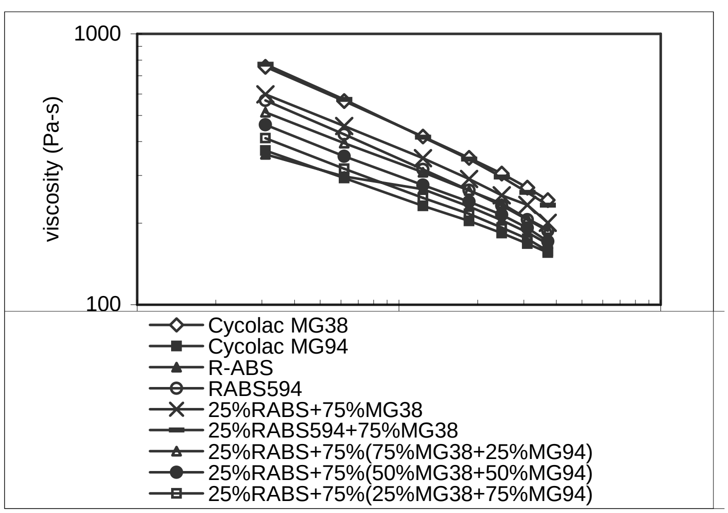

Figure 15. Shear viscosity as function of shear rate as measured by the on-line viscometer at 260° C.

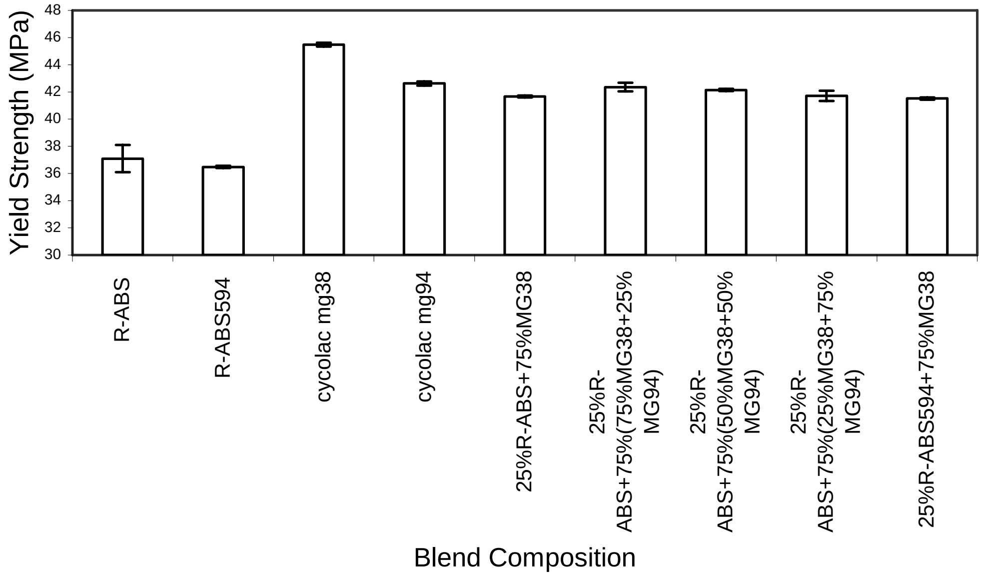

Figure 16. Yield strength of various blends of recycled and virgin ABS.

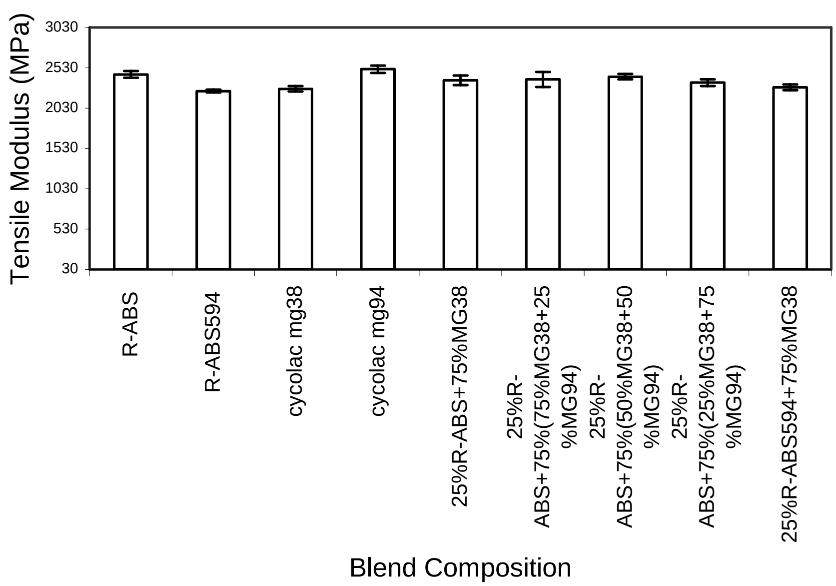

Figure 17. Tensile modulus of recycled and virgin ABS blends.

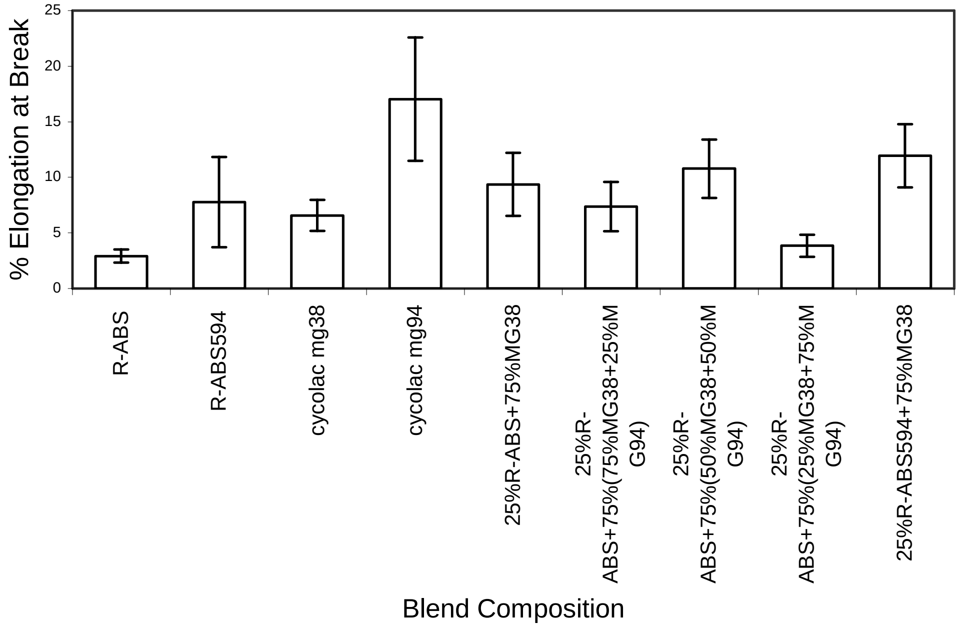

Figure 18. Elongation at break for ABS blends. It is based on initial length of 11.43cm.

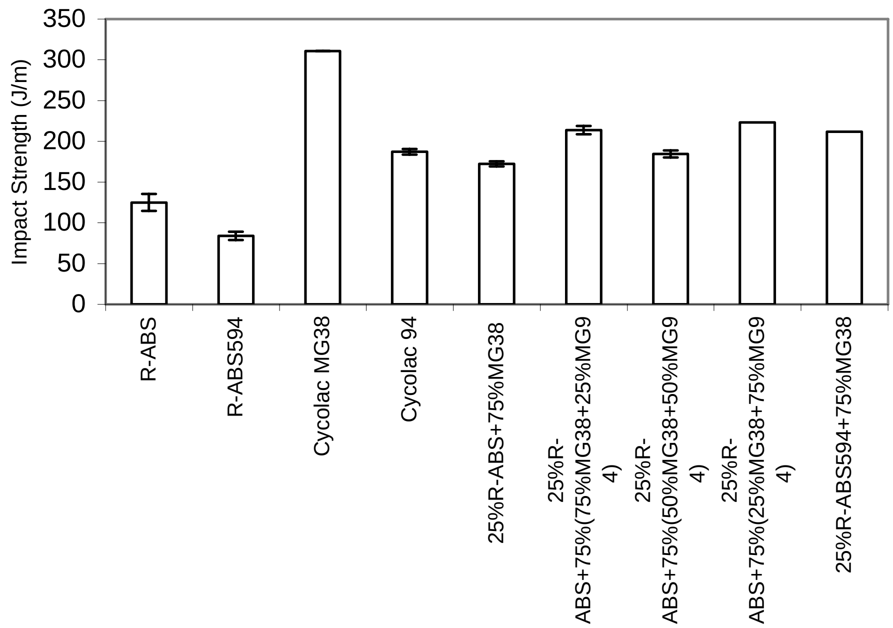

Figure 19. Impact strength of ABS blends.

Additional information about the work done under Task 2.3 can be found in Appendix I.

Task 2.4 Applications and Product Development (Hota)

The Recipient shall determine mechanical, thermal, and aging properties of mixed streams of virgin/recycled polymer blends to be used in automotive, infrastructure and other applications. The Recipient will promote the use of recycled polymers in transportation vehicles through establishing working relationships with automotive component manufacturers and by developing sample automotive products such as prototype headlight housings, bumper shapes, vehicle cross-beams, reinforced door/window frames. The Recipient will promote the use of highway and transportation infrastructure products through establishing working relationship with state and federal highway departments, manufacturers of highway and transportation infrastructure products, and by developing sample infrastructure products, such as prototype guardrails, and guardrail parts. The Recipient shall assess the potential for maximizing the recycled polymer content of computers and electronic equipment.

<u>Description of work performed, accomplishments and results:</u>

Characterization and application of recycled engineering thermoplastics referred to as electronic shredder residue (ESR), which is retrieved from discarded computers, monitors and printers are described in this paper. Mechanical characterization of virgin, blend of virgin and recycled, and 100% recycled polymers such as acrylonitrile butadiene styrene (ABS) and Polycarbonate (PC) conditioned under a harsh environment is carried out as a part of this research. Tension, bending, compression, impact, hardness and creep properties of the virgin, blend and recycled polymers are evaluated in this research. It was found that recycled polymers retain at least 70% of their tensile, bending and compressive strength after aging (conditioning) under harsh environment. Based on our test results it is concluded that recycled polymers have significant potential for high-volume infrastructure and automotive applications.

In this research, offset blocks for highway and bridge guardrail systems were developed using recycled polymers reinforced with glass fabric as shell and discarded tire strips/wood as core materials. Optimum compression molding process parameters for typical manufacturing core block modules (12.5” ´ 4.5” ´ 2”) were 20 minutes of preheating followed by 15 tons of load application at 450° F for about 15 minutes, however, prototype offset block were preheated for about 30 minutes at 450° F followed by applying 30 tons of load for about 30 minutes at the same temperature. These blocks were successfully manufactured and installed near the Star city bridge, Morgantown, WV in 2004 and found to be in excellent shape after 8 months of installation based on visual inspection.

In order to evaluate mechanical properties of recycled polymers (ABS) used to manufacture offset blocks, coupon specimens were manufactured conforming to ASTM standards, with and without glass fabrics and tested in compression, tension, bending, and impact. A limited comparison was made with vinyl ester (thermoset) specimens with and without glass fabric and with specimens cut from a field-installed wooden offset block. Impact strength of the recycled polymers suitable for automobile applications was studied with and without glass fibers. Use of chopped fibers reduced its impact resistance whereas use of continuous fabric increased the impact resistance of pure ABS whereas use of continuous fibers increased the impact resistance of pure ABS. ABS specimens with continuous fabric (bi-directional fibers) showed higher impact strength than the specimens cut from a field installed wooden offset block.

To evaluate heat propagation in thermoplastics (ABS) during processing, a sliced section of a guardrail-offset block manufactured at CFC-WVU was tested for its heat conduction properties using infrared thermography. A finite element model was created to represent the manufactured specimen and analyzed under the effect of thermal loading. Results from FEM and thermography support the amount of time used to manufacture offset blocks. Additional composite products like angle plates and dowel bars were manufactured using recycled ABS and their properties were evaluated under 3-point bending test. Optimum process temperature and pressure were suggested for laboratory manufacture. Use of recycled polymer resins (thermoplastic ABS) for manufacturing structural/non-structural composite products and their mechanical property evaluation indicate significant potential for wide range of applications. Finally, recommendations based on this research and suggestions for future research have been provided.

Additional information about the work done under Task 2.4 can be found in Appendix J.

Task 2.5 Project Master Plan: Site Selection, Financial Plan, Construction and Training Programs (PAZ)

The Recipient shall develop a 5-year implementation of a master plan for the industrial site/park; 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 that was started in Phase I; and, assess transportation options for shipment and receipt of materials for the industrial park.

The Recipient will continue to develop financial plans for short and long-term funding, to assure long-term sustainability of the recycling center as discussed in Task 1.5; continue validation of the economic viability of locating end-of-life electronics recycling companies, as well as other related businesses in the local region as outlined in Task 1.5, and, follow-up with the federal agencies that attended the federal policy conference to continue the open dialogue and lead to a plan on how to recycle EOL electronics.

The Recipient will develop curricula and training programs that are needed in the electronics reuse/recycling industry.

Description of work performed, accomplishments and results:

PAZ purchased a one-fifty-six acre tract of land that had an existing 315,500 square foot building and is currently developing the tract into a state-of-the- art industrial park aptly named the Polymer Technology Park (PTP). The PTP will be the home of the Mid-Atlantic Recycling Center for End-of-life Electronics (MARCEE Project). The site will house a cluster of facilities that are dedicated to recycling, re-engineering and remanufacturing projects from end-of-life electronics. The brick and mortar portion of the project will not utilize any DOE or EPA funds. It will be entirely financed by lease income from the existing 313,500 square foot building as well as other public ($4.3 million grant from the State of WV for purchase) and private financial sources.

The long term financial success of the Polymer Technology Park and the "MARCEE Project" will be accomplished by the Polymer Alliance Zone's continued reinvestment of its' lease income (approximately $600,000 per year) from the existing 315,500 square foot building and by matching the public sectors financing programs with private sectors entrepreneurial capabilities and industry's technology. This financing will upgrade the existing facility as well as build out the infrastructure in the PTP. Once this is accomplished PAZ will step out of the project and will only be involved as requested.

The second part of Task 2.5 is as follows: the Recipient will develop curricula and training programs that are needed in the electronics reuse/recycling industry.

Description of work performed, accomplishments and results:

The Polymer Alliance Zone Pre-employment Training Recycle Work Force Development named PAZ-PET was a partnership between the Polymer Alliance Zone, its industry members, the West Virginia Development Office (WVDO) and West Virginia University Parkersburg (WVU Parkersburg). Final statistics are in Appendix K.

The PAZ- PET is a consortium of Polymer Zone member companies, educational providers, PAZ and the WV Development Office whose mission was to train and establish a readily available pool of workers for the companies in the Polymer Alliance Zone counties of Wood, Jackson, and Mason in West Virginia.

The PAZ-PET was organized in October of 1999 and developed a curriculum that delivered training to prospective employees of the member companies. The training was delivered by industry trainers who were experienced Polymer company employees. The training offered was based on projected hiring in the member companies. Three classes were trained with 42 graduates and 13 of the graduates were hired.

The design of the program allowed the prospective employee to see and tour the work sites of the member companies. The training was high quality and provided the employers with a first hand look at potential employees while they are in the training environment.

In order to serve the needs of the PAZ this project was designed to expand the scope of the PAZ-PET to include the potential training of a workforce to support the anticipated de-manufacturing and recycle of end-of-life electronic equipment. This was an innovative application of polymer firm production and required an innovative design of curriculum; instead of "ready made" curriculum harvested from the training resources of member companies the recycle training program. The PAZ-PET/R required development of new materials and associated with support jobs that are not wide spread in the industry.

The PAZ-PET coordinators had expertise in development of the materials, and in the innovative delivery of the new designed curriculum. The project used current administrative structure, e.g. the PAZ-PET coordinator was the administrative coordinator and the WVU Parkersburg as the management service and fiscal agent. WVU Parkersburg had the resources to provide the needed expertise in training materials by drawing on current Polymer Industry knowledge, the training expertise of Business Industry and Development Services (BIDS) , and the vast store of knowledge in the marketplace.

PAZ-PET/R utilized a leadership team that was in place as the PAZ-PET using the expertise of the stakeholders as available and to develop additional expertise through research and development.

As a result of this effort, the PAZ-PET, the PAZ-PET/R, the PAZ, the "Recycle" Project, WVU Parkersburg improved the capacities for workforce development initiatives.

Project Priorities (goals, objectives, strategies)

Curriculums were developed for the projected jobs in the developing polymer EOL Electronics de-manufacturing and recycle industry. The project identified the job titles, duties, competencies and the level of need for training in the project geographic area. (Wood, Jackson, Mason counties in West Virginia)

Once the jobs were identified, teams worked to develop the task lists, job descriptions, and competencies required for the industry. Additional teams were designed to revise, and refine the curriculum for the jobs.

Regular leadership team meetings, that include status updates and progress reporting, were held to evaluate the project performance and direct the effort.

Coordination with Other Partners

WVU Parkersburg hired a PAZ-PET coordinator that partnered with key stakeholders in the PAZ and the Recycle project team to achieve the project objectives. Members of the PAZ-PET project management team attended various meetings of the larger project and had a working knowledge of the larger project and the contribution the job descriptions and the training curriculum of the total project.

WVU Parkersburg primary staff member for this project was David P. Bell, PH.D., Dean of BIDS. Members of the faculty and others were added as the project developed to fulfill the needs identified.

Evaluation Plan

Monthly progress reports to the PAZ-PET consortium were matched to the project and timeline. This ensured regular achievement of milestones throughout the project. A final report detailing the project measures of success and outcomes was developed at the conclusion of the effort. The following outcomes were achieved.

- Task lists, job descriptions and competencies for up to ten jobs needed in the polymer recycle industry.
- A selection process to select potential candidates for the training
- Curriculum supporting the workforce training needs for the polymer recycle jobs.
- Trainers and participants in a pilot training session
- Ongoing installed structure for the training of potential workers in the polymer recycle industry.

Task 2.6 Maintenance of Websites and Portals Developed in Phase I: Continue to Modify and Update the Portals and Relevant Information on Websites Developed in Phase I of the Effort (DN American)

Manage and support the transition of the existing web-based data system to enhance the existing host Internet services, build out marketplaces and business development, and continue to develop trading and e-commerce support tools.

<u>Description of work performed, accomplishments and results:</u>

Maintenance of Websites and Portals Developed in Phase I

<u>Executive Summary</u>

D.N. American has been working with the Polymer Alliance Zone (PAZ) in developing a Information Technology Architecture to support the emerging Electronics Recycling Industry. This architecture is a rapidly expanding model which builds upon several different industry related inputs and provides a feedback loop to include all industry related players such as Original Equipment Manufacturer's (OEM's), recyclers, manufacturers, injection molders, smelters, academia, etc.

In support of D.N. American's effort to assist the PAZ, an effort was put forth to bring to the table the best of breed technologies and industry partners to help solidify the Information Architecture and make sure it reflected the current and future state-of-the-industry approaches. In order to do this D.N. American has worked closely with SAIC and MAPA Ventures. In order to develop a strong e-services capability within the Information Technology Architecture, SAIC was identified as having a strong presence in the area of Environmental e-commerce, with a software platform called GreenOnline[1].

SAIC was utilizing the GreenOnline technology as an Internet based trading network for the rapidly growing field of e-commerce in the environmental domain. The GreenOnline system provided SAIC with the capability to offer customized transactions and web services for business-to-business environmental commerce in both the U.S. and internationally. SAIC then decided through an internal shift in management philosophy to find where their technologies could make the most impact in a market and either sell or donate their software platforms. Since the MARCEE project was already involved in discussions with SAIC on to how to integrate their software suite of tools for the electronics recycling industry, a donation of those software tools was made to PAZ for use in the MARCEE project. D.N. American has since transitioned all of those tools over to the MARCEE project and has enhanced the original GreenOnline tools to become a Digital Services Platform for projects trying to solve tough problems like handling end-of-life electronics.

In order to make sure that the Information Technology Architecture plan could provide support for the emerging electronics recycling industry in the United States. Emphasis was placed on looking at international programs that were already involved with recycling electronic components. In order to make sure we had insight into those electronics recycling initiatives, D.N. American has worked closely with the PAZ and a consulting organization called MAPA Ventures. MAPA works in many environmental areas dealing with things like

[1] For additional information refer to http://www.greenonline.com.

eco-redesign, renewable energy, and electronics recycling efforts both here in the U.S. and internationally.

Information Technology Architecture

Since the electronics recycling industry is an emerging industry the integration of technology early in the growth process of this industry will help support the initiatives to keep this process as cost effective as possible. The sharing of information, access to research and development results, interaction of industry partners, and government / private sector relationships are vital to the success of this industry. The Information Technology Architecture that D.N. American has developed takes into account how dynamic this industry is and how players come and go as funding opportunities exist. Therefore, the overall architecture for the information technology support of this industry follows a software development paradigm that includes a three-tiered approach. The first tier focuses on Internet technologies and how information can flow between industry stakeholders to provide a more comprehensive resource for information relating to electronics recycling. The second tier focuses on Intranet technologies and how software tools can enable specific industry partners to collaborate on projects and share ideas among team members but not be part of the public Internet presence. The third tier focuses primarily on an area referred to as the Extranet. These are tools and technologies that provide business potential or marketing opportunities to industry members.

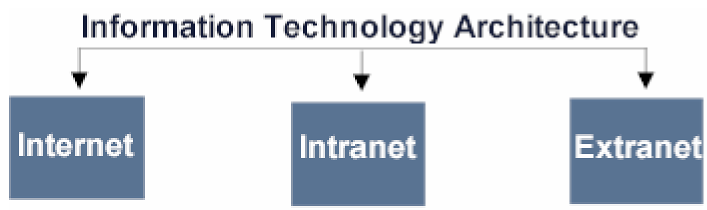

Figure 20 – The Information Architecture is the foundation for the electronics recycling industry support.

By following this Information Technology Architecture, D.N. American can demonstrate how technology can greatly impact activities that take place in all areas of the electronics recycling industry. As part of the MARCEE project D.N. American has spent a great deal of time researching and talking to industry partners as to how technology could impact their day-to-day operations. During Phase II of this project D.N. American has been able to show core competencies in several areas of this Information Architecture and have provided support on a demonstration or pilot project level in order to show industry partners how an emerging industry can utilize technology in order to pull together a very fragmented industry segment. The following section will outline our activities in each of these areas and discuss the success that each area has been able to achieve during this research and development effort.

Research and Development Results

Tier One – Internet Focus

In order to get a better handle on the types of information that exist in the electronics recycling domain area, D.N. American embarked on an extensive research effort in order to identify information resources relating to this industry segment. However, information was very scattered and there was no central repository for items like ongoing research efforts, pilot projects, business opportunities, etc. So the area of focus for this first tier was to demonstrate and provide information technology solutions to help provide a coordinated sharing of information between government agencies, Original Equipment Manufacturers, and the recycling industry. This would provide multiple benefits to the industry and also provide a platform for public awareness to the problems with disposing of end-of-life electronics. Out of this effort was the creation of the electronics recycling web portal.[2] The web portal was the information resource on the Internet for information relating to electronics recycling. At first the emphasis was placed on Information sharing and the development of a platform for finding information on industry news, related research, federal and state legislation, and industry related events. The second emphasis was placed on providing a vehicle for public awareness and outreach to the consumer markets of electronics equipment. The electronics recycling web portal now has the ability to provide an information medium and public awareness to the problem of disposing end of life electronics. As support of this effort the Electronics Industry Alliance (EIA) has integrated our industry web portal as part of their consumer initiative program.[3] As part of the electronics recycling web portal we also wanted to show support for industry activities like the Stakeholder Dialogues. This is an industry led working group based out of Tuft's University in Boston. All of the Stakeholder Dialogue information has now been integrated into the electronics recycling web portal and provides a common information sharing solution for all industry members that are currently involved with Stakeholder Dialogue sessions. This industry participation has led to exposure with OEM's like Sony Sharp, Panasonic, HP, IBM, etc. The use of the electronics recycling web portal has greatly increased the exposure of the Stakeholder Dialogue meetings. As part of this increased Internet presence, individuals that are not able to attend the scheduled

Figure 21 – The Electronics Recycling web portal information repository site.

Figure 22 – The web site for the Stakeholder Dialogues integrated into the electronics recycling web portal.

[2] The electronics recycling web portal can be accessed through the following URL http://www.electronicsrecycling.org.

[3] The EIA consumer initiative program web site is available at http://www.eiae.org.

meetings can access all meeting information like agendas, meeting minutes, working group sessions, etc. The overall public awareness impact due to the creation of the electronics recycling web portal has been overwhelming. The web portal has been mentioned in several newspaper articles in major media markets like Los Angeles, Chicago, Pittsburgh, and Philadelphia. It has been mentioned on radio talk programs in Chicago and Washington D.C. And currently over 50 Internet sites have links or featured stories on the electronics recycling web portal. Please refer to Appendix L Section 1 for a complete reference list of these resources.

Tier Two – Intranet Focus

In order to successfully demonstrate how information technology tools could impact the activities surrounding electronics recycling, D.N. American has enhanced the GreenOnline platform by adding a Data Management & Reporting capability. Through initial discussions with industry partners, the collection and analysis of industry data was identified as a need not only for government agencies but also for organizations like PAZ who are trying to develop simulations and models as to how the electronics recycling industry may emerge. In order to access some of the most time sensitive data on electronics collection, D.N. American applied their data collection tools to a pilot eCycling project that was administered by the Environmental Protection Agency (EPA). The technology tools allowed a very time consuming data collection process to become web enabled and greatly reduced the time spent in administering the forms and converted a paper process to a fully electronic process. The data collected was then used as inputs in the PAZ simulation and modeling tool. An added feature was that PAZ administered a small recycling grant for 3 major OEM's (Sharp, Sony, and Panasonic) and used this online reporting system as part of the invoicing and reimbursement process. Once again demonstrating how technology support is a critical component to this emerging industry. This was a very successful demonstration project and received tremendous exposure throughout the ranks of EPA and the OEM's.

Figure 23 – GreenOnline Data Collection tools used for data collection for eCycling project.

The GreenOnline Intranet tools are also being deployed for use by the PAZ in an effort to provide information to industry members relating to the MARCEE project. This includes PAZ members, West Virginia University research staff, and potential industry partners like IBM, GE, and others.

Tier Three – Extranet Focus

The third area of the Information Architecture deals primarily with tools that enable industry partners the opportunity to develop new marketplaces or provide a mechanism to impact the supply chain of electronics recycling. In order to do this D.N. American will be relying on some of the features SAIC had built into GreenOnline to handle electronic marketplace development. After numerous discussions with industry stakeholders, one problem that was stated numerous times is the ability to maintain a consistent flow of materials through the supply chain. Processors cannot recycle if they do not have buyers for the material and Buyers will be reluctant to manufacture a product if they cannot be guaranteed a consistent supply of materials. Therefore, GreenOnline is focusing on how technology can be integrated to help enhance these distribution channels. One identified area is in developing tools that will allow processors to become more efficient at finding raw materials for processing. Efforts are underway to develop a platform where processors will be able to identify materials they have for sale as well as materials they need for processing. Some initial PAZ companies have helped provide initial direction for this effort. Also, D.N. American has been identifying how an electronic marketplace may in fact be applicable to the manufactured products market. This would include companies that are currently manufacturing products out of recycled plastics. Again, the GreenOnline platform will be the technology vehicle through which these efforts will take place. Additionally, research is underway to determine how GreenOnline can become the infrastructure for a Virtual Research & Development platform which will provide a mechanism for increased information sharing between industry and academia.

Figure 24 – GreenOnline Digital Services Platform.

D.N. American Task Summaries – (As reported in Monthly Reports)

The following list includes summary information for the tasks included in D.N. American's monthly reports.

Task 1 – Transition GreenOnline

D.N. American worked closely with SAIC in transitioning GreenOnline technology over to the Polymer Alliance Zone for use in the MARCEE project. D.N. American analyzed source code and developed a transition plan for migrating source code and databases over to D.N. American hosted servers. Domain name registrations were transferred and DNS server entries were updated. Acquired needed software licenses and performed initial system tests on the software platform. Transition of GreenOnline is complete.

Task 2 – GreenOnline Technology Revamp

In order to migrate this technology over to the electronics recycling industry some system updates and a revamp of the user interface was needed. D.N. American has successfully migrated this technology over to the Microsoft .NET framework and is moving away from the older COM technologies. D.N. American also worked with Dimension Data in designing a new user interface and a limited demonstration capability of the software platform. Revamp of the GreenOnline technology is now complete.

Task 3 – Support and development of Electronicsrecycling.com

This task has primarily focused on parts of the electronics recycling web portal that deals with overall system architecture. D.N. American has solidified the presence of the electronics recycling domain name by registering the .com, .net, .org, .biz, and .info domain names. This allows the MARCEE project to fully take advantage of the electronics recycling domain name. Also, D.N. American continues to provide web hosting, network connectivity, and system administration support for the electronics recycling web portal.

Task 4 – Support and Development of ElectronicsRecycling.net web portal

D.N. American has positioned the web portal to become the industry resource on information relating to electronics recycling. Industry alliances were formed to share information with organizations such as EPA, EIA, PAZ, and the Stakeholder Dialogues. D.N. American maintains all content on the web portal and monitors all web activity by compiling web statistics. D.N. American continues to provide web hosting, network connectivity, and system administration support for the web portal.

Task 5 – eCommerce Support / PAZ Marketplace / XML Technologies

D.N. American has research and developed several technologies that can share information between industry partners. One area that D.N. American has stressed is the use of XML for data transformation between industry partners. D.N. American researched several options and possible solutions to XML integration and has starting adopting the Microsoft .NET framework for XML usage. This integration is being implemented throughout the GreenOnline platform and will be evident as part of future demonstration marketplaces. D.N. American identified potential areas of supply chain integration and developed a plan to create two demonstration marketplaces.

Task 6 – Develop specific electronic trading platforms through GreenOnline

Once GreenOnline was transitioned from SAIC, D.N. American started analyzing the various feature sets and how they could be applied to electronics recycling. As part of this process a information architecture was developed and GreenOnline has transitioned from a set of trading engines to an entire digital services platform capable of supporting various environmental related projects or activities. This adaptation is now being utilized to support multiple stakeholders like the electronics recycling web portal, Polymer Alliance Zone web site, and Stakeholder Dialogues site. Additional targets include a potential virtual research and development platform and a eco-redesign platform.

Summary of Task Objectives

As a result of the 6 tasks listed above D.N. American has developed a summary of the objectives accomplished during this time period.

- Created public awareness and exposure to the problem of disposing of end-of-life electronics through the electronics recycling web portal. Refer to Appendix A for a more detailed list.

- Industry coordination and database collaboration with EIA and their Consumer Initiative program.
- Demonstration data collection and management capabilities in conjunction with the EPA eCycling pilot project.
- Demonstration of industry data analysis support through coordination with EPA data, US Census Data, and PAZ simulation data.
- Demonstration of Plastic Regrind Matrix / Characterization Matrix while working in conjunction with the Stakeholder Dialogue working committee.
- Demonstration of cross industry information coordination based on integration of GreenOnline with electronicsrecycling.org.
- Industry participation on information technology needs with industry stakeholders through the Polymer Alliance Zone.
- Industry participation at electronics recycling related events like IEEE and EPR2 conferences.

Information Web Portal Statistics

As part of the web hosting process for the electronics recycling web portal D.N. American compiles monthly site traffic and statistics for the electronicsrecycling.org domain. The reports fall into 4 categories: (See Appendix E Section 2 for a sample report format)

1. **Domain Report –** This report shows all web requests and breaks down traffic by domain as well as by location. During the time period ending December 2002 the electronics recycling web portal was averaging about 119,000 requests per month.
2. **Quick Summary Report –** This report allows for monitoring of information like Most active day of the week, Most common web browser, Most requested search word, etc.
3. **Organization Report –** This report shows the most common Internet Service Providers (ISP) as related to amount of traffic visiting the web site. To date Google and AOL generate the most traffic requests.
4. **Search Query Report –** This report identifies the most common search words used to access the web portal from search engines.

Future Research for Information Technology Support

As stated earlier the Information Technology Architecture to support the electronics recycling industry is a very dynamic and ever-changing model. Therefore, in order to continue to provide support to the emerging electronics recycling industry there are additional areas that need to be addressed. The first is the continuation of the content management for the electronics recycling web portal. In order for this to maintain its position as the industry leading resource on recycling of end-of-life-electronics, the information needs to stay current. The second is the development of a Best Practices / Lessons Learned electronic repository that will contain information on electronics recycling efforts both here in the U.S. and internationally. This will provide a very dynamic information rich repository of information collected from various industry stakeholders, academia, and research / development. This repository will utilize the GreenOnline platform and become an industry focal point for Best Practices. Additionally, research efforts need to continue to develop an XML representation of the Material Characterization Matrix and work with industry partners in integrating this matrix into the overall supply chain. Additional work will also focus on integration of technology tools into manufacturing environments that concentrate on plastics recycling.

Key Technology Assets and Benefits

This section outlines all of the key technology assets as related to the MARCEE project and their benefit that they have brought to the project.

Table 15: Internet Technologies – Domain Name Recognition

ASSET:	BENEFIT:
❑ www.ElectronicsRecycling.org ❑ www.ElectronicsRecycling.com ❑ www.ElectronicsRecycling.net	Widespread industry recognition through the use of intuitive domain names.
❑ www.GreenOnline.com	Established marketing and name recognition through SAIC donation.

Table 16: Internet Technologies – Information Exchanges

ASSET:	BENEFIT:
❑ Dynamic Content Framework	Rapid creation of Information rich industry platform that provides guidance to key players to promote current industry issues and efforts. Utilized in an e-waste information portal and solution center.
❑ Content Administration	Ability to manage and maintain extensive and elaborate information repositories.
❑ Statistics	Offers real-time tracking & monitoring statistics of site content and user activity

Table 17: Electronic Data Collection & Management

ASSET:	BENEFIT:
❑ Web-based data collection system	Demonstration of data collection capabilities in support of EPA eCycling Region III pilot project.
❑ Innovative real-time reporting solution	Provides users with rich, real-time reporting solution to aid in data analysis and information dissemination.
❑ Data Management Tools	Controls and monitors data access, protects integrity of collected data, and provides means of data manipulation and administration.

Table 18: E-Commerce & Electronic Marketplaces

ASSET:	BENEFIT:
❑ Customizable marketplace	Rapid customization and deployment in new markets and communities of interest.
❑ Integrated suite of Internet-based trading engines and communication tools	Provides medium for new business opportunities and offers up professional services and customized modular tools to expedite business partner identification, deal negotiation and closure in individual markets.
❑ Industry Exchange platform	Innovative platform that will support remote users and enhance industry communication and collaboration.

Table 19: Data Warehousing & Business Intelligence

ASSET:	BENEFIT:
❑ Business Intelligence Tools	Help quickly and efficiently make use of substantial amounts of collected data within the electronics recycling and e-waste industry while supplying the overall context for information delivery throughout an organization and beyond.
❑ Data transformation and analysis tools	Transforms large amounts of collected data into valuable business information.
❑ Web-based data mining and manipulation tools and reporting utilities	Brings together information, people, and technology to create successful business strategies and provide accurate, real-time data in order to measure, plan and respond to customer and employee demands.

Task 2.7 Organize and Conduct the National Electronics Stewardship Workshop (PAZ)

The Recipient shall organize and conduct the National Electronics Stewardship Workshop. The purpose of this workshop is to gather state-of-the-art information about the electronics/recycling industry for promoting the efforts of the research, commercialization, and workforce development in the polymer/electronics recycling industry project.

Description of work performed, accomplishments and results:

Please see Appendix M for the conference proceedings.

The Gordon Institute at Tufts University

Investigators: - Patty Dillon, Gordon Institute at Tufts

Meeting Overview

The 7th in the series of Stakeholder Dialogues on Recycling Engineering Thermoplastics from Used Electronic Equipment was held on June 14, 2001 at Tufts University in Medford, Massachusetts. Thirty-six participants attended the meeting, including original equipment manufacturers, plastics processors, recyclers, industry trade organizations, government officials and other experts (see Appendix F Section 1).

The agenda for the June 14^{th} Dialogue focused on several topics, including:

- markets for mixed plastic resins;
- activities of industry standards organizations (Underwriters Laboratory and Institute for Scrap Recycling Industries);
- characterization and testing of recovered resins;
- Stakeholder Dialogue Task Force activities; and
- future directions for the Stakeholder Dialogue project.

The complete agenda is provided as Appendix F Section 2. Below is a summary of the presentations and discussions**.** Presentations that were made available in electronic format can be viewed on our web site at www.electronicsrecycling.net/stakeholder.

Evaluating the Dialogue Process

As the Stakeholder Dialogue project completed its second year, participants at the June Stakeholder Dialogue were asked to reflect on the value of the Dialogue process to date, and provide suggestions on future directions and projects for the Stakeholder Dialogues. Written evaluation forms completed by participants gave the Stakeholder Dialogue process to date high marks overall (4.23/5.0). The networking opportunities provided by the Dialogues were considered the most important feature of the Dialogue process (4.45/5.0), followed by discussion sessions (4.26/5.0) and formal presentations (4.05/5.0).

As for future activities of the Dialogue project, participants ranked demonstration projects as the top priority, followed closely by additional meetings (with formal presentations and network opportunities) and data collection and analysis. Specific suggestions for future activities of the Dialogue process are discussed below.

Presentations (by Topic)

Market Development

- **Charles Beatty** of the **University of Florida** presented his research on compatabilization of co-mingled plastics, which uses a reactive extrusion process to create a polymer composite with consistent mechanical properties (such as impact strength).
- **Terry Crouthamel** of **Paving Technologies** introduced a promising new technology, Plasphalt™ that can utilize mixed plastic resins from used electronics. Plasphalt™ is a hot mix asphalt concrete containing 1-2 % (by weight) Treated Recycled Plastic Aggregate (TRPA). TRPA is composed of ground, unsorted recovered thermoplastics (most resin types) treated with a proprietary process that improves the bond strength of the plastic. When mixed with liquid asphalt, TRPA forms a chemical bond that encapsulates the aggregate fraction of the asphalt concrete, creating a flexible matrix. In laboratory and field tests, Plasphalt demonstrates improved structural performance (e.g., rut resistance) and yields per ton compared to standard asphalt pavement.

Material Characterization and Development

- **Rob Lang** of **RC Plastics**, a supplier of recycled-content resins, discussed material sourcing, testing and quality assurance procedures at his company. Material testing occurs throughout the purchasing and processing sequence to ensure the quality of the finished product. RC Plastics requires a material sample for "fingerprinting" prior to purchase. Each gaylord of purchased materials is also tested prior to acceptance of the lot to ensure that the material properties match the sample. Tests include, for example, tensile strength, elongation, IZOD impact and differential scanning calorimeter to detect the presence of other resin species.
- **Chris Ryan,** Metech International**, Mark Corbett,** Pitney Bowes, and **Robert Malloy**, UMass Lowell presented and led a discussion on the draft EETP Recycled Material Characterization Matrix, the preliminary work product of the Material Characterization and Development Task Force of the Stakeholder Dialogue project. The Matrix defines a range of quality grades (from loose, unsorted plastic to compounded & pelletized single resin product) and material specifications for plastics from used electronics. It is intended to facilitate the purchase and sale of recovered electronic engineering thermoplastics (EETPs) by creating a common "language" for transactions within the industry. A summary of the Matrix discussion is below.

Activities of Industry Standards Associations

- **Scott Horne** from the **Institute for Scrap Recycling Industries (ISRI)** discussed the organization's scrap specifications and Design for Recycling efforts. ISRI scrap specifications, which are widely recognized as industry standards, are designed to promote consistent, quality feedstreams for scrap-consuming manufacturers. The specifications provide information on the preparation and transportation of scrap materials, but are flexible enough to allow for variation in consumers' production technologies and negotiation on a transactional basis.
- **Stephen Giannoni** of **Underwriters Laboratory (UL)** provided an overview of UL's testing and certification programs for products and materials (such as plastics) used in the manufacture of end products. UL's current test program for recycled thermoplastics (UL 746D) requires a complete series of flammability, mechanical, electrical, thermal distortion under load, thermal endurance (aging), resistance to ignition, and dimensional-change tests be conducted on samples from a minimum of 3-5 production batches (depending on whether the material origin is traceable) to determine whether variations between production batches significantly affect critical material properties. Recognizing that these testing requirements are more rigorous than the test program for virgin materials, UL recently established a committee, the Reuse Material Ad Hoc Group, to develop a new standard for recycled-content materials.

Stakeholder Briefings

- **Chris Beling, USEPA**, provided an update on EPA's activities on electronics recycling. She sees EPA taking more active leadership role on the issue, and states willingness to work together to develop multi-stakeholder solutions. Chris went on to discuss several of EPA's activities, including the National Electronic Product Stewardship Initiative (NEPSI), a multi-state pilot electronics recycling program in Region 3, proposed Design for Environment initiatives targeting lead-free solder and brominated flame retardants, and the Memorandum of Understanding recently signed by five federal Agencies to improve the management of government-owned electronic equipment.
- **Peter Muscanelli** of the **International Association of Electronics Recyclers (IAER)** summarized the recommendations of the recent IAER Roadmap Development workshop, held in April 2001. The group recommended that IAER continue to work with and support the efforts of the Stakeholder Dialogue project.
- **Patricia Dillon, The Gordon Institute at Tufts University**, summarized the work of the three Stakeholder Dialogue Task Forces, and their progress to date.

Discussion Sessions

Participants at the June Stakeholder Dialogue took part in two plenary discussion sessions: 1) the proposed use and content of the EETP Recycled Material Characterization Matrix, a work product of the Material Characterization and Development Task Force; and 2) future directions and projects of the Stakeholder Dialogue process. Each of these discussions is summarized below.

1) EETP Recycled Material Characterization Matrix

In general, Stakeholder Dialogue participants were impressed with the structure and content of the EETP Recycled Material Characterization Matrix, and agreed that it will be a valuable tool for the industry. It will help buyers and sellers communicate, and will help improve the overall quality and consistency of recovered materials.

Participants discussed how the Matrix would be used and which quality parameters should be included in the Matrix. The group agreed to create an expanded "expert" working group, made up of potential users of the Matrix (e.g., generators, plastics processors, and end users of engineering thermoplastics), to assist the Matrix development team (Chris Ryan, Mark Corbett, Bob Malloy) in further refining the Matrix and validating proposed values and definitions. This group will also assist the development team in moving the Matrix from the development phase into commerce. These discussion points are captured below.

Goal/Use of Matrix

- Need to decide whether the goal is to create guidelines or specifications, as this will shape the structure and type of details in the final product.
- Consider adding a "decision tree" to guide processors in deciding whether to upgrade material

Scoping Issues

- Resin types
  - Include largest volume resins found in electronics
  - Include FR grades (Note: ASTM Standard on flame retardants is available)
- Color is important. The group reached consensus on the following categories for color:
  - Clear
  - White
  - Light Mixed
  - Dark Mixed
  - Mixed Colors
  - Tinted
- Specify contaminants, which may vary by category/resin type
- Should allow users the flexibility to specify additional or higher quality material characteristics (e.g., contaminants)
- Add applicable test protocols
- e.g., what procedures to use to determine material quality
- Definitions: link to ASTM standard for plastic abbreviations
- Should the matrix be limited to electronics or any sources of ETP resins? The group recognized that broader inclusion would complicate the Matrix, but might be more relevant to the real world of buying, selling and processing ETP resins.

Steps to Creating an ISRI specification

- Bring together good cross-section of supply chain & other experts
- Can decide on level of detail wanted
- Can be an iterative process

Participants Volunteering to be a Resource in Further Matrix Development

- Rob Lang, RC Plastic
- Scott Horne, ISRI
- Ron Roberto, RST
- Other possible organizations to include: IBM, GE Plastics, Aurora Plastics, MBA Polymers

2) Proposed Future Directions & Projects for the Stakeholder Dialogues

The following ideas were suggested by the participants of the June 14th Stakeholder Dialogue in a discussion session focused on "what types of activities or issues should the Stakeholder Dialogue project work on in the next year?" These topics are listed in the order in which they were suggested. No attempt was made to prioritize ideas.

- EETP Recycled Material Characterization Matrix
  - Create subcommittee to further develop Matrix, working towards industry guidelines
- Plastics Generation Survey
  - Evaluate results to determine need for and potential demonstration project
- Catalogue Related Projects to Avoid Duplication of Effort (E.g., DOE, DOD)
- Assist in Defining “Green Computers” for Plastics
  - Much interest in issue, e.g., emerging government procurement efforts such as the MOU
- Revisit Initial Brainstorm List (generated at December 1999 Stakeholder Dialogue)
- Collaborate with Underwriters Laboratory on Revisions to UL Testing Specifications for Recycled Content (such changes would help stimulate new market development efforts by the industry)
  - P. Dillon to contact UL to discuss how Stakeholder Dialogue process can contribute to UL committee work
  - Several attendees of the 6/14 Dialogue volunteered to explore further potential UL collaboration and next steps: Mark Corbett, Pitney Bowes; Tony Hainault, Mn; and Scott Horne, ISRI
- Design for Recycling in collaboration with ISRI, and possibly, the National Electronic Product Stewardship Initiative (NEPSI)
  - Also explore potential linkages with other efforts, including NEPSI, EPA’s Environmentally Preferable Purchasing (EPP) and Design for Environment (DfE) programs and DEER2

In addition to the discussion session, participants were asked to provide feedback on future directions for the Stakeholder project via a written evaluation form. Participants ranked demonstration projects as the top priority for the Stakeholder project, followed closely by additional meetings (with formal presentations and network opportunities) and data collection and analysis. Industry collaborative projects and information dissemination were considered lower priorities. Participants also had the opportunity to make recommendations on specific projects or issues that the Stakeholder Dialogues should address. The following compilation of ideas was extracted directly from evaluation forms and no attempt was made at prioritization.

- Develop case studies/success stories, particularly commercial successes.
- Showcase/demonstrate market-based efforts in closed loop recycling of post-consumer engineering plastics.
- Research what is going on in Europe and Asia to find out if there are other approaches to recycling [plastics from] electronics.
- Provide design considerations for product designers.
- Identify issues in the reuse of resins (e.g., standards such as UL).
- Continue efforts to develop regional resin processing model as means to lower costs.

- Identify applications for recycled materials and additional sources of recyclable materials.
- Develop computer model of resin degradation through continued use of regrind (e.g., more detail on model presented by UL).
- Overcoming barriers to recycling – regulatory, social, technical and political—both external and internal to the stakeholders.
- Compatabilization of mixed resins.

Future Directions

Stakeholder Dialogues for Recycling Engineering Thermoplastics from Used Electronic Equipment

The Gordon Institute at Tufts University will continue the Stakeholder Dialogues for Recycling Engineering Thermoplastics from Used Electronic Equipment. The Stakeholder Dialogues bring together the plastics supply chain to develop collaborative industry solutions to overcome challenges in the development of the recycling infrastructure and markets for engineering thermoplastics from used electronics. Over 70 organizations representing resin suppliers, original equipment manufacturers, electronics recyclers, plastics processors, government officials and alternative end markets participate in the Dialogue process. The Stakeholder Dialogues are a vital conduit of information, an incubator of ideas, and a forum for the development of industry data and standards for use by the MARCEE project. The work products of the Stakeholder Dialogues, as detailed below, focus mostly on developing markets for recycled plastics.

The Gordon Institute at Tufts University's primary tasks will be:

Task 1 Convene Stakeholder Dialogue Meetings

The Stakeholder Dialogue meetings combine information exchange and networking among participants with the presentation and development of Stakeholder Dialogue work products as discussed further below. We expect to convene two Stakeholder Dialogue meetings. Summaries of the meetings, including copies of presentations, will be made available on the PAZ-sponsored website, Electronicsrecycling.net.

Task 2 EETP Recycled Material Guidelines

The Stakeholder Dialogue project developed the EETP Recycled Material Guidelines that defines a common language, quality grades, specifications and testing procedures for recovered engineering thermoplastics from disassembled electronics to compounded resin product. In this task, the Dialogue project will work to integrate the Guidelines into industry practice and commerce via three mechanisms: 1) adoption of the guidelines by the Institute for Scrap Recycling Industries (ISRI), the dominant international standards organization for the scrap recycling industry; 2) utilization of the guidelines as the framework for e-commerce transactions in the GreenOnline marketplace; and 3) promote the use of the Guidelines through appropriate mechanisms (e.g., IAER) and publicity.

Task 3 Generator Survey

In order to develop markets for recovered engineering thermoplastics, the Stakeholder Dialogue project identified the need to better understand the current supply of plastics resins from used electronics (e.g., volume, resin types, condition, location, current disposition), and the processing capabilities of suppliers to identify any "gaps" in the supply stream. For this task, the Stakeholder project will conduct a survey of electronics recyclers and original equipment manufacturers to characterize the supply of recovered engineering thermoplastics, and processing capabilities of suppliers. The survey will be conducted on-line via the PAZ-sponsored web site Electronicsrecycling.net.

Task 4 Matrix of Applications for Recovered Engineering Thermoplastics Resins

This compilation of known and promising applications for recovered engineering thermoplastics will compliment the plastics generation survey and will be used to identify "gaps" between supply and demand for specific recovered resins. Primary information sources will include Stakeholder Dialogue participants and their supply chain partners, survey participants and various published sources. Data from the generator survey and applications matrix will assist the MARCEE project in identifying promising market development opportunities.

Task 5 Identify & Coordinate Demonstration Projects for Recovered Engineering Thermoplastics

The Stakeholder Project will identify "hot" prospects as they emerge from the applications research, introduced PAZ to the technology and its sponsors, and catalyze further commercialization of the technology, where possible, in the Zone. If appropriate, the Stakeholder Dialogue project may decide to pull participant resources together to demonstrate new technologies.

Task 6 Create New Working Group to Develop UL Test Standards

Underwriters Laboratory (UL) has requested the assistance of the Stakeholder Dialogue project in revising its testing protocols for the recognition of recycled resins, and in developing a new certification program for listed or banned plastic additives (e.g., brominated flame retardants, cadmium). Current UL testing protocols were designed for virgin materials and are considered inappropriate for recycled resins, making it difficult and costly for recycled resins to gain UL recognition, even when the resins meet UL performance specifications (e.g., flame rating). UL recognition is often a minimum requirement for material selection in high-end markets, such as electronic products. The development of appropriate testing procedures for recycled resins will help "level the playing field" between virgin and recycled resins, and open up new markets for recycled resins. For this task, we will assemble an expert working group from among Stakeholder participants to work with and advise UL.

Task 7 Manage Overall Project, Participate in Industry Forums & Collaborate with Industry Organizations

Project management duties includes developing project strategies and new directions, keeping mailing lists and website current, communication with current and prospective participants, attending MARCEE project meetings and preparing reports and published papers. The Stakeholder Dialogue project will collaborate with industry organizations and participate in industry events, as needed and advantageous, in order to advance and augment the goals of the Stakeholder Dialogue and MARCEE projects. This includes participation in the National Electronics Product Stewardship Initiative.

Task 2.8 Topical Report (Irwin)

The Recipient shall prepare and submit a draft topical report that covers the efforts under Tasks 2.1 - 2.7 in accordance with the Reporting Requirements Checklist after completion of Phase II. This report shall provide a comprehensive description of the results achieved and shall include tabulations of data, figures, photographs, and other bibliographic citations to support the investigations undertaken. It shall summarize all technical reports where applicable. Within thirty (30) days after submittal, the COR will accept the draft topical report or recommend changes and the Recipient shall revise the topical report and submit the final topical report with 30 days after receipt of review comments. If the Government elects not to continue with the remaining effort, the Topical Report will become the Final Report.

Description of work performed, accomplishments and results:

The Topical Report for Phase II is being submitted as part of the Final Report.

Phase III - Completion of Industrial Information Exchange, Technology Transfer, and Internet Trading Platform Development

Task 3.1 Business Model Development and Industry Participation

The Recipient shall develop the electronics and polymer recycle market and customer database by using the latest computer/Internet technology tools and other standard methods available in the industrial sector.

Description of work performed, accomplishments and results:

The Polymer Alliance Zone in coordination with subcontractor SAIC completed a business plan. The simulation tool information is constantly updated and is used to validate business assumptions. (See Appendix G)

Task 3.1.1 Economic Simulation Tool Development (PAZ)

The Recipient shall expand the baseline simulation (the latest computer/Internet technology tools) tool to include end-of-life electronics (EOLE) beyond computers, i.e., televisions, VCRs, and printers. The model will include the ability to examine the economic realities of recycling glass and metals derived from EOLE. The Recipient shall also develop a stand-alone EOLE collection and transportation simulation tool to differentiate the economic feasibility of various types of EOLE collection systems including household, business users, institutional users, and retail.

Description of work performed, accomplishments and results:

This work was begun in this project and is delineated and interspersed throughout many of the tasks and deliverables that are reported in this report. The actual implementation of a collection and transportation system will be carried out in the new grant.

Task 3.1.2 Industry Participation (PAZ)

The simulation tool developed in Task 2.1 has shown a need for economic assistance in the startup phase of this project. The Recipient will work closely to form an association to facilitate the collection and recycling of EOLE. The Recipient will continue to develop the simulation tool and the internet trading tool (Task 3.6.1) to enhance the usefulness of the industry association.

<u>Description of work performed, accomplishments and results:</u>

The recipient worked closely with virtually all of the major electronics manufacturers and their primary trade association (the Electronic Industries Alliance) under this subtask. Building upon work performed during phases I and II of MARCEE, the recipient worked under the guidance of industry to build and enhance the simulation and modeling tools of the electronics recycling industry. Specific accomplishments included development of tools to project the top-line costs of various regional configurations of a national electronics recycling system, and a projection of unit-level fees potentially required to support a national Advanced Recovery Fee system.

The recipient also provided technical support in conjunction with industry during the National Electronic Product Stewardship Initiative (NEPSI) process.
NEPSI's multi-stakeholder participants worked together to help define an overall plan for a national system, including the management structure for such a system. The NEPSI process included a recommendation for a National Coordinating Entity prior to enactment of any federal legislation on electronics, an industry-led organization intended to facilitate and coordinate the plethora of recycling collection and recycling activities underway around the country.

The primary accomplishment of this task is the creation of a new non-profit organization in Wood County, West Virginia to serve as this national coordinator: the National Center for Electronics Recycling (NCER). The NCER was formed in February 2005 during a conference call with 20 different manufacturers, including the top 3 sellers of televisions, computers and printers in the United States, and was highlighted at EPA's National Meeting on Electronics held March 1-2, 2005. The NCER actively utilizes IT products developed with MARCEE support is a direct result of the work undertaken during Task 3.1.2. The NCER serves as a major milestone in the development of the electronics recycling national infrastructure.

Task 3.2 Process Model Validation and New Product Assessment

Task 3.2.1 Application of Research Results (Turton)

<u>Description of work performed, accomplishments and results:</u>

3.2.1.1 Evaluation of Plastics Separation via Froth Floatation - Best Available Technology

In order to assess the viability of mechanical separation of mixed waste plastics, a froth floatation cell was used to perform a series of experiments on EOL-electronics-derived plastics. To obtain plastic samples suitable for froth floatation, the plastic material was shredded in the high-speed cutting mill, Fritsch cutting mill no. LC-136, shown in Figure 25.

Figure 25: Fritsch cutting mill no. LC-136 used to shred waste EOL Plastic

A froth floatation rig, Figure 26, was used to evaluate the effect of different surfactants on the froth floatation of different plastics with similar densities. The aim of this work was to evaluate the effectiveness, in terms of separation purity and recovery, of the froth floatation unit operation, which is regarded as one of the "best available" separation technologies for plastic streams derived from EOL electronics.

Figure 26: Experimental Rig used in Froth Floatation of EOL Plastic

The level of frother and two ionic surfactants were used as independent variables in an experimental matrix, Table 20 Experimental runs were carried out at 3 different concentration levels of each chemical. Methyl isobutyl carbinol (MIBC) was used as the frother, while oleic acid and n-dodecylamine hydrochloride were used as the two surfactants. It was desired to observe the effect of completely different surfactants on the flotation and separation efficiency. It was decided to observe the effect of oppositely charged surfactant ions on the flotation and separation efficiency of HIPS and ABS. Hence, n-dodecylamine hydrochloride was chosen as the *cationic* surfactant, while oleic acid was representative of the *anionic* surfactant group.

Table 20: Surfactant type and amounts used in the experimental matrix

	Type		
	Anionic	*Neutral*	*Cationic*
Surfactant / Frother	Oleic Acid	MIBC	Dodecylamine hydrochloride
Amount	(0, 10, 20) ml	(1, 3, 5) ml	(0, 2, 4) gm

This matrix is represented in the form of volume of MIBC (in ml), volume of oleic acid (in ml) and weight of amine (in grams) used in each experimental run, viz (MICB, Acid, Amine). Since oleic acid and amine are found to have opposing effects on the floatability of both plastics, only one of them was considered in each experimental run as a surfactant along with MIBC in order to achieve separation with reasonable yield and purity.

3.2.1.2 Results of Froth Floatation Experiments

MIBC Results

Samples of 10 grams of plastic were floated using only MIBC as the frothing agent in different experimental runs, in the absence of any surfactant. The flotation curves for different amounts of MIBC for ABS plastic are shown in Figure 27. It is observed that addition of MIBC decreases the hydrophobicity of the ABS plastic surface, thereby hindering its floatability and reducing the amount of ABS that floats to the surface at any given time. Figure 28 shows the effect of addition of MIBC on the floatability of PS. As can be seen from the graph, addition of 1 ml MIBC increases the floatation of PS, while any further addition has no significant effect.

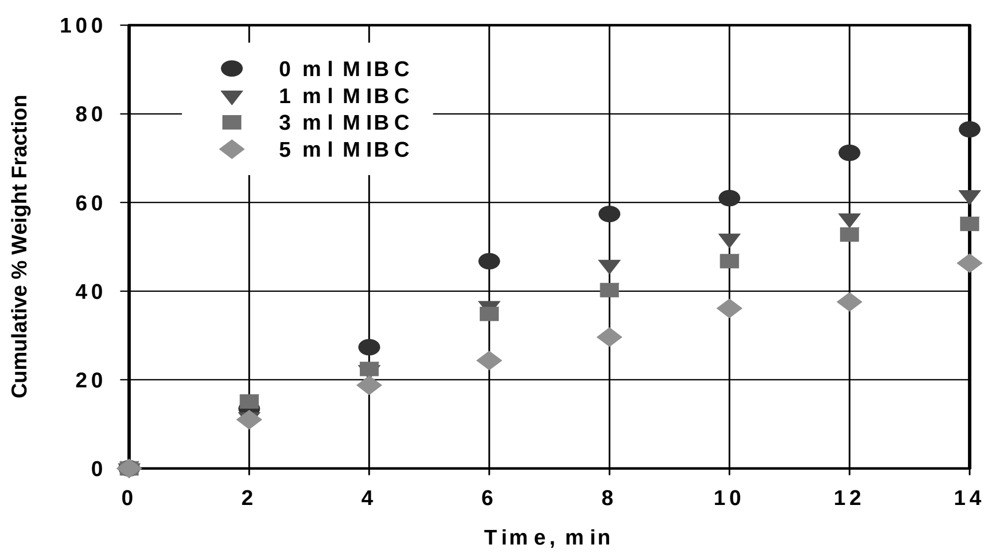

Figure 27 Effect of MIBC on ABS Floatability

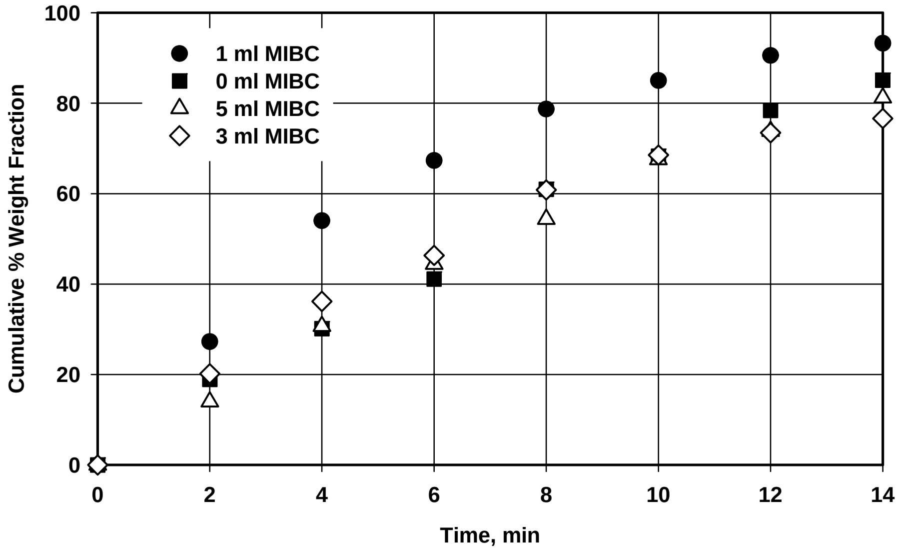

Figure 28 Effect of MIBC on PS Floatability

The yields and purities of ABS and PS was then calculated assuming that flotation behavior observed when both plastics are floated simultaneously would be same as that observed when they were floated separately. In other words, the presence of more solids or presence of another plastic was assumed to have no effect on the floatability behavior of the individual plastic. A set of experiments was performed to observe the effect of inter-particle interactions when both plastics were floated simultaneously and are discussed later.

Figures 29 and 30 show an analysis of the % purity and % yield of PS and ABS obtained as top products at all time intervals respectively. The % yield is calculated as the % of a particular plastic that is obtained as top or bottom product as compared to the original amount of that plastic fed to the column. At any instant, the plastic that remains in the column and does not float to the top along with the froth is considered as the bottom product. Hence, at t = 0, since all the plastic is present in the tank, the yield of the top product is 0% and that of the bottom product is 100%. A comparison of the figures shows that although yields of both PS and ABS increases with time, purity of PS increases while ABS is obtained at lower purities at the top of the column. On the other hand, Figure 31 shows that purity of ABS increases at the bottom of the column with time, albeit at a decreasing yield. A comparison of Figures 29 and 31 shows opposing trends in both yields and purities of PS and ABS, when they are considered as top product and bottom product respectively. It was necessary to perform further analysis by selecting a particular batch time at which both plastics were obtained at reasonable yields and purities. It can be seen that at a batch time of about 6 minutes, both PS and ABS are obtained at yields of about 64% and 62% at the top of the column respectively. Also, for the same batch time, the purities obtained are 62% and 61% for PS and ABS. Hence, a batch time of 6 minutes was arbitrarily chosen as the residence time in each flotation stage to perform a theoretical multi-stage analysis. A 2-stage and 3-stage floatation scheme is designed to calculate the overall yield and purity of PS and ABS. It was assumed that identical separations are achieved in each flotation cell of the multi-stage setup.

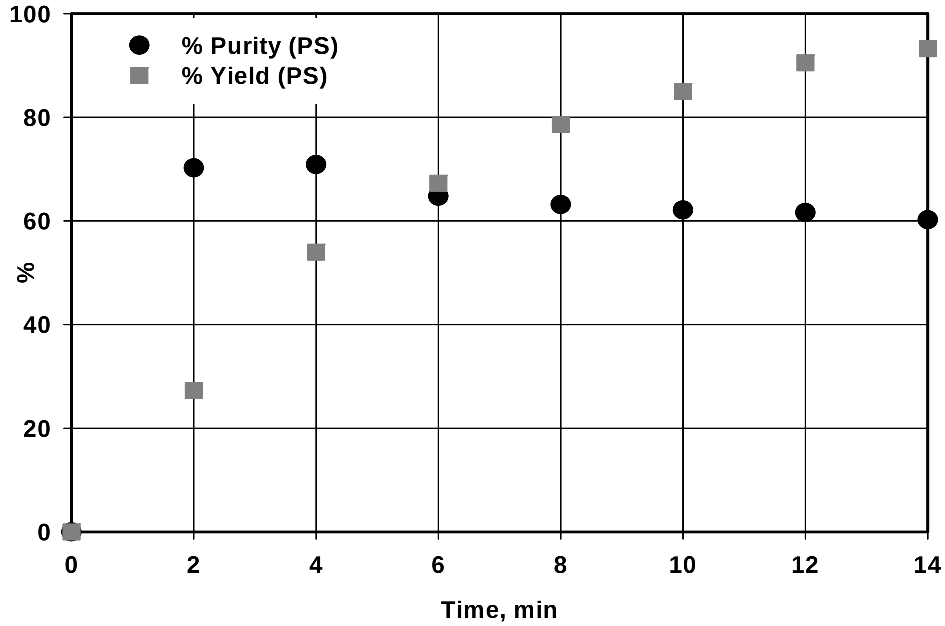

Figure 29: % Yield and % Purity of PS in the top fraction when using 1 ml MIBC

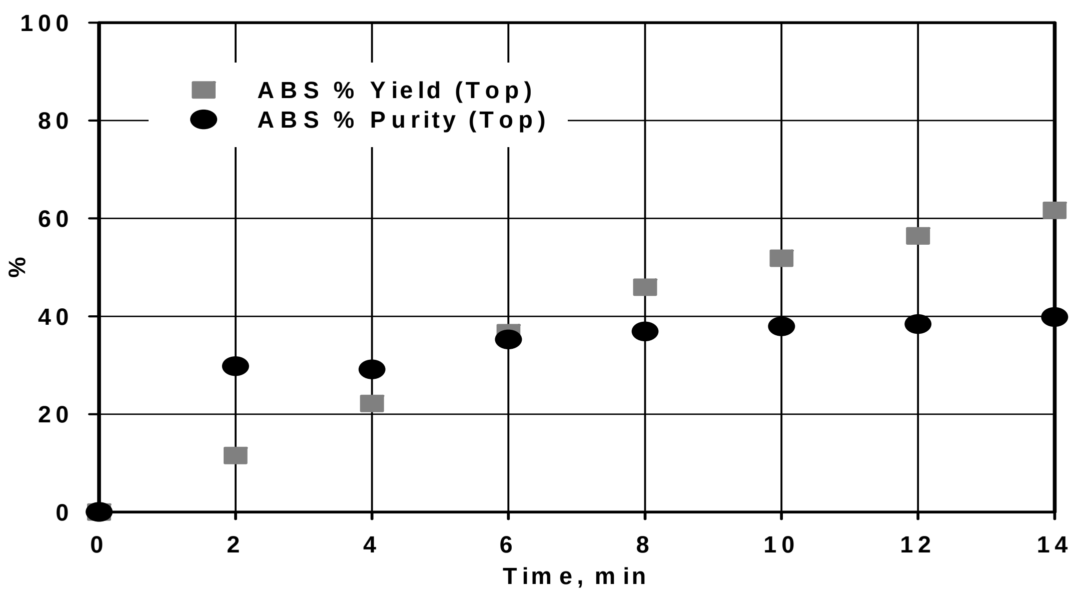

Figure 30: % Yield and % Purity of ABS in the top fraction when using 1 ml MIBC

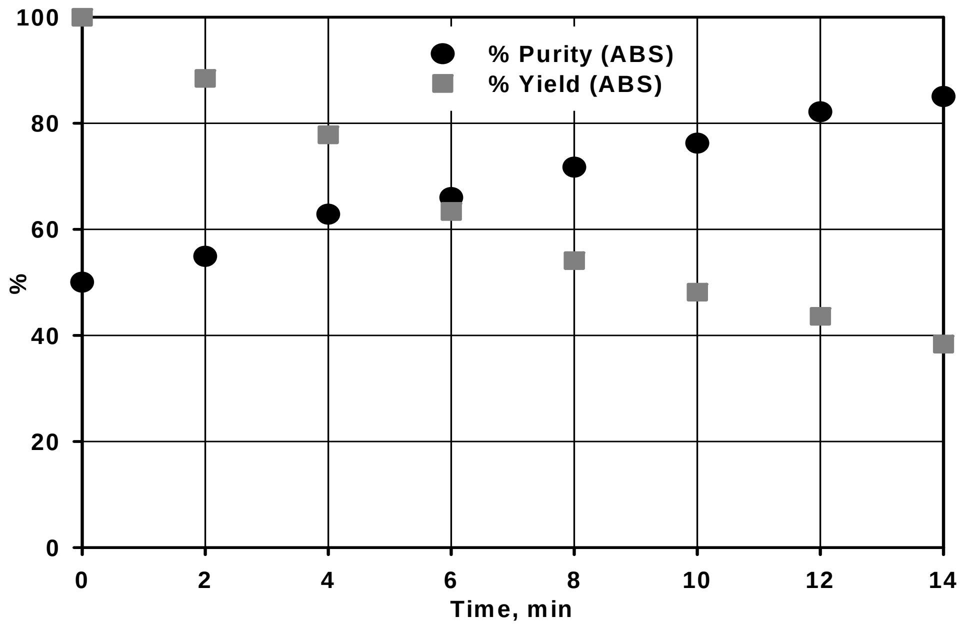

Figure 31: % Yield and % Purity of ABS in the bottom fraction when using 1 ml MIBC

Figure 32 shows a theoretical schematic diagram of a 2-stage froth flotation setup for the separation of PS and ABS based on the flotation data collected separately for the individual plastics. The feed consists of 10 grams ABS and 10 grams of PS plastic. A material balance for the case of 6 minutes residence time in each flotation cell is also shown in the figure. PS is collected from the top of column II, while ABS is collected from the bottom of column III and the remaining streams are discarded as 'waste' streams. It should be noted that although the process shown in the figure appears to be a continuous separation, each piece of equipment is run in a batch mode and materials are transferred after the end of each separation.

Although both PS and ABS are obtained at purities of 77% and 79% respectively, the plastics are obtained at very low yields of 45% and 40%. A 3-stage scenario, Figure 33, operated in a similar fashion is considered in an effort to obtain higher purities. In this case, PS is collected from the top of column IV at 86% purity, while 88% pure ABS is collected from the bottom of column V. However, increase in purity is compensated by extremely low yields of the two plastics, viz. 31% and 25% respectively.

In order to achieve both higher yields and reasonable purities, similar 2-stage and 3-stage schemes are theoretically designed where the 'waste' streams are recycled back into the system. It can be observed from Figure 10 that PS is obtained at 76% purity and 81% yield. The purity and yield for ABS are 80% and 75% respectively. In the 3-stage setup, as seen from Figure 11, both purity and yield increases. PS is obtained about 85% pure at almost 90% yield, while the purity and yield for ABS are 89% and 84% respectively.

The purities and yields of PS and ABS obtained from the various multi-stage flotation set-ups are summarized in Table 21.

Table 21: Purity and Yield for ABS and PS in various multi-stage floatation set-ups using 1ml MIBC and batch time of 6 minutes

	No Recycle				With Recycle			
	2-Stage		3-Stage		2-Stage		3-Stage	
	Yield	Purity	Yield	Purity	Yield	Purity	Yield	Purity
PS	45 %	77 %	31 %	86 %	81 %	76 %	90 %	85 %
ABS	40 %	79 %	25 %	88 %	75 %	80 %	84 %	89 %

It can be concluded that on recycling the ‘waste’ streams, although the purity of the plastics remains almost the same, there is a significant increase in the overall yield of both ABS and PS.

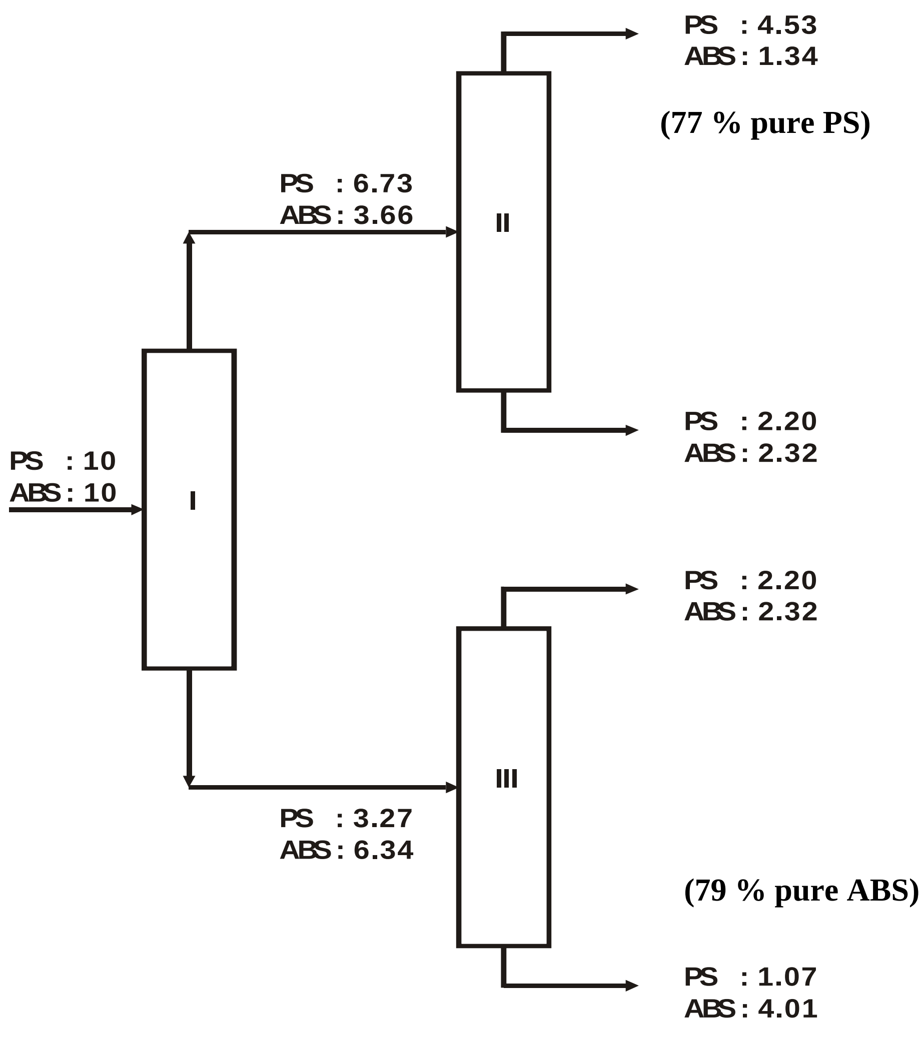

Figure 32: Material Balance for Two-Stage Floatation Setup (no recycle) using 1ml MIBC & batch time of 6 minutes

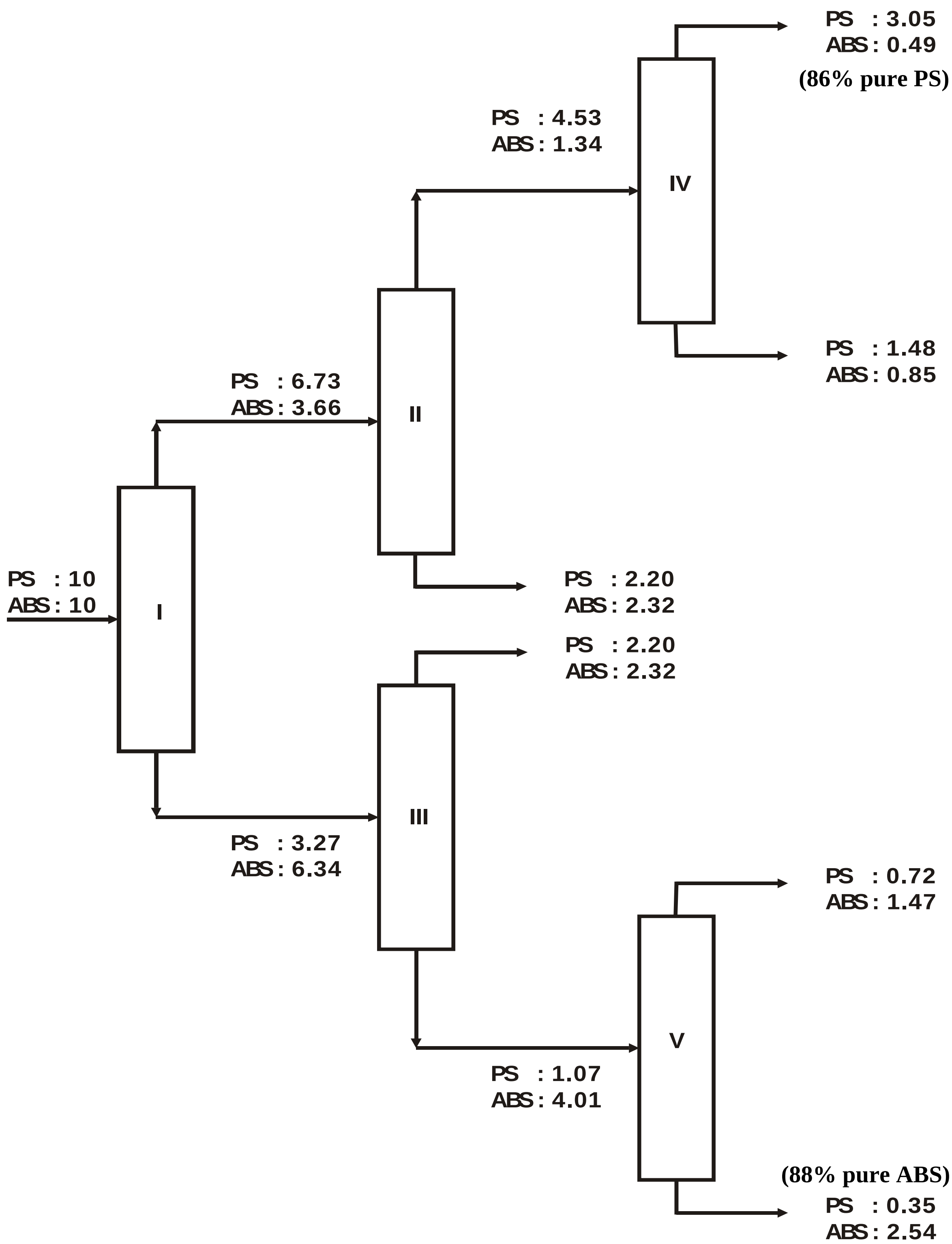

Figure 33: Material Balance for Three-stage Floatation Setup (no recycle) using 1ml MIBC & batch time of 6 minutes

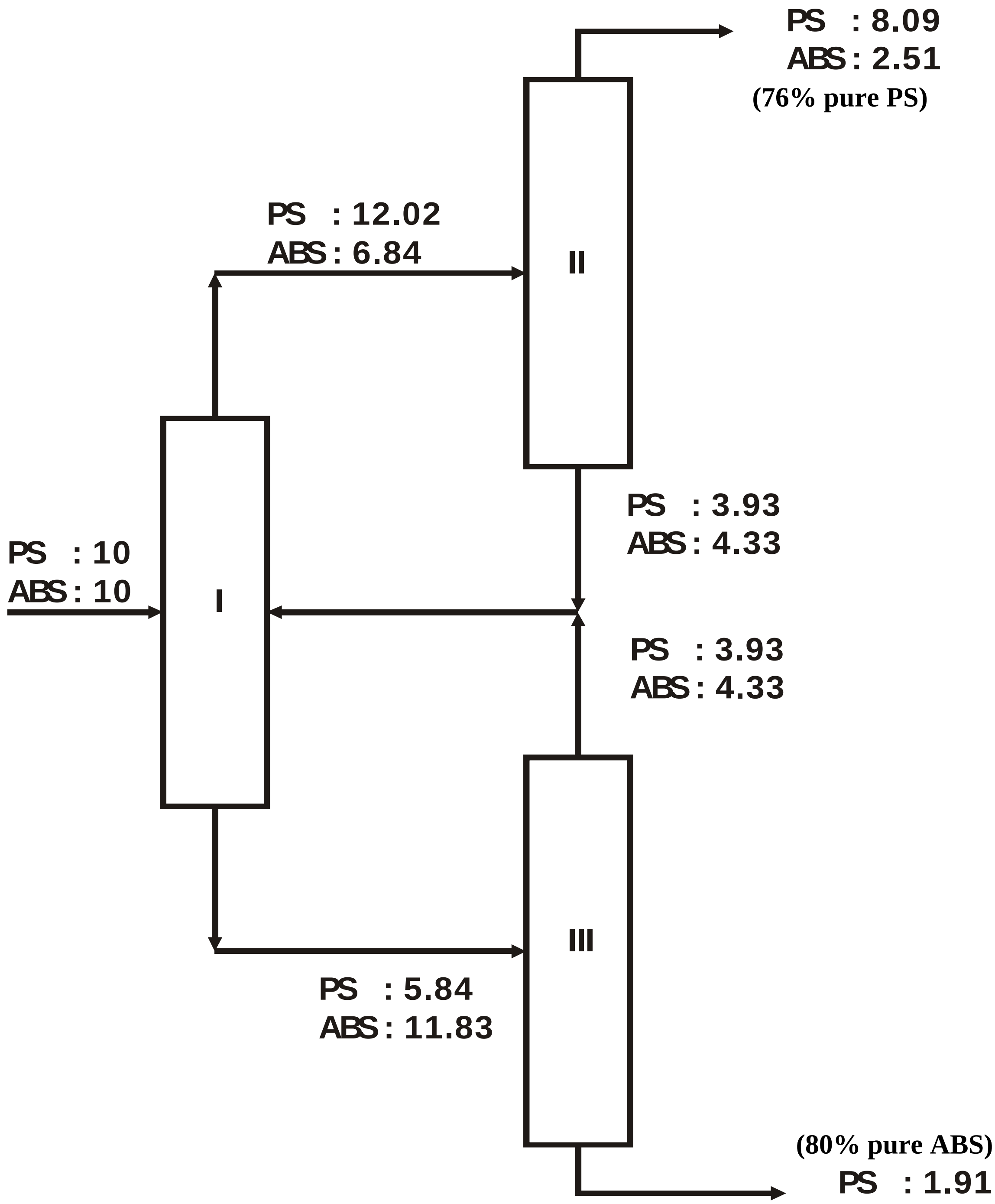

Figure 34: Material Balance for Two-Stage Floatation Setup (with recycle) using 1ml MIBC & batch time of 6 minutes

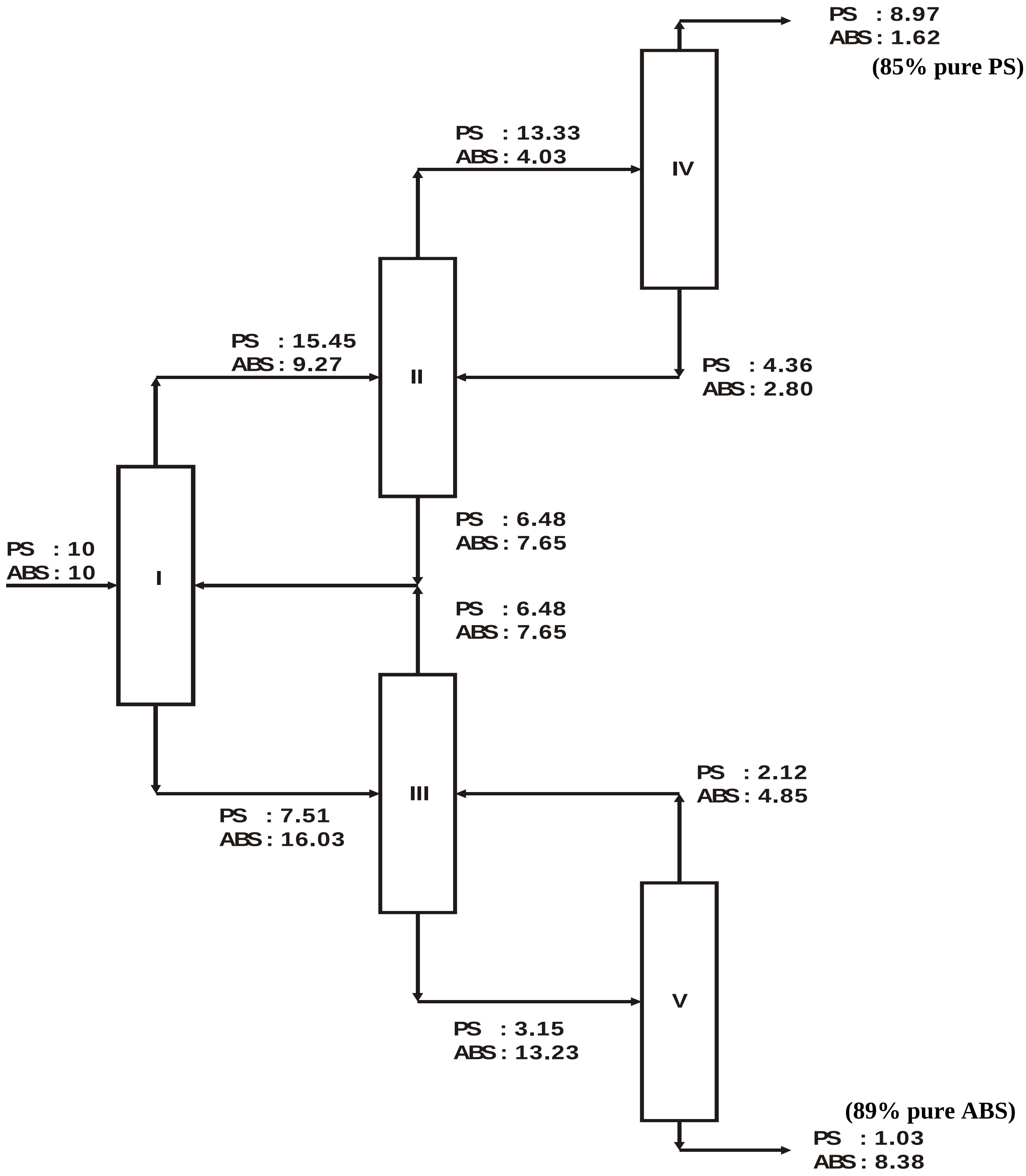

Figure 35: Material Balance for Three-stage Floatation Setup (with recycle) using 1ml MIBC & batch time of 6 minutes

Oleic Acid Results

Samples of 10 grams of plastic were floated using oleic acid emulsion along with 1 ml MIBC as frothing agent in different experimental runs. Figures 36 and 37 show the effect of addition of oleic acid emulsion and 1ml MIBC on ABS and PS floatabilities respectively. It is seen that addition of acid significantly increases the floatability of both plastics. An analysis of % yield for PS and ABS as top product (Figures 38 and 39) shows that both plastics are obtained at high yields at the top. However, % purity of ABS increases marginally while that of PS decreases marginally with time. A batch time of 4 minutes was arbitrarily chosen to perform multi-stage analysis using 10 ml oleic acid as both PS and ABS were obtained at reasonable yields and purities at a batch time of 4 minutes as top and bottom products respectively (Figures 38 and 40). Table 22 summarizes the yields and purities of the plastics in multi-stage set-ups using 1ml MIBC and 10 ml oleic acid emulsion with each floatation cell operated for a batch time of 4 minutes.

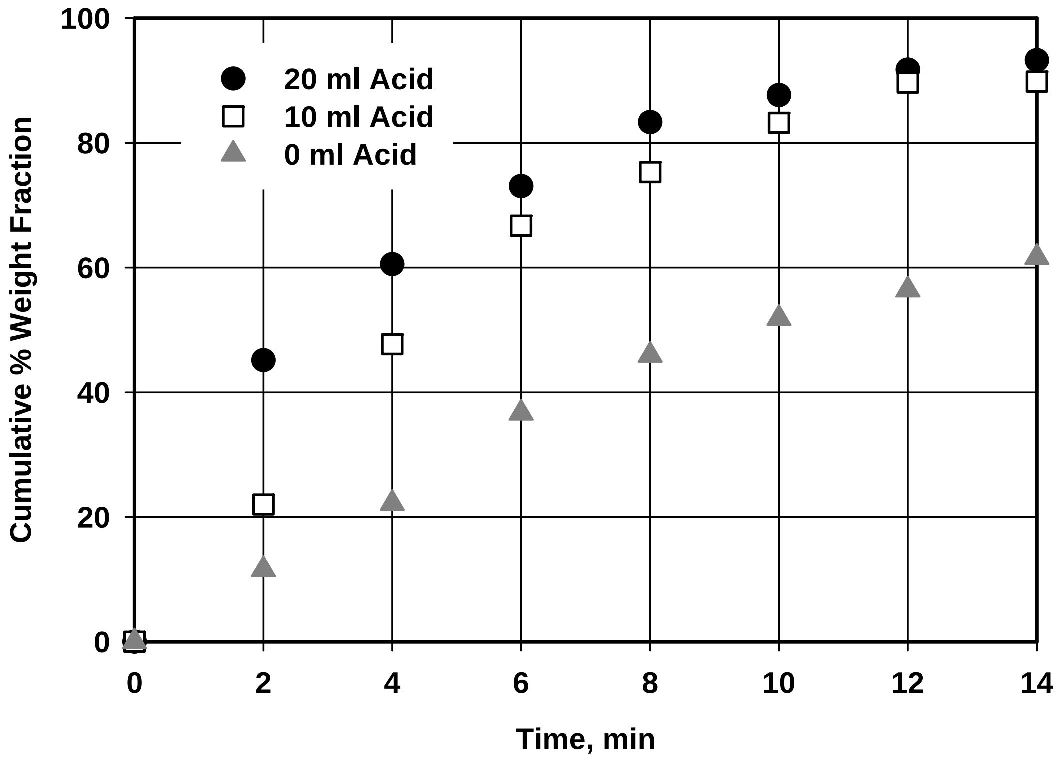

Figure 36: Effect of Oleic Acid on ABS Floatability

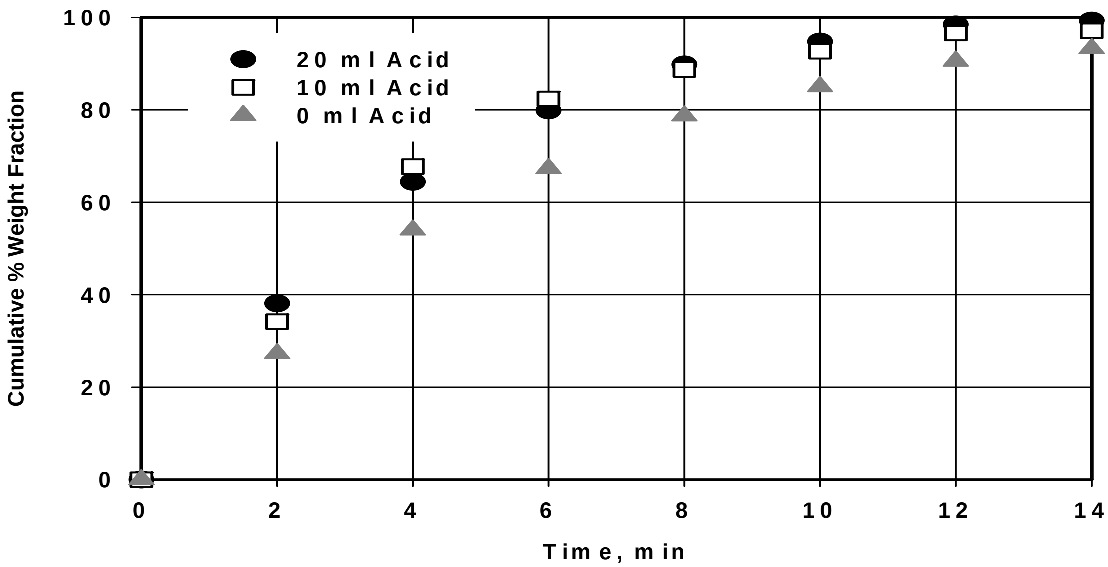

Figure 37: Effect of Oleic Acid on PS Floatability

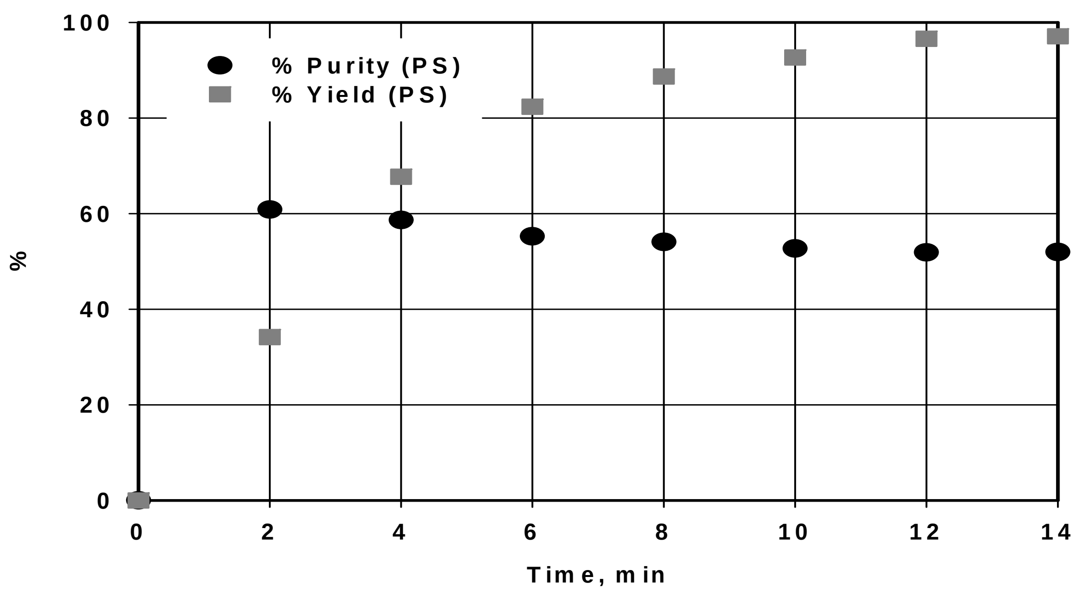

Figure 38: % Yield and % Purity of PS in the top fraction when using 1 ml MIBC and 10 ml oleic acid emulsion

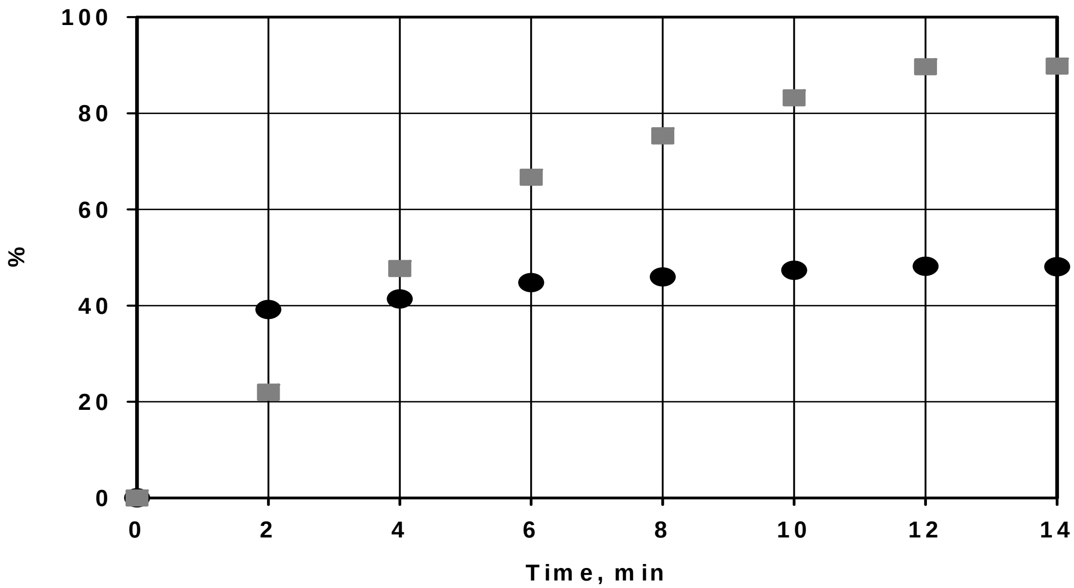

Figure 39: % Yield and % Purity of ABS in the top fraction when using 1 ml MIBC and 10 ml oleic acid emulsion

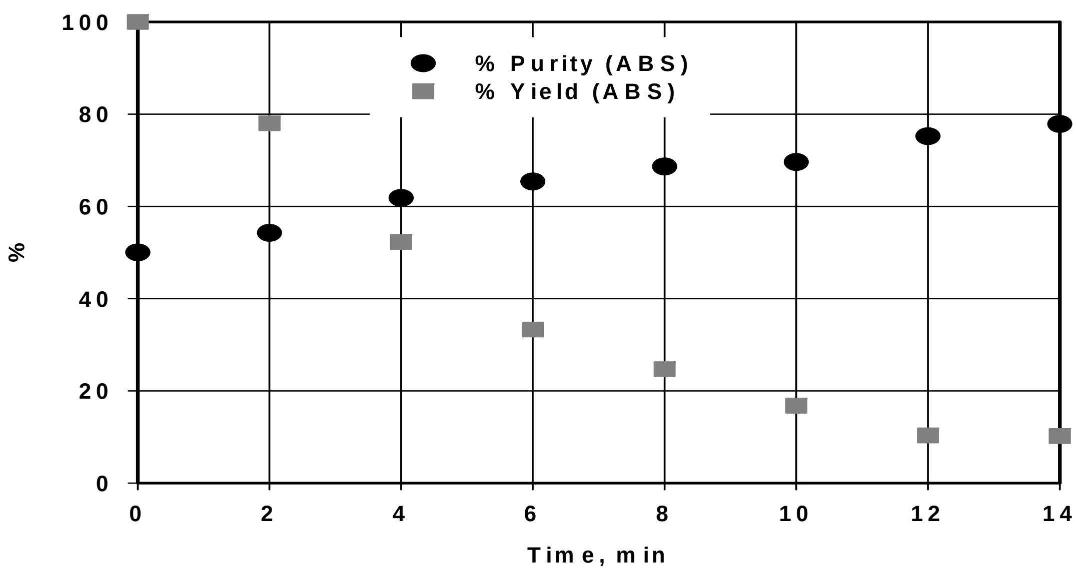

Figure 40: % Yield and % Purity of ABS in the bottom fraction when using 1 ml MIBC and 10 ml oleic acid emulsion

Table 22: Purity and Yield for ABS and PS in various multi-stage floatation set-ups (with recycle) using 1ml MIBC, 10 ml oleic acid emulsion and a batch time of 4 minutes

	2-Stage		3-Stage	
	Yield	Purity	Yield	Purity
PS	82 %	64 %	90 %	68 %
ABS	55 %	75 %	57 %	85 %

It was observed that the purities and yields are obtained using MIBC and oleic acid are lower than those obtained when using only MIBC.

Dodecylamine Hydrochloride Results

Samples of 10 grams of plastic were floated using dodecylamine hydrochloride along with 1 ml MIBC as frothing agent in different experimental runs. Figures 41 and 42 show the effect of addition of amine and 1ml MIBC on ABS and PS floatabilities respectively. It is seen that addition of amine significantly decreases the floatability of both plastics. An analysis of % purity and % yield for PS and ABS as top products (Figures 43 and 44) shows that ABS is obtained at extremely low yields while PS yield also decreases due to addition of amine. However, PS and ABS were obtained at reasonable yields and purities as top and bottom products (Figures 43 and 45) at batch times of 12 and 14 minutes. Hence, multi-stage analysis was performed for both arbitrarily chosen batch times. Table 23 summarizes the yields and purities of the plastics in multi-stage set-ups using 1ml MIBC and 2 grams amine with each floatation cell operated for a batch time of 12 and 14 minutes.

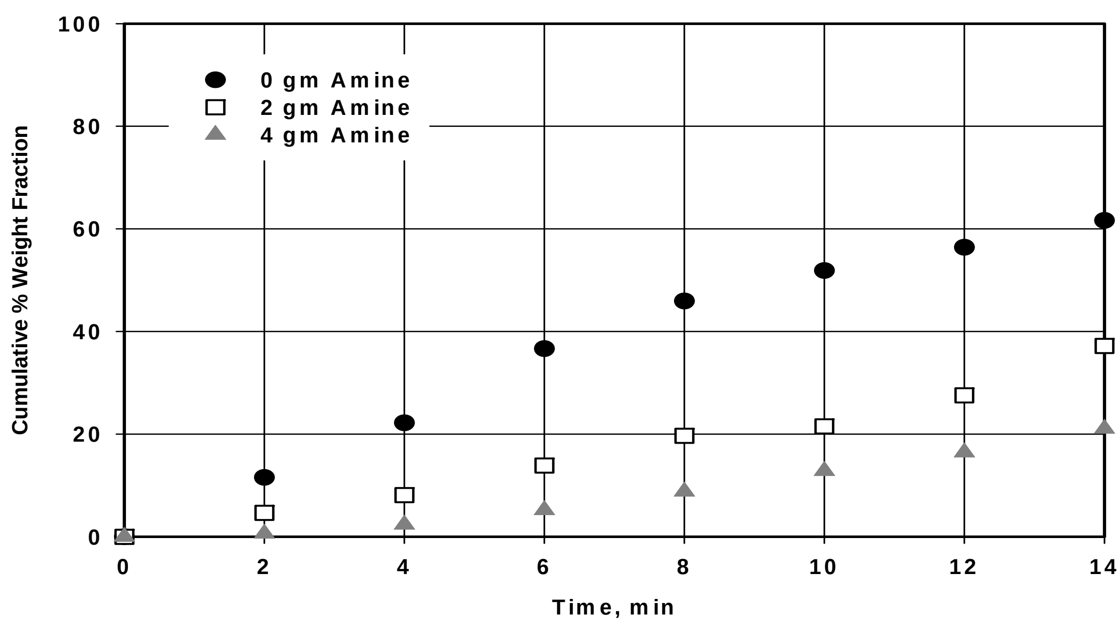

Figure 41: Effect of Dodecylamine Hydrochloride on ABS Floatability

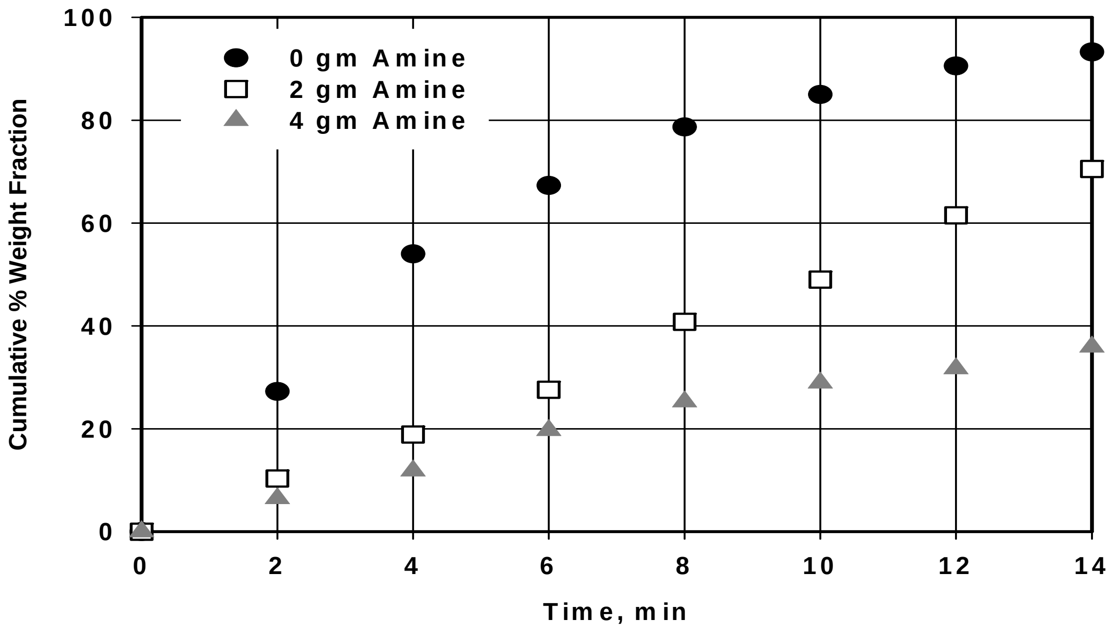

Figure 42: Effect of Dodecylamine Hydrochloride on PS Floatability

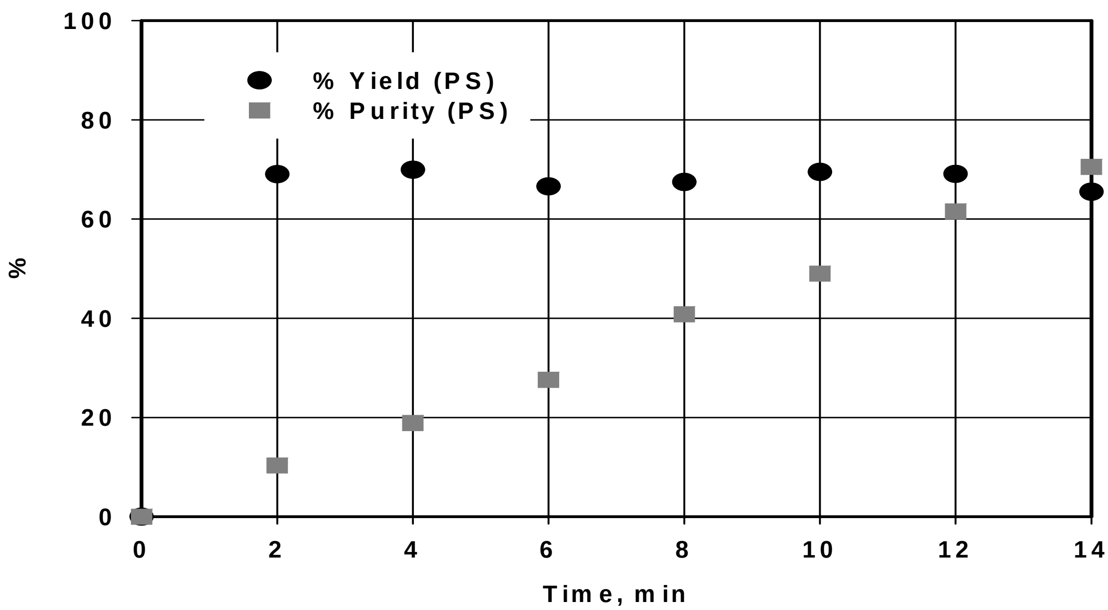

Figure 43: % Yield and % Purity of PS in the top fraction when using 1 ml MIBC and 2 gm amine

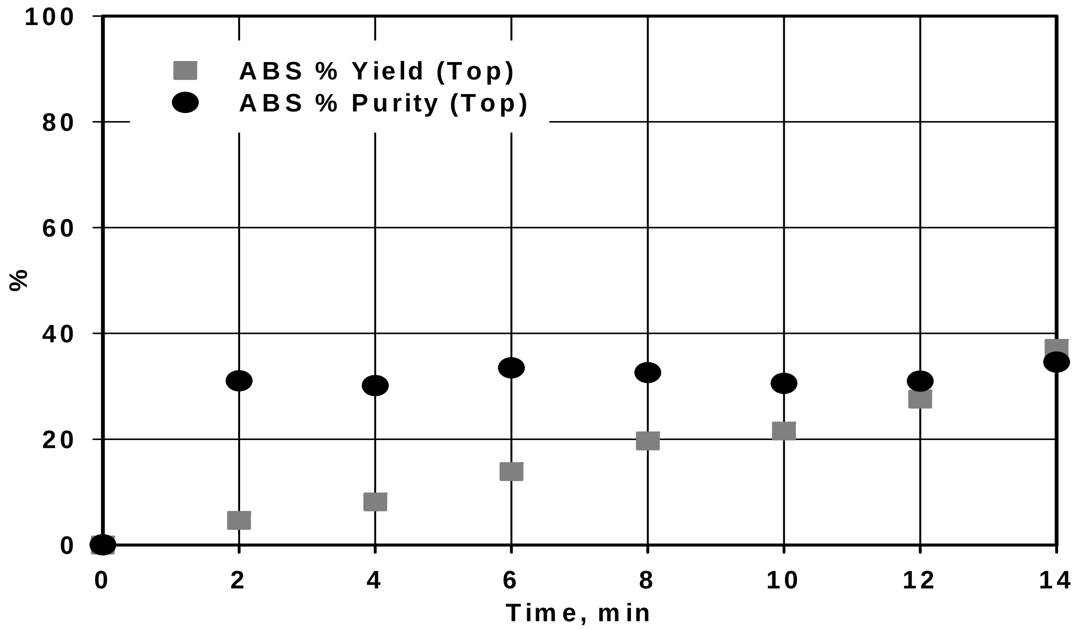

Figure 44: % Yield and % Purity of ABS in the top fraction when using 1 ml MIBC and 2 gm amine

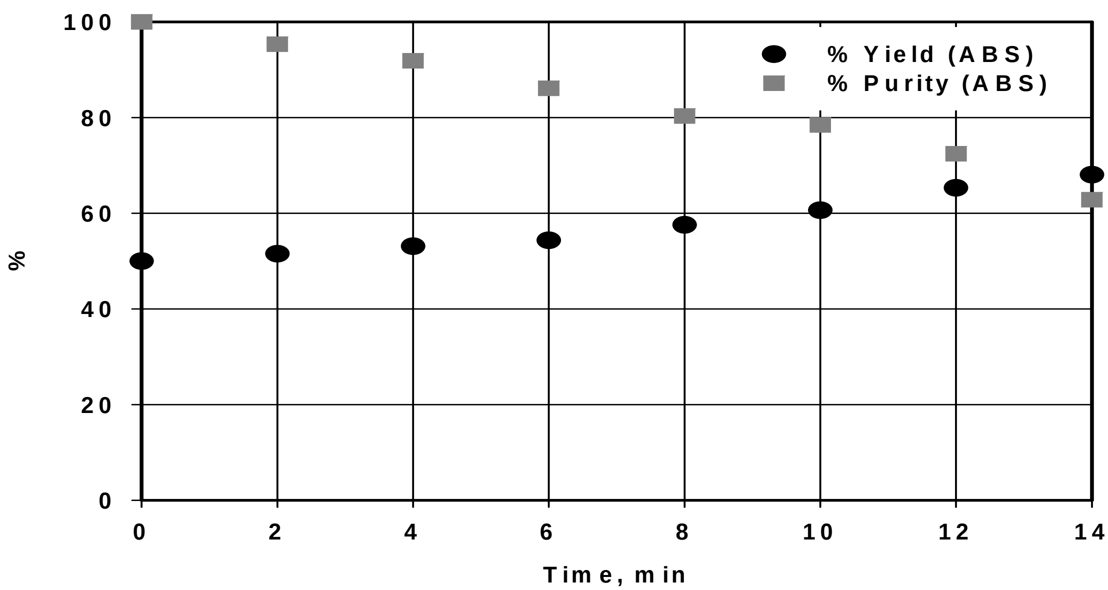

Figure 45: % Yield and % Purity of ABS in the bottom fraction when using 1 ml MIBC and 2 gm amine

Table 23: Purity and Yield for ABS and PS in various multi-stage floatation set-ups (with recycle) using 1ml MIBC and 2 gm amine

	Batch time = 12 minutes				Batch time = 14 minutes			
	2-Stage		3-Stage		2-Stage		3-Stage	
	Yield	Purity	Yield	Purity	Yield	Purity	Yield	Purity
PS	72 %	85 %	80 %	94 %	85 %	77 %	93 %	85 %
ABS	87 %	76 %	95 %	83 %	74 %	83 %	83 %	92 %

It is observed that depending on the batch time of operation, ABS or PS is obtained at a higher purity.

Comparison of Results

As seen from the previous data, oleic acid and amine tend to have opposing effects on the floatability of different plastics. Hence, only one of them was used as surfactant in addition to the MIBC frother in the experimental matrix. Figure 46 shows a comparison of the purity and yield of PS obtained in 3-stage setups using the experimental matrix described earlier.

The comparison is made at the batch times indicated in Tables 21-23 for MIBC, oleic acid and amine respectively. It is seen that using amine as surfactant with MIBC as a frother and operating the flotation cells for 14 minutes each gives 85 % pure PS at a yield of 93%, the best possible combination for the cases studied in this work, while oleic acid seems to be a bad choice. A similar comparison for ABS is shown in Figure 47. It is seen that as in the case with PS, amine as surfactant with MIBC as frother and a batch time of 14 minutes gives the best possible quality of ABS, viz. 93% purity and 83% yield. It is also seen that use of oleic acid gives significantly lower quality of ABS.

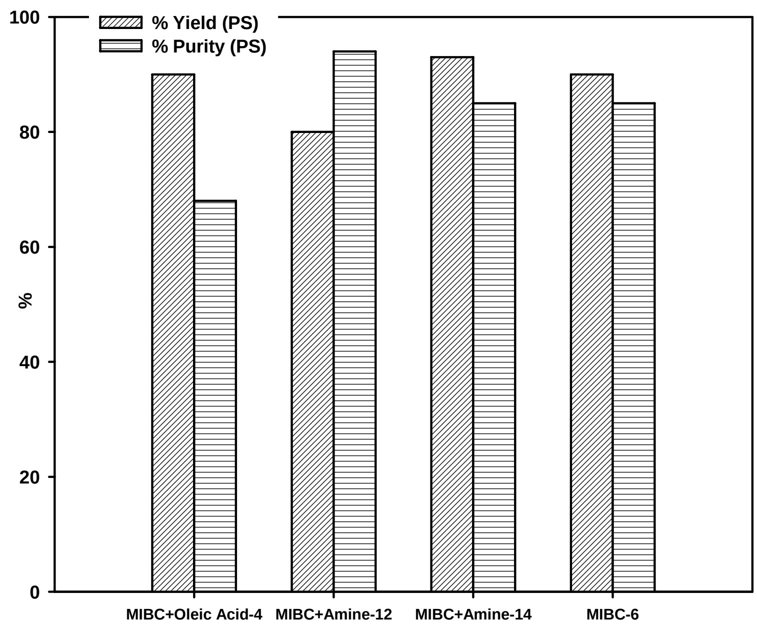

Figure 46: Yields and Purities for PS with different surfactant-frother combinations

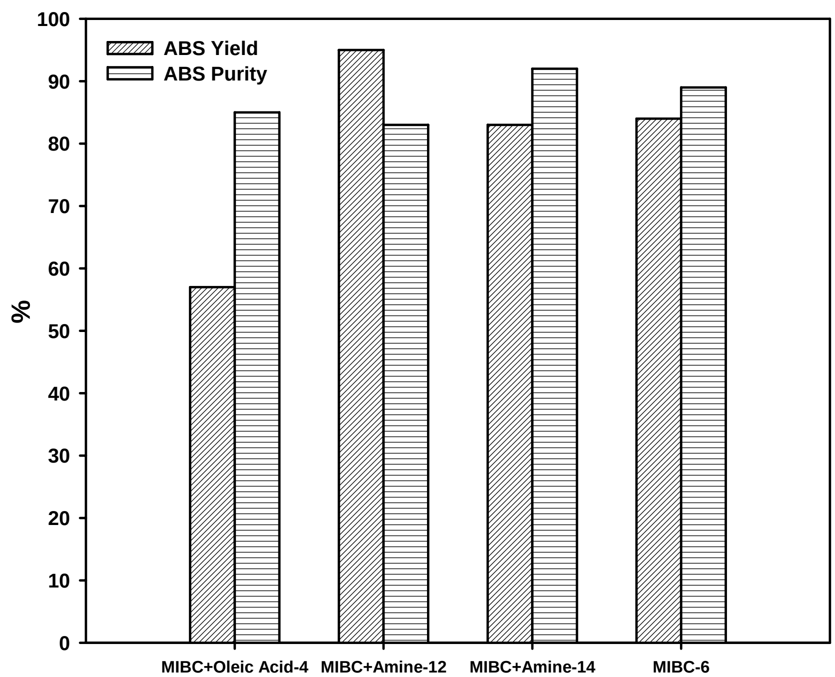

Figure 47: Yields and Purities for ABS with different surfactant-frother combinations

“Mixed Plastics” Results

A set of experiments was performed to confirm that flotation with both ABS and PS did not affect the multi-stage yields and purities predicted by the experiments performed using individual plastics. Figure 48 shows the calibration data for testing the complete dissolution of PS in CS_2 from a given mixture of PS and ABS. As seen in the figure, the experimentally observed points almost overlap with that expected from theory assuming complete dissolution of PS and no dissolution of ABS in CS_2. A slight variation is observed due the presence of 0.5% ash in the PS samples that remains un-dissolved. However, due to such low ash content, the theoretical values were used to calculate the amount of PS present in mixtures of PS and ABS obtained from ‘mixed’ flotation. Table 24 shows the actual experimental data with amount of ABS and PS taken in each known mixture and the amount of solids recovered in each case after dissolution in CS_2.

Figures 49 and 50 show a comparison of flotation results obtained using 20 grams of ABS and PS (10 grams each) and those obtained from individual experiments using 10 grams of ABS and 10 grams of PS, respectively. A set of experiments using 5 grams of each plastic was also carried out to verify the effect of ‘mixed’ flotation. This was done so as to maintain the overall solid loading constant at 10 grams. However, due to the small amounts of each plastic, small experimental errors were magnified and the results obtained were inconclusive. Hence, 10 grams of each plastic was used to verify inter-particle interaction, albeit at a higher overall solid loading.

Table 24: Calibration Data for PS Solubility in CS_2

PS Weight (gm)	ABS Weight (gm)	CS_2 Volume (ml)	Experimental Recovery (gm)	% PS	Theoretical Recovery (gm)
2.0	0.0	50	0.01	100	0.0
1.5	0.5	50	0.508	75	0.5
1.0	1.0	50	1.005	50	1.0
0.5	1.5	50	1.503	25	1.5
0.0	2.0	50	2	0	2.0

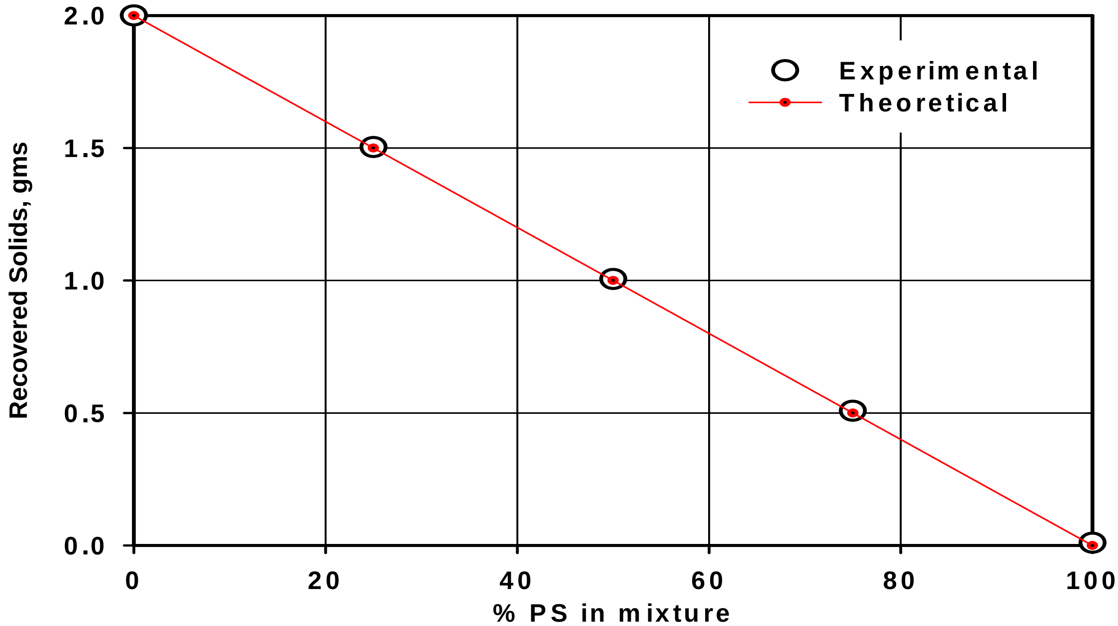

Figure 48: Calibration curve for PS solubility in CS_2

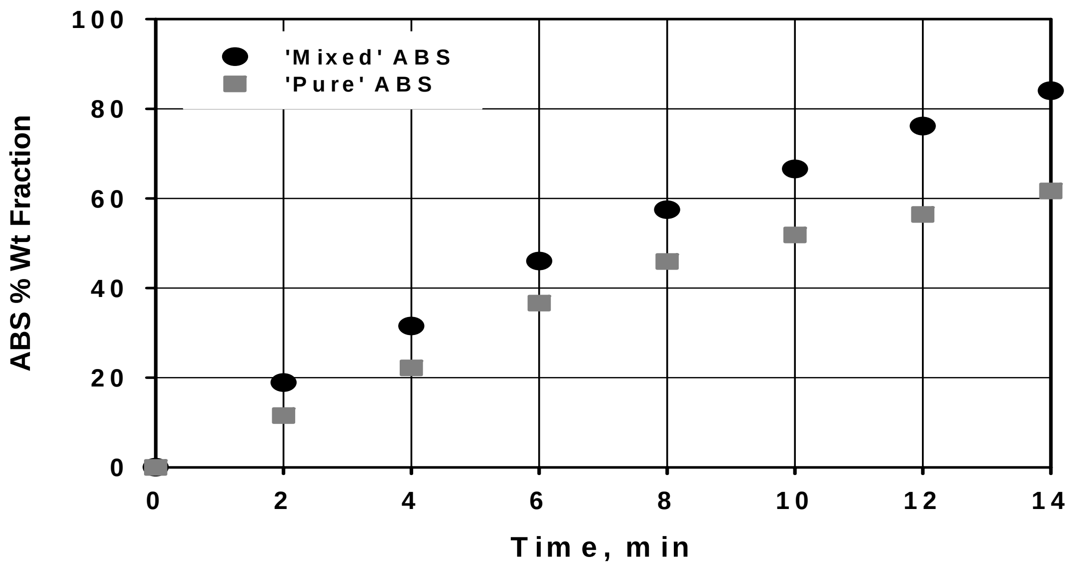

Figure 49: Flotation results for 'pure' and 'mixed' ABS using only 1 ml MIBC

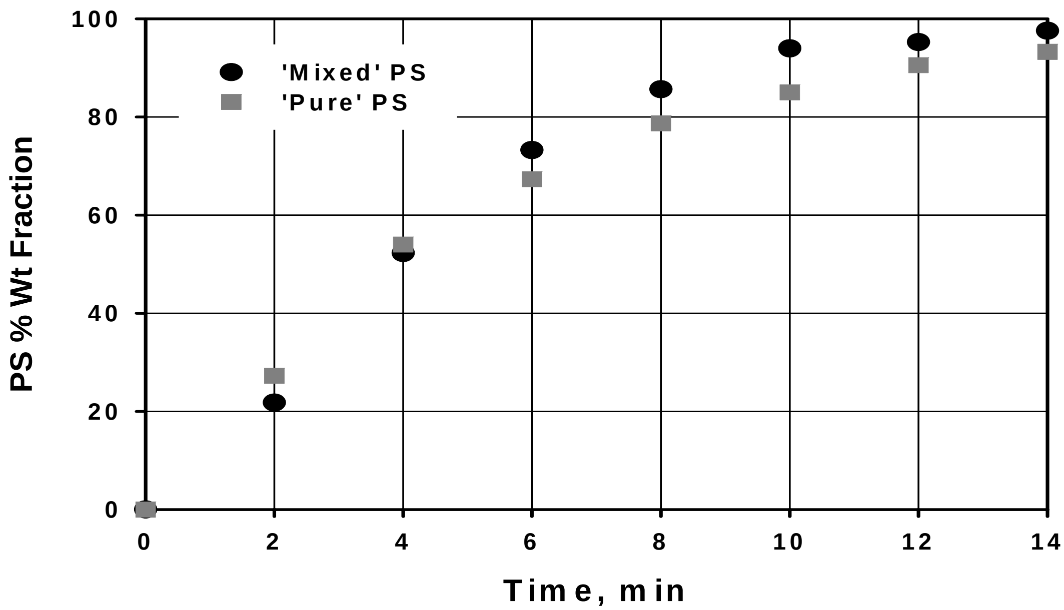

Figure 50: Flotation results for 'pure' and 'mixed' PS using only 1 ml MIBC

A multi-stage analysis performed for the flotation results using 'mixed' plastics is shown in Table 25.

Table 25: Comparison of purity and yield for 'pure' and 'mixed' ABS and PS in multi-stage flotation set-ups using only 1 ml MIBC at a batch time of 6 minutes

	Individual Plastics				'Mixed' Plastics			
	2-Stage		3-Stage		2-Stage		3-Stage	
	Yield	Purity	Yield	Purity	Yield	Purity	Yield	Purity
PS	81 %	76 %	90 %	85 %	88 %	68 %	95 %	71 %
ABS	75 %	80 %	84 %	89 %	58 %	83 %	62 %	93 %

It is seen that in most cases, both ABS and PS are obtained at lower yield and purity when flotation is carried out using both plastics, as compared to those obtained when floated separately. This could be due to inter-particle interactions causing more ABS to float than would normally do when floated individually.

3.2.1.3 Manufacturing Cost and Marketing Potential of Plastics Separation via Froth Floatation

Froth floatation is relatively effective for separating two plastics with dissimilar surface chemistry (difference in hydrophobicity). However, it is generally not recommended for mixtures of three or more polymers due to the large amount of recycle required because of the non-specific or sharp separations.

A formal economic analysis of a froth floatation process has not been carried out but processes utilizing this technique typically cost between 5 – 15 ¢/lb of feed material. Scrap ABS sells for around 10¢/ per lb (http://africa.recycle.net/a/3065.html) while mixed (unseperable) scrap sells for as little as 0.01 ¢/ per lb. The price differential between the scrap ABS and the mixed scrap is similar in magnitude to the cost of processing via froth floatation, which suggests that this type of separation makes sense for purifying presorted streams of ABS with a single impurity (such as HIPS or polycarbonate).

Task 3.2.2 Market Study (PAZ)

The economic simulation model, developed for EOLE recycling, demonstrates that finding an economic use for the mixed plastics generated during the de-manufacturing process is one of the least profitable steps in the entire recycling chain. Building upon simulation results and market potential analysis conducted in 2.2, the Recipient will conduct a market study to determine where mixed plastics are being generated, potential manufacturers for products from mixed plastics, and the types of products that could be made from mixed plastics in the future. This study will include identification of electronics OEM requirements for use of recycled plastics recovered from a mixed plastic feedstock.

The deliverable for this task will identify 10 top sources of mixed plastic generation based on generation and material quality, the estimated quantities currently available, material form, a list of targeted plastic applications for recycled plastic, and a projection of OEM recycled plastic requirements.

The deliverable for this task will identify 10 top sources of mixed plastic generation based on generation and material quality, the estimated quantities currently available, material form, a list of targeted plastic applications for recycled plastic, and a projection of OEM recycled plastic requirements.

Description of work performed, accomplishments and results:

Below is a summary of the top sources derived from data collected by the recipient in 2002 during the development of the PAZ Simulation Tool (www.pazwv.org/pazsim/). Volumes presented are estimates and have not been updated.

Targeted plastic applications for recycled plastic include use as internal parts in new electronics (highest value use/closed loop) and use in somewhat lower value applications identified by WVU researchers (e.g., railroad ties, decking, spacer blocks).

OEM recycled plastic requirements vary by application. In general, the higher the value of the application the higher the purity and physical properties required of the recycled plastic.

10 Top Sources of Mixed Plastic Generation

Sources 1 & 2: Envirocycle (Halstead PA & Pittsburgh PA)

Generation/material quality: As a major disassembler of televisions and monitors, much of Envirocycle's plastic output will be HIPS and ABS with a relatively high percentage of FR plastic scrap.

Estimated quantities currently available: Based on publicly available sources Envirocycle produces approximately 15 million pounds of plastic scrap per year.

Material form: Mostly baled, loose.

Sources 3, 4 & 5: MicroMetallics (Roseville CA, Nashville TN, Brampton ON)

Generation/material quality: Electronic shredder residue (ESR) from IT and consumer electronics.

Estimated quantities currently available: Approximately 8 million pounds per year of ESR plastic

Material form: Shredded ¼" to ½" with some fluff, contaminants

Source 6: IBM (Endicott, NY)

Generation/material quality: Demanufactured plastic parts from returned IT equipment with significant contamination (fasteners, labels, etc.). Mostly ABS with some FR expected.

Estimated quantities currently available: Approximately 1 million pounds of plastic scrap per year

Material form: Baled parts with some fluff, contaminants

Source 7: United Recycling (Chicago IL)

Generation/material quality: Both electronic shredder residue and demanufactured plastic parts

Estimated quantities currently available: Approximately 3 million pounds of plastic scrap per year (mostly shredder residue)

Material form: Baled parts and ESR, both with contaminants

Source 8: Total Reclaim (Portland, OR)

Generation/material quality: Demanufactured plastic parts

Estimated quantities currently available: Approximately 2 million pounds of plastic scrap per year

Material form: Baled parts with contaminants

Source 9: Dlubak Glass Company (Cleveland OH)

Generation/material quality*:* As a shredder of glass-bearing equipment, Dlubak generates much electronic shredder residue plastic with a relatively high percentage of FR.

Estimated quantities currently available: Estimates for Dlubak are uncertain; best estimate is approximately 5 million pounds of plastic scrap per year.

Material form: Shredded ¼” to ½” with some fluff, contaminants

Source 10: Asset Recovery Corporation (Durham NC & Minneapolis MN)

Generation/material quality: Demanufactured plastic parts

Estimated quantities currently available: Approximately 2 million pounds of plastic scrap per year

Material form: Baled parts with contaminants

Task 3.3 Polymer Characterization, Research, and Testing

Task 3.3.1 Polymer Characterization (Gupta and Sushant)

The Recipient shall continue to analyze the effects of reinforcement additives such as rubber, mica, and glass fiber on the properties of various blends of recycled and virgin polymers, for example, a range of recycled PC blends toughened with rubber, a range recycled PC blends filled with mica or other filler, and a range of blends of recycled PC reinforced with glass fibers. The Recipient will continue to provide sample products for testing and fabricate component parts for electronics application using various blends of recycled/virgin polymers both with and without reinforcements and additives, and document results of tests conducted on sample products. Also, the Recipient will continue to maintain and continue working relationships with existing polymer companies and product manufacturers to develop processes that yield consistent quality resin blends acceptable for commercial use.

3.3.1.1 Flame-Retardant Testing (Gupta and Sushant)

The Recipient shall determine (1) the effect of flame retardants (FR) on physical, thermal, and rheological properties of plastics, (2) if FRs can be separated out, (3) how to apply blending, additives, and other treatments so that recycled plastics that contain FR can be utilized.

Description of work performed, accomplishments and results:

Recycled PC and ABS flammability

Accomplishments and Results

- Facilities were developed to perform flammability tests according to UL 94 and limiting oxygen index (LOI) test according to ASTM D 2863 standards.
- Virgin resins of PC, with and without flame retardants, were subject to 5-6 cycles of extrusion and injection molding to impart them a recycling history. Subsequently their mechanical properties were measured. It was found that even after 5-6 cycles no significant decrease in tensile modulus and strength was observed.
- UL94 V-0 rating of flammability can be attained for PC obtained from recycled CDs if it is blended with a virgin PC containing FR such as Bayer Makrolon 6555.

- Recycled PC can also be blended with no-FR containing virgin PC and a non-halogenated FR Fyroflex BDP to obtain desirable LOI and UL94 ratings.
- FR Fyroflex BDP can be added to an unknown PC sample containing halogenated FR to obtain desirable FR properties.
- Adding Fyroflex BDP does not result in significant change in tensile properties but impact strength is reduced considerably.
- ABS containing 15% halogenated FR retains its flammability properties even after 5 cycles of recycling. Also no change in mechanical properties is observed.
- ABS containing no FRs can be made flame retardant by adding a brominated FR tetrabromobisphenol A (TBBA) together with a synergist such as antimony pentoxide. This blend also retains its flammability properties even after 5 recycling steps.

Polycarbonate

To study the flammability properties of PC following materials were used:

BAYER Makrolon 2608

Makrolon 2608 is of a medium viscosity grade of polycarbonate from Bayer. It was supplied by Dr. Pierre Moulinie.

BAYER Makrolon 6555

Makrolon 2608 is of a medium viscosity grade of polycarbonate from Bayer that is flame retarded with a brominated flame retardant.

Recycled Compact Disks made from Polycarbonate

An unknown source of recycled compact disks were used in some flammability and internal mixing experiments. This was done to get a feel of how the different flame retarded additives perform with a recycled polycarbonate.

Fyrolflex BDP

Bisphenol A bis(diphenyl phosphate) is a non-halogen phosphorous based flame retardant. The material was supplied by Paul Moy from Supresta. Supresta is a new company that was formally known as Phosphorous Chemicals, a subdivision of Akzo Nobel.

Fryolflex RDP

Resorcinol bis(diphenyl phosphate) is a non-halogen phosphorous based flame retardant. The material was supplied by Paul Moy from Supresta.

Recycling of Makrolon by re-Extrusion

As preliminary results, re-extrusions of Makrolon 2608 and 6555 were evaluated. For each material, 7 kg of was extruded in the Brabender Counter Rotating Extruder, then 1 kg was set aside while the remaining was extruded again. This continued with up to 5 or 6 cycles, with drying in between. Results are shown under their listed sections below. In all the figures, A represents Virgin material, and B, C, D, etc., represent 1st, 2nd, 3rd, etc., re-extrusions.

Different weight percents of Fyrolflex BDP with Makrolon 2608 and Recycled CDs were mixed in the PolyHaake internal mixer at 280°C and 40 RPM's. Figure 51 shows a plot of the LOI versus the weight percent flame retardant (wt%FR). The plot also depicts the UL94 rating. From this figure it can be seen that a positive trend in LOI as the weight percent of flame retardant is increased. Most importantly, it can be observed that the UL94 rating changes from v-2 to v-0; v-0 being the best rating. One point to note is that for the Makrolon 2608 samples, it switched from v-1 to v-0 at 12wt% Fyrolflex BDP. This value is consistent with observations reported in the literature.

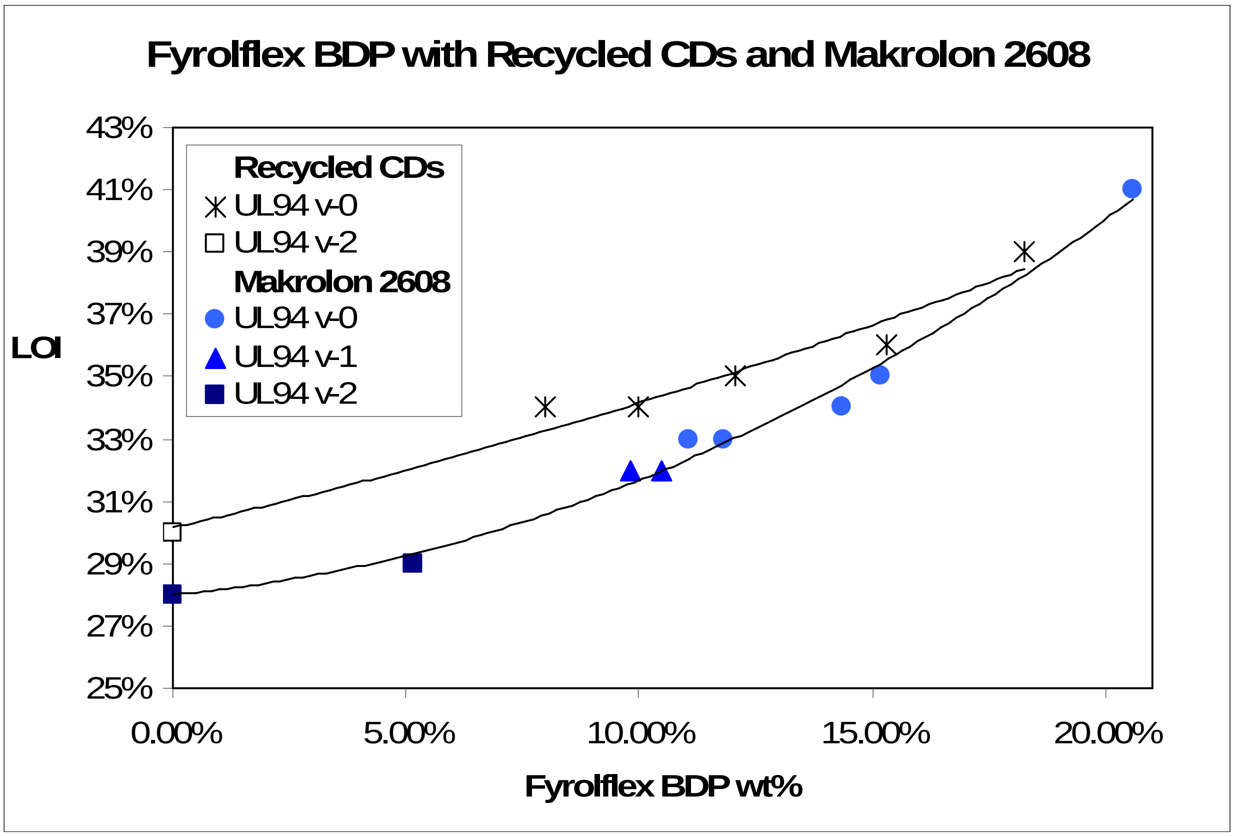

Figure 51. LOI vs. wt% of Fyrolflex BDP added to Makrolon 2608 and Recycled CDs.

Different ratios of Makrolon 6555 with Makrolon 2608 and Recycled CDs were blended to see if we could essentially dilute the Makrolon 6555 flame retarded sample and still hold a UL94 v-0 rating. Figure 52 shows the results of this experiment. From this, it can be seen that the UL94 rating goes from v-2 to v-0 at about a 60/40 ratio of both the Makrolon 6555 / Makrolon 2608 samples and the Makrolon 6555 / Recycled CDs samples. This shows that we can run an experiment to determine the amount of fyrolflex BDP needed to raise the UL94 rating of an unknown sample to v-0. The 'unknown sample' of PC could be a lesser ratio of Makrolon 6555 / Makrolon 2608 and is shown next.

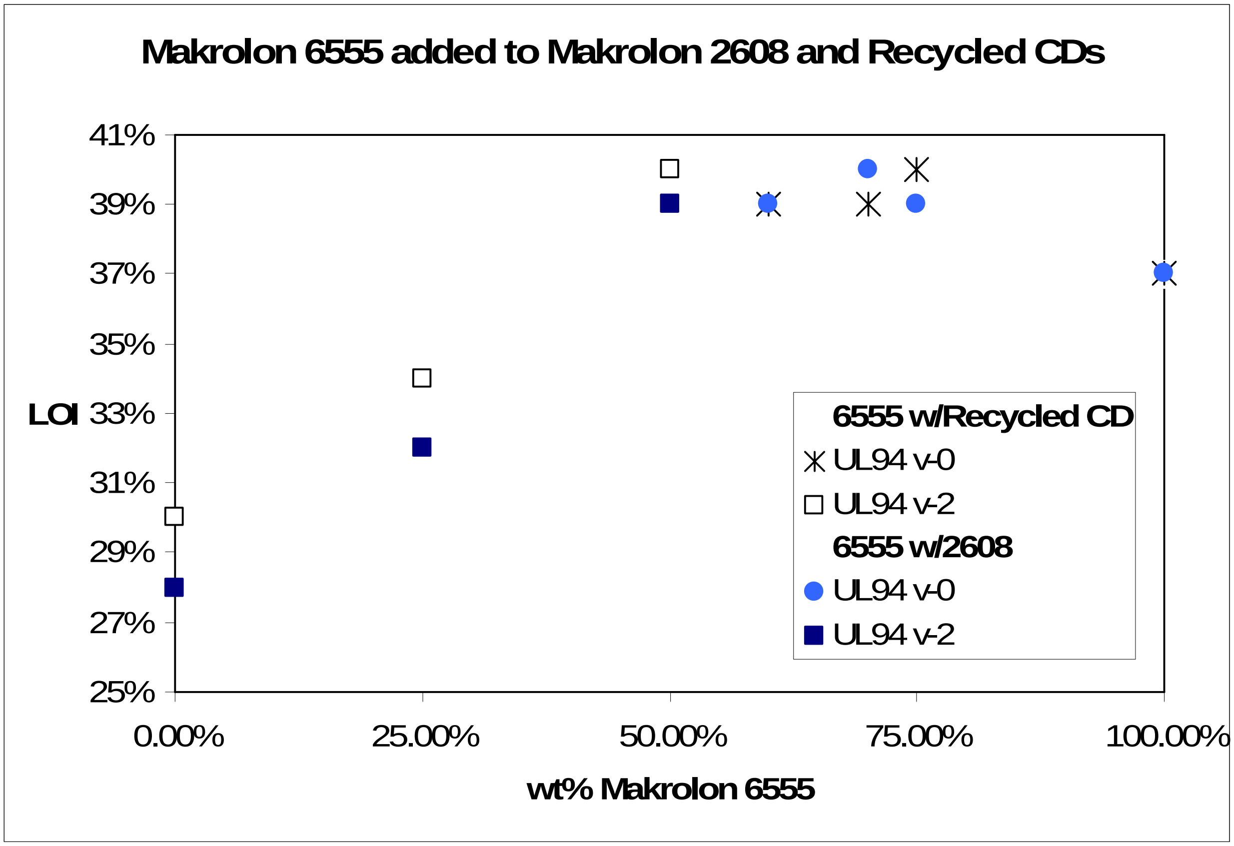

Figure 52. LOI vs. wt% of Makrolon 6555 added to Makrolon 2608 and Recycled CDs.

Treating a 25/75 blend of Makrolon 6555 / Makrolon 2608 as an ‘unknown’ PC source, different weight percents of Fyrolflex BDP was added. Figure 53 shows the results of this experiment. From the Figure 53 it can be seen that the UL94 went to a v-0 rating with the loading of 8 wt%FR for the 25/75 blend. This result shows that we can raise the UL94 rating of a potential ‘unknown’ sample to v-0.

From the data sheet on Makrolon 6555, it says that it contains Bromine. We do not know exactly what the flame retardant is in Makrolon 6555 but it is safe to assume it is a Brominated one. From these results, it can also be concluded that Fyrolflex BDP, a phosphorous based FR, has a synergistic effect with the Brominated FR, because samples went to a v-0 rating.

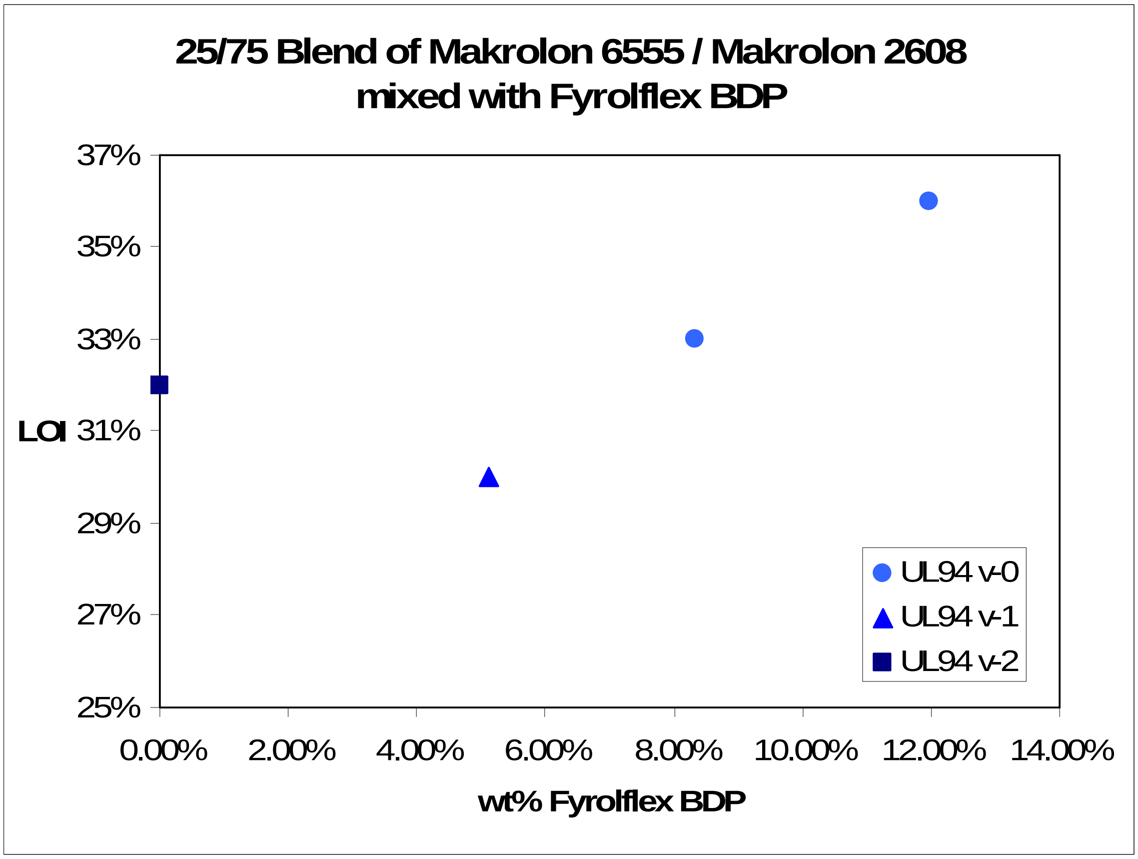

Figure 53. LOI vs. wt% of Fyrolflex BDP added to a 25/75 mix of Makrolon 6555 / Makrolon 2608.

To feed Fyrolflex BDP, a viscous liquid, a syringe pump was used. The polycarbonate fed to the extruder was Makrolon 6555, the flame retarded sample, to see if their were any antagonistic effects with the phosphorous and bromine. The temperature profile for the extruder was kept the same at 265, 280, 290, and 285^{o}C from hopper to the die, respectfully, and ran at 40 RPM's. The sample was then injection molded.

Two mechanical tests were performed- tensile test and Izod Impact Test. The results for these are summarized in Table 26 and Table 27, respectfully. To summarize, Young's modulus was 412,686 ± 8784 lb/in^2, which is 17.9% above the neat polymer. The tensile strength was 9179.7 ± 2.4 lb/in^2, which is slightly below the neat polymer value by 2.3 %. Izod impact strength was 0.856 ± 0.031 ft-lb/in, which is close to 95% lower than the known neat polymer value.

Table 26. Instron Test Data for Makrolon 6555 with 12wt% Fyrolflex BDP

Known Youngs Modulus of PC 6555 =		350000	lb/in^2		
Known Tensile Stress at Yield of PC 6555 =		9400	lb/in^2		
Sample	Youngs Modulus (lb/in^2)	Average	SD	%SD	% error from known
1	421850	412686	8783.8	2.13%	17.91%
2	415270				
3	417170				
4	398820				
5	410320				
Sample	Tensile Stress at Yield (lb/in^2)	Average	SD	%SD	% error from known
2	9177.0	9179.7	2.353	0.03%	-2.34%
3	9179.7				
4	9182.8				
5	9179.3				

Table 27. Izod Impact Test Data for Makrolon 6555 with 12wt% Fyrolflex BDP

Known Izod Impact Strength of PC 6555 =		16	ft-lb/in		
Sample	Impact Strength (ft-lb/in)	Average	SD	%SD	% error from known
1	0.864	0.856	0.031	3.57%	-94.65%
2	0.872				
3	0.7984				
4	0.888				
5	0.856				
6	0.856				

Acrylonitrile Butadiene Styrene (ABS)

Materials

A flame-retarded ABS called ‘CYCOLAC ABS-FR15’, was obtained from GE plastics. Cycolac MG 94 ABS resin was also obtained from GE plastics but it does not contain any FR. A brominated flame retardant, tetrabromobisphenol A (TBBA) was purchased from Dead Sea Bromine Group. Antimony pentoxide, which is from Nyacol nano technologies, Inc., was utilized as a synergist.

ABS blends were subject several rounds of recycling. The definition of one recycle is one extrusion plus injection molding. After each recycling step flammability and mechanical properties were measured. Table 28 shows the LOI and UL94 test results for ABS-FR15. The value of LOI test increases after recycling. UL-94 test for all reaches the V-0 level. Thus, it can be concluded After recycling, ABS remains to keep its flame resistance. The possible reason may be due to the improvement of mixing of flame retardant with polymer after multiple extrusions. Tensile stress yield, Young’s modulus and impact strength did not change after five times of recycling as shown in Table 29.

Non-FR cycolac MG94 virgin resin was also subject to multiple cycles of extrusion and injection molding. Then a brominated flame retardant, tetrabromobisphenol A (TBBA) from Dead Sea Bromine Group, was added into each cycle and tests were performed on the thermal and viscosity properties. In order to enhance the effect of TBBA, we used antimony pentoxide, which is a synergist. The mole ratio of flame retardant to synergist was 3/1.

For convenience and ease of comparison reasons, when we say "FR 16%" in this experiment, it means the weight percentage of the flame retardant in a mixture containing flame retardant and ABS copolymer without synergist is 16%. But we need to recognize that synergist always accompanies the flame retardant in the mole ratio of 1/3. Samples were made by using the Haake PolyDrive Internal Mixer at T=210 ^{o}C and 50rpms for 3 minutes.

It was found that adding FR16% of TBBA in virgin ABS resin, UL-94 test reached V-0 level, and adding 15% of TBBA just achieved V-2 level. In other words, total additives, TBBA plus antimony pentoxide, must be 21 weight percentage to achieve V-0 of UL-94 test and 19.8 weight percentage to obtain V-2 of UL-94 test. Knowing the amount of TBBA reaching V-0 test, we want to know that after recycling, if the thermal properties remain or change.

Therefore, adding the same amount of TBBA into each recycled ABS-MG94, the results showed that for the first five cycles of recycling, all of them maintain the V-0 level. From above, we know that for the loading of FR15%, UL-94 test is at the V-2 level. Next, we would like to see what level of UL-94 test by that amount can recycled ABS-mg94 reach? The results showed that with FR15% loading, the V-0 level is reached after recycling. The values for the LOI test in the loading of FR16% are showed in Table 30. The results seem to show that the LOI value goes up after being recycled.

In addition to TBBA, we also investigated another halogenated flame retardant, 2,4,6-Tris(2,4,6-tribromophenoxy)-1,3,5 triazine (FR-245) from Dead Sea Bromine Group, and non-halogenated flame retardants, triphenyl phosphate (TPP) from Aldrich Sigma and Bisphenol A bis(diphenyl phosphate) (Fyrolflex BDP) from Phosphorous Chemicals. Samples were made by using the Haake PolyDrive Internal Mixer. FR-245 has higher bromine content, 67%, than TBBA, 58.5%, and good thermal stability. Due to its higher bromine content, we can expect that the less loading is needed to retard ABS. We need to emphasize our definition here again. For convenience and ease comparison reasons, when we said FR 16% in this experiment, it means that weight percentage of flame retardant in a mixture containing flame retardant and ABS copolymer without synergist is 16%. But we need to recognize that synergist always accompanies with flame retardant in the mole ratio of 1/3 due to the generation of $SbBr_3$ during the combustion. So the total amount of additives should be higher than 16%.

From Table 31, we see that adding 14% of FR-245 in virgin ABS resin, UL-94 test reached V-0 level, and adding 12% of FR-245 just achieved V-2 level. In other words, total additives, FR-245 plus antimony pentoxide, must be 19.1 weight percentage to achieve V-0 of UL-94 test and 16.6 weight percentage to obtain V-2 of UL-94 test. Compared to TBBA, the total loading of additives was reduced about 2wt% to retard ABS. With loading of 13% of FR-245, UL-94 test failed due to the generation of dripping, and the dripping ignited the burning of the cotton underneath the test sample.

Due to environmental consideration, the use of non-halogen flame retardants is preferable. However, it is still a challenge for ABS copolymer. In our investigation, we tried to use TPP and BDP to see how those phosphorus flame retardants work. For comparison, the value of LOI of pure ABS is provided as 20. From Table 32, we can see that with the loading of TPP below 15 wt%, the value of LOI is less than 23. Furthermore, with increasing the loading up to 25 wt%, the value of LOI reached 24. For BDP, it also shows that with the loading of 25 wt%, the value of LOI was 23. The effects of these two flame retardants are not so remarkable by themselves.

The synergism is one way of reducing the unfavorable halogenated FRs. For example, the use of antimony pentoxide reduces the loading of halogenated flame retardant. From this point of view, we tried to seek a solution for recycling ABS containing flame retardants. Since there is still no commercial non-halogenated flame retardants for ABS, we can expect that the flame retardants in recycled ABS are halogen-containing. Here, we try to use TPP as synergist to lower the addition of halogen flame retardant. From the results of Table 33, we can achieve the highest value of LOI as 29 with the total amount of additives equal 25 wt%, TBBA plus antimony pentoxide equal 15 wt% and TPP 10 wt%. From previous experiments, we need to load 21 wt% of TBBA plus antimony pentoxide to obtain the value of LOI as 30. Therefore, there is a possible way to recycle ABS: adding non FR virgin materials, which dilutes the concentration of flame retardants in the matrix, and maintains the mechanical properties and adding non-halogen flame retardants to maintain the requirement of fire regulations.

Table 28. Flammability properties of FR-ABS.

Material	ABS-FR15					
Recycle time	Non-recycled	First recycle	Second recycle	Third recycle	Fourth recycle	Fifth recycle
LOI (O_2%)	30	35	36	36	39	37
UL-94	V-0	V-0	V-0	V-0	V-0	V-0
Tg (^{0}C)	88.36	91.2	94	92.6	93.8	92.4

Table 29. Tensile properties of ABS-FR15.

ABS-FR15			
	Tensile Str, yld(MPa)	Tensile Modulus(MPa)	Impact notched (J/m)
From Company	41	2340	214
Non-extruded	36.7	2243	208.8
First recycle	36.8	2273	190.1
Second recycle	36.2	2270	201.5
Third recycle	35.7	2222	205.3
Fourth recycle	35.4	2233	208.1
Fifth recycle	35.3	2192	211.4

Table 30. UL94 and LOI values for ABS-MG94 with 16 and 15%FR added

ABS-MG94						
Recycling times	Virgin	First	Second	Third	Fourth	Fifth
UL-94 (16%FR)	V-0	V-0	V-0	V-0	V-0	V-0
UL-94 (15%FR)	V-2	V-0	V-0	V-0	V-0	V-0
LOI (16%FR)	30	30	30	30	32	32

Table 31. UL-94 values for ABS-MG94 with different %FR added

Polymer	ABS-MG94				
Temperature(^{0}C)	220				
Rpm	60				
FR-245(wt%)	12	13	14	15	16
Total additives (wt%)	16.6	17.9	19.1	20.4	21.7
UL-94	V-2	Fail	V-0	V-0	V-0

Table 32. LOI values for ABS-MG94 with different FR and %FR added

Polymer	ABS-MG94							
TPP (wt%)	13	15	17	19	25	30	0	0
BDP (wt%)	0	0	0	0	0	0	20	25
LOI	22	23	23	23	24	24	23	23

Table 33. LOI values for ABS-MG94 with different %FR added

Polymer	ABS-MG94						
TPP (wt%)	15	15	15	13	10	5	10
TBBA (wt%)	0	5	0	5	7.16	10.74	10.74
Antimony pentoxide (wt%)	0	0	5	2	2.84	4.26	4.26
LOI	23	24	23	24	25	27	29

Task 3.3.2 Utilization of mixed plastics (Hota and Vijay)

The Recipient shall continue to determine mechanical, thermal, and aging properties of mixed streams of virgin/recycled polymer blends to be used in automotive, infrastructure and other applications, and promote the use of recycled polymers in transportation vehicles through establishing working relationships with automotive component manufacturers and by developing sample automotive products such as prototype headlight housings, bumper shapes, vehicle cross-beams, reinforced door/window frames.

Description of work performed, accomplishments and results:

Please refer to the report entitled "Thermo-Mechanical Characterization Of Recycled Thermoplastic Polymers Aged Under Harsh Environment" in Appendix N for the results for Task 3.3.2.

Task 3.3.3 Use of Mixed Plastics in Highway Products (Hota and Vijay)

The Recipient shall continue to promote the use of highway and transportation infrastructure products through establishing working relationship with state and federal highway departments, manufacturers of highway and transportation infrastructure products, and by developing sample infrastructure products, such as prototype guardrails, and guardrail parts. Further, the Recipient will continue to assess the potential for maximizing the recycled polymer content of computers and electronic equipment

The Recipient will produce infrastructure products using recycled thermoplastic polymers (polypropylene, polycarbonate, polyamide and ABS) and glass fibers for structural applications. Products will include dowel bars and baskets, used in highway jointed plain concrete pavements. Also, the Recipient shall develop production methods for spacer blocks at a suitable location in West Virginia with regional recycled polymer suppliers. Cooperative projects will be initiated to produce highway products.

Description of work performed, accomplishments and results:

Please refer to the report entitled "Manufacturing and Evaluation of Structural Products with Recycled Polymers" in Appendix O for the results for Task 3.3.3.

Patent was applied for manufacturing of guardrail offset-blocks with recycled polymers. Production aspects of guardrail offset-blocks are being coordinated by WVU with suitable manufacturers.

Task 3.3.4 EOLE Plastic Separation Definition (PAZ)

The Recipient shall characterize feed streams from EOLE manufacturers and define the parameters of input, operating conditions and output from the separation process.

Description of work performed, accomplishments and results:

This work is being carried over to new grant and will be completed by SDR Technologies.

Task 3.3.4.1 Mixed Plastic Separation Definition (PAZ)

The Recipient shall acquire mixed plastics from computer de-manufacturers and separate this material into original components utilizing industrial processes and define the parameters of input, operating conditions and output from the separation process. The Recipient will purchase mixed plastics from electronic recyclers, characterize the input material, and process it through the selected separation process.

Description of work performed, accomplishments and results:

Very little activities were able to begin under this grant due to a lack of funding. All additional tasks will be carried out under the new grant when it is funded.

SDR Technologies began to sample materials yielded by the contractor's process, as well as from other sources

- Purchased 192,120 pounds of material
- Classified materials as ABS FR and ABS general purpose (GP)
- Evaluated and analyzed materials for composition and properties

Task 3.3.4.1.1 Feed Stream and Process Parameter Identification (PAZ)

The Recipient shall define the incoming material and the variability of the input streams, as well as locate the optimum operating parameters.

Description of work performed, accomplishments and results:

- ***Explored options for separating commercial commingled EOLE plastics***
    - Reviewed contractor's presentation of capabilities
    - Focused evaluation on flame retardant (FR) materials to achieve optimal value
- ***Analyzed material's suitability for additional processing***
    - Put materials through initial processing and reevaluated
    - Further modified materials through the use of additives and additional processing
    - Reevaluated materials with respect to the value provided by processing and modification options
- ***Findings / Status***
    - Quality level of the materials received have been deemed inadequate for the targeted market
    - SDR Technologies maintains the inventory for further evaluation and work in progress of additional separation steps

Task 3.3.4.1.2 Process Capabilities, Purity, and Yield (PAZ)

The Recipient shall define the capability of the process to deliver high purity material for recycle, and determine what percentage of the input will end up as mixed plastics and what percentage will be high purity.

Description of work performed, accomplishments and results:

This work is being carried over to new grant and will be completed by SDR Technologies.

Task 3.3.4.2 Closed Loop Systems Plastic Separation Definition (PAZ)

In order to test the plastics recycling knowledge acquired during earlier phases of this project, and integrate the newest technology that is being developed by the project the Recipient shall develop processes that identify the real costs and viability of a closed loop plastic recycling system. The effort will focus on the recovery of scrap electronics plastic from OEM recycling operations, followed by separation and recycling of plastic at a quality and scale consistent with OEM requirements for use in new electronic products. It will also determine the feasibility and the viability of recycling, re-engineering as well as remanufacturing products into high valued uses.

<u>Description of work performed, accomplishments and results:</u>

In preparation for truckload-scale plastics recycling demonstration which was planned and scheduled for the fall of 2004, PAZ and subcontractors continued pre-demo activities including a continuation of discussions among PAZ, Envirocycle, IBM, Panasonic, HP and Dell re: possible joint work on the plastics recycling demonstration project now in the planning stage.

Because of the delay in releasing the funding, the bulk of the work is being carried over to new grant and will be completed by SDR Technologies.

Task 3.3.4.2.1 Feed Stream and Process Parameter Identification (PAZ)

The Recipient shall define the incoming material and the variability of the input streams, as well as locate the optimum operating parameters.

<u>Description of work performed, accomplishments and results:</u>

The bulk of the work is being carried over to new grant and will be completed by SDR Technologies.

Task 3.3.4.2.2 Process Capabilities, Purity and Yield (PAZ Demo)

The Recipient shall define the capability of the process to deliver high purity material for recycle, and determine what percentage

<u>Description of work performed, accomplishments and results:</u>

SDR Technologies invested time, resources, and expertise in conjunction with the Polymer Alliance Zone (PAZ) to continue the review of best available technologies (BAT) for end-of-life electronics (EOLE) recycling. But once again much of the finalization on this work is being carried over to new grant and will be completed by SDR Technologies with support from PAZ.

Task 3.3.5 Assessment of Solvent-Based Separation Technologies (Turton)

The Recipient shall evaluate processes based on dissolution and recrystallization/precipitation of mixed polymers/plastics streams to effect separation of virgin-quality plastics. Separation of common EOL plastics (e.g. polycarbonate and polystyrene plastics) will be evaluated using a variety of common organic solvents.

<u>Description of work performed, accomplishments and results:</u>

Work was performed to assess the feasibility of separating polycarbonate (PC) and ABS/PS using solvent separation.

3.3.5.1 Identification of samples

The identification of plastics prior to recycling is a crucial step in the plastic recycling industry. The purpose of identification is to determine what plastic resins are present in computer scrap. Because different plastics have distinguishable light absorption spectra, electromagnetic absorption and reflectance measurements can be used to sort them. Reflected spectra are detected and analyzed to determine the type of plastic.

Representative samples collected from computer scrap were taken from each piece and identified using a Perkin Elmer FT-IR (Fourier Transform Infrared Spectroscope). It was shown that the three most prominent types of plastics in computer waste are ABS, PS and PC. Therefore this work focuses on the separations of these three polymers. FT-IR spectra for ABS, PS and PC are shown in Figure 1.

In Figure 54, spectra are presented with wavelength as the X-axis. The region 4000-1500 cm^{-1}in the x-axis is usually a functional group region and peaks in this region are characteristic of specific kinds of bonds and, therefore, can be used to identify whether a specific functional group is present. As can be seen, a carbonyl group (C=O) for PC appears at around 1730 cm^{-1}; a $C \equiv N$ bond is a characteristic functional group of ABS and appears at around 2300 cm^{-1}. Also, benzene rings show “overtones” in the 1500-1700 cm^{-1} region. By comparing the PS and ABS spectra, it was found that these two spectra are almost the same except for the absence of the $C \equiv N$ bond in the PS spectrum.

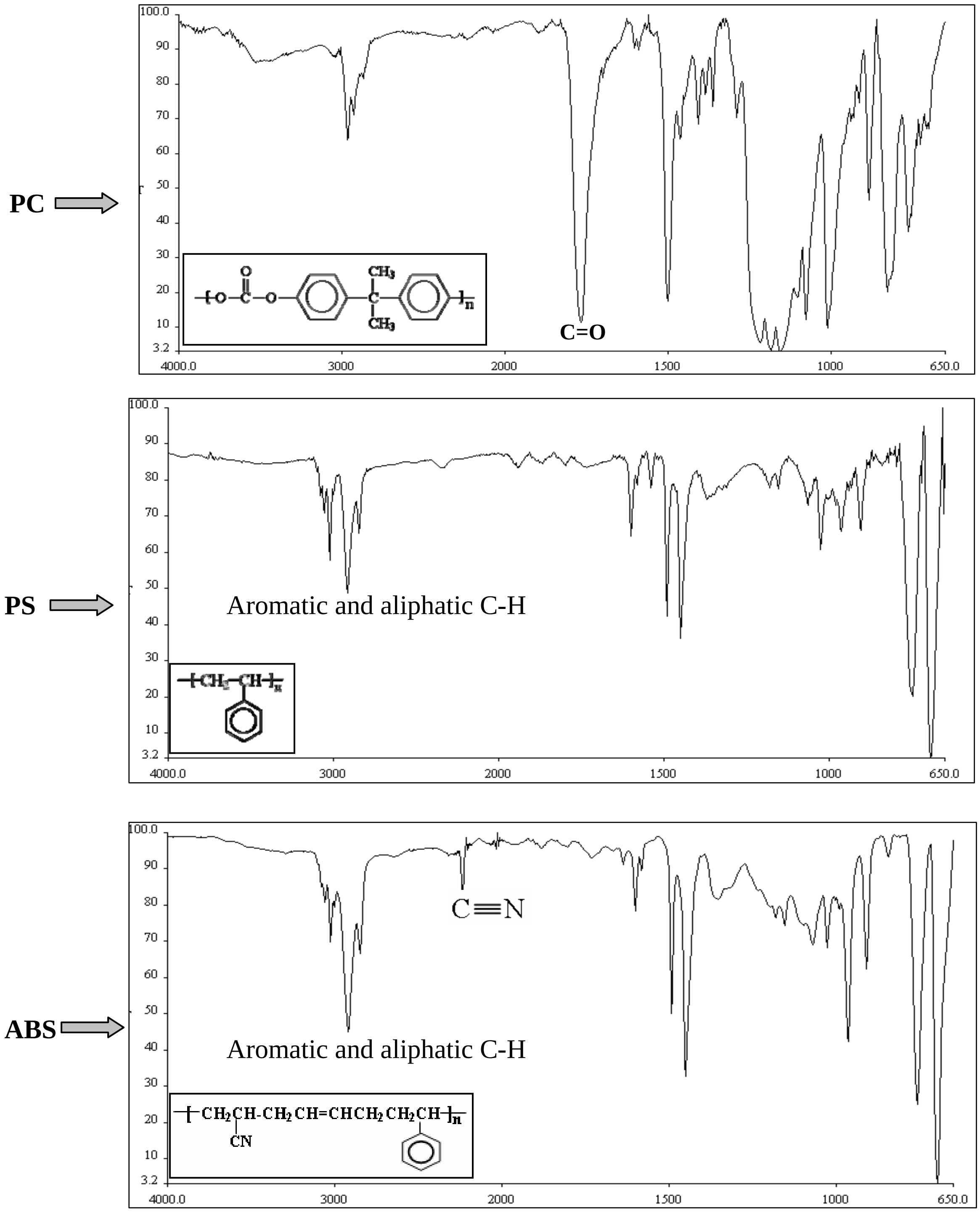

Figure 54: FT-IR Spectra of PC, PS, and ABS

Based on these functional groups and "fingerprints" of these polymers, software in the FT-IR has been used to compare measured spectra against libraries of reference spectra, and results of matches were reported automatically.

It is clear that FT-IR is a powerful tool for qualitative identification of chemical bonds in a molecule. However, efforts at quantitative analysis using FT-IR proved to be particularly difficult. The peak height and peak area of the functional groups in polymers were both calculated to obtain a calibration curve, so that it could be used to predict the composition of plastic mixtures. Such efforts failed because of the poor reproducibility and variability in the calculated data. Therefore, elemental analysis was used because of the very good repeatability and linearity of the experimental data. It is used to determine the percent composition of each element present in an organic chemical compound.

3.3.5.2 Design of separation experiments

Separations of two binary mixtures of PC/PS and PC/ABS, and a ternary mixture of PC/PS/ABS were investigated. Solvents used were cyclohexane and acetone.

Separation of PC/PS

Figure 55 shows the basic steps required for the separation of PC from PS. As illustrated in Figure 55, when the mixture of PC/PS is added to cyclohexane, only PS is dissolved. Therefore PC can be filtered out. Adding ethanol into the PS/cyclohexane solution causes PS to be precipitated out immediately. The PS is then filtered and dried, and cyclohexane and ethanol can be recycled and reused.

Figure 56 shows the basic steps for the separation of PC and ABS. As shown in Figure 56, when the PC/ABS mixture is added to acetone, only ABS is dissolved. Therefore PC can be filtered out and then water is added to the ABS/acetone solution, ABS precipitates out immediately and is dried subsequently in a vacuum oven. Acetone and water can be separated by normal distillation and reused.

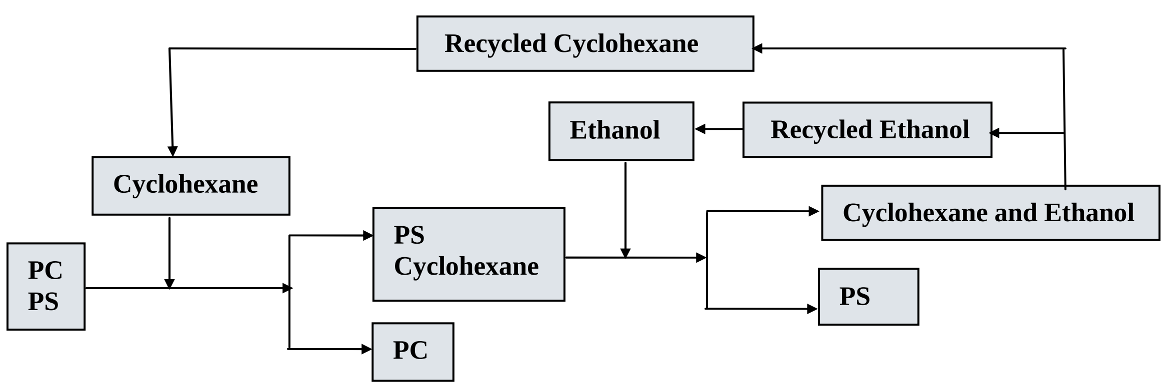

Figure 55: PC and PS separation process using selective dissolution method Separation of PC/ABS

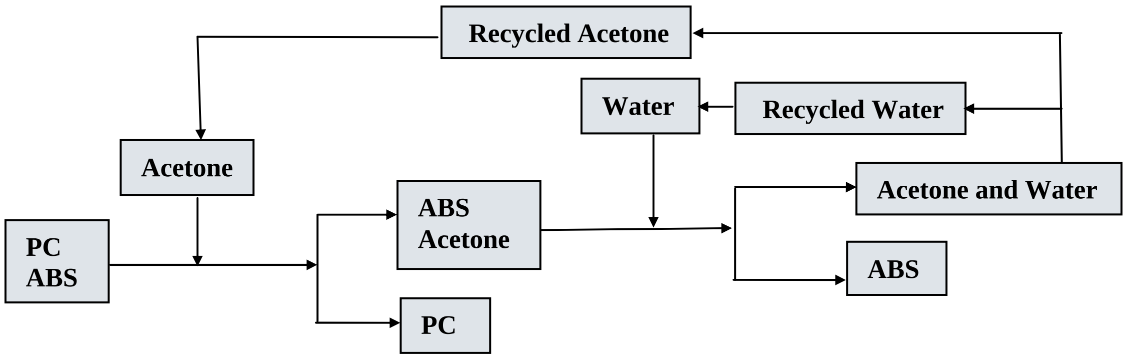

Figure 56 PC and ABS separation process using selective dissolution method

Separation of PC/PS/ABS

Figure 57 demonstrates the basic steps for the separation of a ternary mixture of PC/PS/ABS.

The separation process for PC/PS/ABS mixture is simply a combination of the two previous separations. Initially, it was expected that the ternary mixture could be added into a mixture of cyclohexane and acetone. However it was noticed that although cyclohexane and acetone are miscible, cyclohexane is a good antisolvent for ABS in acetone, which means that ABS will not dissolve in the mixture of cyclohexane and acetone. Therefore the PC/PS/ABS mixture cannot be added to the mixture of cyclohexane and acetone. Consequently, the separation of these three plastics must be carried out by removing one component first followed by subsequent removals.

Theoretically, either step of removing PS or ABS can be the first step, but it was decided that acetone should be used first, because ABS can be dissolved in acetone very easily at room temperature, while PS has to be dissolved in cyclohexane at the normal boiling point of cyclohexane. By removing ABS first, the whole process is simpler, and the energy to heat the mixture of polymers is saved because the amount of the polymer mixture is reduced since ABS has already been removed. Another reason is that the boiling point of acetone is 56.5°C, and cyclohexane is 80.7°C. So before cyclohexane was heated to its boiling point, part of the acetone can be evaporated, which will result in significant separation of the solvents.

Therefore, this separation experiment was carried out by first dissolving ABS in acetone, and then the precipitated mixture of PC/PS was treated using cyclohexane to remove PS from the mixture. Finally, a pure stream of PC was obtained.

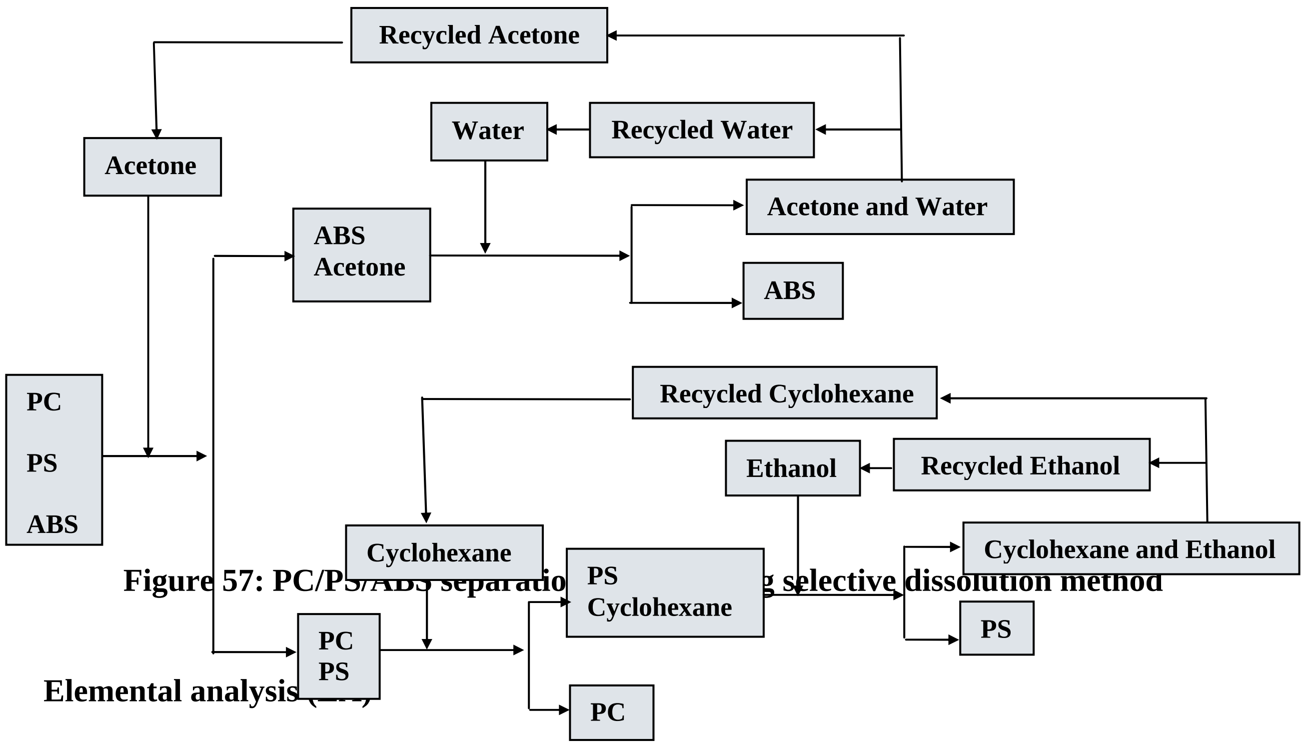

Figure 57: PC/PS/ABS separation using selective dissolution method

Elemental analysis (EA)

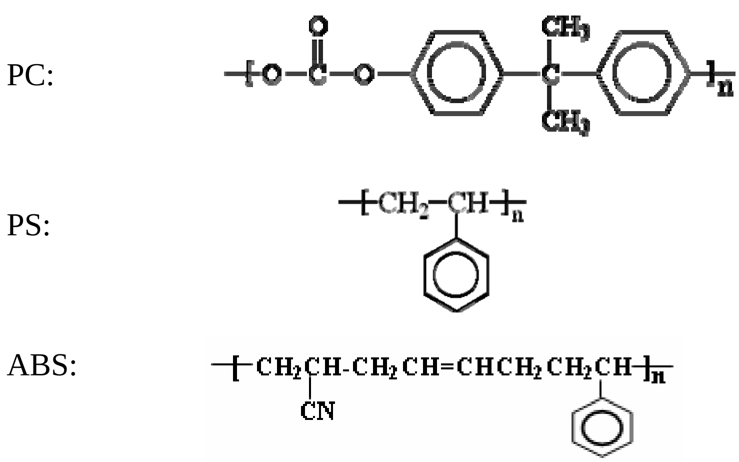

Figure 58: Molecular structures of PC, PS and ABS

By comparing the molecular structure of PC, PS, and ABS in Figure 58, it is clear that an oxygen analysis may be used to determine the relative quantities of PC and ABS or PS in a given mixture because only PC contains oxygen. Therefore, for a mixture of PC and PS or ABS, if the oxygen percent of the mixture can be measured, the ratio of PC in the mixture can be calculated.

The method of calculating the purity of recovered polymer is as follows. Referring to Table 34 and assuming that there is X percent of "pure" PC in the recovered PC from a mixture of PC and PS. Based on the oxygen material balance, the following equation was obtained:

Table 34: Results of oxygen analysis

sample	O% in Virgin sample	O% in recovered sample
PC	A	A'
PS	B	B'

$$XA + (1 - X)B = A' \qquad (1)$$

Hence, the purity of PC is:

$$X = (A' - B)/(A - B) \qquad (2)$$

Experimental Procedure Used in Elemental Analysis

Elemental analysis was performed with a Thermo Quest Flash 1112 Elemental analyzer, which is manufactured by Thermo Electron Corporation. After drying, the recovered polymer is granulated into fine powder by using a mortar and pestle. About 2.5 mg of fine powder is taken as a sample and introduced into a silver capsule and sealed, the sealed capsule is loaded into an auto-sampler, which allows the sample to be dropped into a combustion chamber made of nickel coated carbon, which is maintained at approx. 1060°C. The pure oxygen in the sample combines with carbon to form CO that is then chromatographically separated from other combustion products. The analyzed gas is available for further quantitative analysis. By following this procedure, the oxygen percent of each polymer mixture was obtained.

Calibration Curve

A calibration curve that relates the relationship between oxygen percent and ratios of PC/PS, or PC/ABS was obtained. If the oxygen percentage of recovered polymer is measured, the purity of the polymer may be estimated from the calibration curve.

Material balance

In order to ensure that experiments are being performed correctly, it is required that a mass balance should be satisfied for each experiment. Results of just one group of experiments are shown here to demonstrate that the calibration curve experiments are conducted correctly. Some mixtures of PC and PS with different known ratios are taken as samples and dissolved in NMP. The material balances, listed in Table 35, show that each experiment performed to date has a recovery better than 93% with an average recovery of 96.8%.

Table 35: Material Balance of calibration curve experiment

PC% in PC/PS mixture	Sample weight(g)	Recovered sample weight(g)	Inorganic filler weight(g)	Recovery (%)
0.00	5	4.9	0	98
0.25	10	8.7	0.7	94
0.50	10	7.9	1.4	93
0.75	10	8.3	1.6	99
1.00	5	3.9	1.1	100

Note: Sample: 1. HP680 Rough Grey PC 2. Fujitsu Limited PS

PC and PS calibration curve

Calibration curves are used to predict the purity of recovered polymers. For a binary mixture of polymers, a theoretical curve can be obtained based on the oxygen content of the mixture.

The oxygen percent of PC and PS mixture with different ratios was analyzed by an Elemental Analyzer (EA) to generate the calibration curve of PC and PS. The calibration curve based on the experimental data is shown in Figure 59.

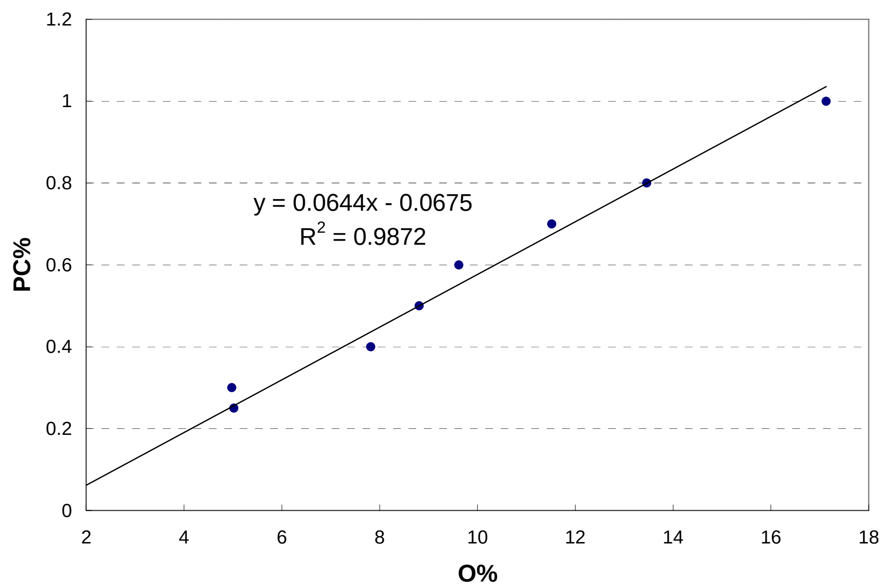

Figure 59: Calibration curve of PC/PS

A linear equation is obtained between oxygen percent and PC percent in the mixture. The result confirms that elemental analysis can be used to measure the purity of the recycled polymer.

PC and ABS Calibration Curve

The same calibration curve experiments were also performed with PC and ABS. The calibration curve is shown in Figure 60.

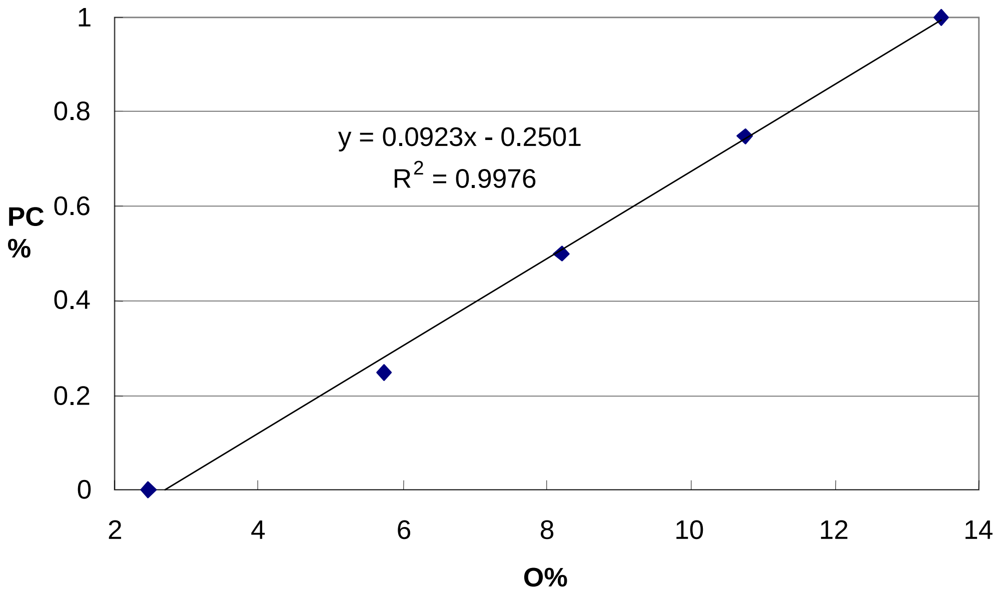

Figure 60: Calibration curve of PC/ABS

Separation experiment results

Material Balance

Three groups of separation experiments were carried out with mixtures of PC/PS=9/1, PC/ABS=9/1 and PC/PS/ABS=9/0.5/0.5. Three replicate experiments are done for each mixture. Material and oxygen balances were always performed for each experiment. A sample of 10 grams of a plastic mixture, 9 grams of PC and 1 gram of PS, were taken to perform the separation experiment. Material balances for three replicate experiments are shown in Table 36.

Table 36: Material balances of separation experiments with PC/PS = 9/1

No.	Recycled PC (g)	Recycled PS (g)	Total Recycled Polymer Weight (g)	Recovery (%)
1	8.90	1.00	9.90	99.00
2	9.00	0.95	9.95	99.50
3	9.02	0.72	9.74	97.40

As shown in Table 36, each separation experiment has a recovery better than 97% with an average recovery of 98.63%. In addition, oxygen balances based on the material balance in Table 36 were also checked and shown in Table 37. The oxygen weight in Table 37 is the amount of oxygen in each sample, and the total oxygen weight is the sum of oxygen weight of each sample in the mixture. Recovery is the ratio of total oxygen weight of separated sample to that of original sample. The results listed in Table 37 show that the material balance for oxygen closes to within less than 4%. An average oxygen recovery of 97.27% proved that it is possible to use an oxygen analysis to determine the purity of recovered polymers.

Table 37: Oxygen balances of separation experiments with PC/PS=9/1

Separation Experiment No.		Name of sample	Weight of sample (g)	O% of sample	Oxygen weight (g)	Total oxygen weight	Recovery (%)
Sample		PC	9.00	13.48	1.2132	1.2232	N/A
		PS	1.00	1.00	0.0069		
Separated sample	1	PC	8.90	13.18	1.1730	1.1806	96.52
		PS	1.00	0.76	0.0076		
	2	PC	9.00	13.20	1.1880	1.1964	97.81
		PS	0.95	0.88	0.0084		
	3	PC	9.02	13.16	1.1870	1.1924	97.48
		PS	0.72	0.75	0.0054		

For the separation experiments with PC/ABS=9/1, an average material recovery of 99.30% and an average oxygen recovery of 99.15% was found. The experimental data of material and oxygen balance were listed in Tables 38 and 39.

Table 38: Material balances of separation experiment with PC/ABS=9/1

No.	PC Weight (g)	ABS Weight (g)	Total Weight (g)	Recycled PC (g)	Recycled ABS (g)	Total Recycled Polymer Weight (g)	Recovery (%)
1	9.00	1.00	10.00	9.10	0.70	9.80	98.00
2	9.00	1.00	10.00	9.00	1.00	10.00	100.00
3	9.00	1.00	10.00	9.15	0.84	10.00	99.90

Table 39: Oxygen balances of separation experiment with PC/ABS=9/1

Experiment No.		Name of sample	Weight of sample (g)	O% of sample	Oxygen weight (g)	Total oxygen weight	Recovery (%)
Sample		PC	9.00	13.48	1.2132	1.2378	N/A
		ABS	1.00	2.46	0.0246		
Separated sample	1	PC	9.10	13.20	1.2012	1.2261	99.05
		ABS	0.70	3.55	0.0249		
	2	PC	9.00	13.18	1.1862	1.2197	98.54
		ABS	1.00	3.35	0.0335		
	3	PC	9.15	13.19	1.2069	1.2360	99.85
		ABS	0.84	3.46	0.0291		

For the separation experiments with PC/PS/ABS=9/0.5/0.5, 96.23% material recovery and 95.82% oxygen recovery were found. Experimental data for PC/PS/ABS separation experiments are shown in Tables 40 and 41.

Table 40: Material Balances of separation experiment with PC/PS/ABS=9/0.5/0.5

No.	PC Weight (g)	PS Weight (g)	ABS Weight (g)	Total Weight (g)	Recycled PC (g)	Recycled PS (g)	Recycled ABS (g)	Total Recycled Polymer Weight (g)	Recovery (%)
1	9.00	0.50	0.50	10.00	8.75	0.30	0.45	9.50	95.00
2	9.00	0.50	0.50	10.00	9.00	0.40	0.40	9.80	98.00
3	9.00	0.50	0.50	10.00	8.70	0.40	0.47	9.57	95.70

Table 41: Oxygen Balances of separation experiment with PC/PS/ABS=9/0.5/0.5

Experiment No.		Name of sample	Weight of sample (g)	O% of sample	Oxygen weight (g)	Total oxygen weight	Recovery (%)
Sample		PC	9.00	13.48	1.2132	1.2305	N/A
		PS	0.50	1.00	0.0050		
		ABS	0.50	2.46	0.0123		
Separated sample	1	PC	8.75	12.80	1.1200	1.1340	92.16
		PS	0.30	0.91	0.0027		
		ABS	0.45	2.52	0.0113		
	2	PC	9.00	13.40	1.2060	1.2194	99.10
		PS	0.40	0.85	0.0034		
		ABS	0.40	2.49	0.0100		
	3	PC	8.70	13.42	1.1675	1.1839	96.21
		PS	0.40	0.82	0.0033		
		ABS	0.47	2.79	0.0131		

From these data, it is clear that the material balances for the separation experiments close within acceptable limits. It is also noticed that a higher oxygen recovery can be obtained if the material recovery is higher. This reasonable relationship between oxygen recovery and material recovery further proves the correctness of the separation experiments. Recoveries of less than 100% occur because there is always some loss of material. Very small amount of plastic can be lost in the filtration process because of sticking to the filter paper and this amount of plastic is too small to collect.

Separation Results

Since pure polymers do not exist in recycled material, samples used in all separation experiments are analyzed by EA to get the oxygen percent of these samples. Based on these data, purity of recovered polymers was calculated. Table 41 shows the EA results of the original samples. All oxygen percentages listed in the tables are average data.

Table 42 Oxygen percentages of original samples

sample	PC	PS	ABS
Oxygen%	13.48	1.00	2.46

PC/PS Separation

As mentioned in the previous section, 10 grams of plastic mixture with 90% PC and 10% PS were taken to perform the separation experiments. Recycled PC and PS were taken for oxygen analysis by EA. Results of oxygen analysis are shown in Table 43.

Table 43: Oxygen analysis results of recycled PC and PS

No. of Experiments	O% in Recycled PC	O% in Recycled PS
1	13.18	0.76
2	13.20	0.88
3	13.16	0.75

It was noticed that after the separation experiments the percentages of oxygen in recycled PC are all lower than 13.48%, which is the oxygen percent in the original sample. This phenomenon may be explained by the fact that a small amount of PS is left in PC if PS does not dissolve completely, which would result in the decreased oxygen percentage in recycled PC. Another possibility is that there are some impurities in the PS. These impurities contain oxygen but do not dissolve in cyclohexane. They are left in PC during the filtration process, which would also result in lower oxygen content in recycled PC. Moreover, the existence of impurity in PS could also explain why there is oxygen in the original PS sample, and when these impurities are removed, the oxygen percentage in PS is also decreased as shown in Table 43.

It was also noticed that after the separation process the oxygen content in PS is also reduced, since impurities that contains oxygen in PS are removed. For this reason, it can be said that PS is purified during the separation process. Theoretically, if this lower oxygen percentage is used to calculate the purity of recycled PS, negative results will be obtained. Therefore, the purity of recovered PS cannot be calculated in this work. It is just assumed that the purity of PS is increased to 100% from 10% by comparing with the original sample.

The purity of PC must be calculated. Referring to data listed in Tables 42 and 43 and assuming that there is X percent "pure" PC in recycled PC, from oxygen mass balance, the following equation is obtained:

$$X \times 13.48 + (1 - X) \times 1.00 = 13.18 \tag{3}$$

Hence

$$X = 97.60\% \tag{4}$$

In this way, the purity of both recovered polymers is calculated. The results for each experiment are shown in Table 44.

Table 44: Calculated purity of recycled polymer

No. of experiment	1	2	3	Average
Purity of recycled PC (%)	97.60	97.76	97.44	97.60

From Table 44, after the separation, the purity of PC is increased from 90% to an average purity of 97.60%. Estimated purity by calibration curve of PC and PS is not presented here because samples of PC used in the separation are different from the PC used in the calibration curve experiments. Because the oxygen content is different in different samples of PC, this difference cannot be accounted for completely from the experiment by removing inorganic fillers from the original sample. Therefore, different calibration curves should be generated for each different sample.

PC/ABS Separation

A 10 gram sample of plastic mixture with 90% PC and 10% ABS were dissolved in acetone to perform separation experiments. The same purity analysis procedure as described in the PC/PS separation process is followed. Oxygen analysis and purity results are shown in Table 45.

Table 45: Oxygen analysis results and calculated purities of PC and ABS

No. of Experiments	O% in Recycled PC	O% in Recycled ABS	Purity of Recycled PC (%)	Purity of Recycled ABS (%)
1	13.20	3.55	97.46	90.11
2	13.18	3.35	97.28	91.94
3	13.19	3.46	97.37	90.93
Average	13.19	3.45	97.37	90.99

As shown in Table 45, the oxygen percentage of recycled PC is decreased from 13.48% in the original sample. This is explained by the fact that impurities in ABS are left in PC. But the oxygen content of recycled ABS increased from 2.46% to an average of 3.45%. The only explanation is that this sample of PC has a very low solubility in acetone, and a small amount of the PC on the surface dissolved in acetone together with ABS, and remained in ABS, which contributes to an increased oxygen percentage in recycled ABS. Also because of this, the purities of PC and ABS are both calculated. Calculated results are listed in Table 45. After separation, the purity of PC is increased from 90% in the original sample to an average purity of 97.37%, and the average purity of the recovered ABS is 90.99% compared to the original sample of 10% ABS.

PC/PS/ABS Separation

A 10 gram sample of plastic mixture with 90% PC, 5% PS, and 5%ABS was taken to perform separation experiments. Oxygen analysis results and calculated purities are shown in Table 46.

Table 46: Oxygen analysis results and calculated purities of PC and ABS

No. of Experiments	O% in Recycled PC	O% in Recycled PS	O% in Recycled ABS	Purity of Recycled PC (%)	Purity of Recycled ABS (%)
1	12.80	0.91	2.52	93.83	99.46
2	13.40	0.85	2.49	99.27	99.73
3	13.42	0.82	2.79	99.46	97.00
Average	13.21	0.86	2.60	97.52	98.73

As mentioned previously, ABS is removed first. For the same reason described in the PC/ABS separation, the percent oxygen of PC is decreased and that of ABS is increased. When calculating the purities of PC and ABS, it is assumed that PS in the mixture is removed completely to simplify the calculation. Therefore, the same purity analysis procedure as described in PC/PS separation is used. As shown in Table 46, an average purity of 97.86% PC is obtained from the 90% PC in the original sample. The purity of ABS is increased from 5% in original sample to 98.73% in recycled ABS. For the same reason described in PC/PS separation, oxygen percentage of recycled PS is reduced, and PS is purified during the separation process. Therefore the purity of PS cannot be predicted by calibration curve. It is also assumed that the purity of PS is increased form 5% to 100% by comparing with the original sample.

3.3.5.3 Preliminary Economic Analysis

In this work, a preliminary investigation of the process economics for a separation process of PC/PS/ABS is carried out. This study assumed that 1000kg/day of mixed plastics is to be treated in a batch process. The components of the mixed plastics are 90% PC, 5% percent PS, and 5% percent ABS.

Flow diagram and flow table

Based on the composition of mixed plastics, a separation process was designed operate 340 day/year, two batches per day, and eight hours per batch to separate the mixed plastics. The flow diagram of this process is shown in Figure 8 and the accompanying stream table is given in Table 46.

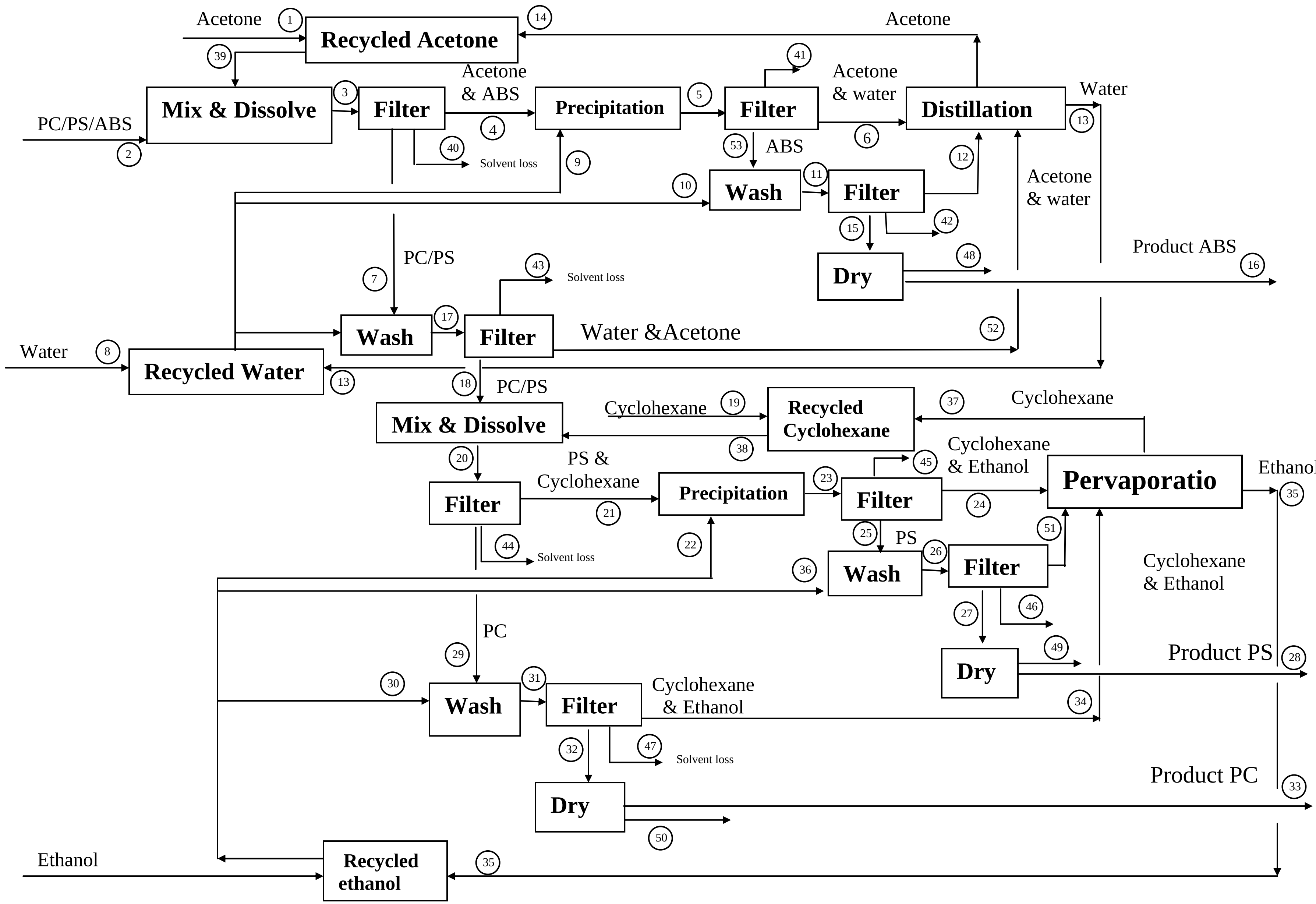

Figure 61: Flow diagram of PC/PS/ABS separation

Table 47: Flow table for PC/PS/ABS separation process

Stream No.		1	2	3	4	5	6	7	8	9	10	11	12	13	14
T (°C)		25	25	25	25	25	25	25	25	25	25	25	25	25	25
Mass Flow (Kg/h)	PC	0.0	4.1	4.1	0.0	0.0	0.0	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	PS	0.0	2.1	2.1	0.0	0.0	0.0	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ABS	0.0	2.1	2.1	2.1	2.1	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0	0.0
	Acetone	0.0	0.0	164.2	164.2	164.2	164.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	164.2
	Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	208.3	20.8	20.8	20.8	41.7	0.0
	Cyclohexane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Ethanol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Total Mass flow	0.0	8.3	172.5	166.3	166.3	164.2	6.2	0.0	208.3	20.8	22.9	20.8	41.7	164.2

Stream No.		15	16	17	18	19	20	21	22	23	24	25	26	27	28
T (°C)		25	50	25	25	25	80	80	25	25	25	25	25	25	50
Mass Flow (Kg/h)	PC	0.0	0.0	4.1	4.1	0.0	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	PS	0.0	0.0	2.1	2.1	0.0	2.1	2.1	0.0	2.1	0.0	2.1	2.1	2.1	2.1
	ABS	2.1	2.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Acetone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Water	0.0	0.0	20.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cyclohexane	0.0	0.0	0.0	0.0	0.0	166.7	166.7	0.0	166.7	166.7	0.0	0.0	0.0	0.0
	Ethanol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	81.8	81.8	81.8	0.0	8.2	0.0	0.0
	Total Mass flow	2.1	2.1	27.0	6.2	0.0	172.9	168.8	81.8	250.6	248.5	2.1	10.3	2.1	2.1

Table 47 (continued)

Stream No.		29	30	31	32	33	34	35	36	37	38	39	40	41	42
T (°C)		25	25	25	25	50	25	25	25	25	25	25	25	25	25
Mass Flow (Kg/h)	PC	4.1	0.0	4.1	4.1	4.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	PS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ABS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Acetone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	164.2	0.0	0.0	0.0
	Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Cyclohexane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	166.7	166.7	0.0	0.0	0.0	0.0
	Ethanol	0.0	8.2	8.2	0.0	0.0	8.2	98.1	8.2	0.0	0.0	0.0	0.0	0.0	0.0
	Total Mass flow	4.1	8.2	12.3	4.1	4.1	8.2	98.2	8.2	166.7	166.7	164.2	0.0	0.0	0.0

Stream No.		43	44	45	46	47	48	49	50	51	52	53	54	55
T (°C)		25	25	25	25	25	25	25	25	25	25	25	25	25
Mass Flow (Kg/h)	PC	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	PS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	ABS	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.1	0.0	0.0
	Acetone	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Water	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	20.8	0.0	0.0	20.8
	Cyclohexane	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Ethanol	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.2	0.0	0.0	0.0	0.0
	Total Mass flow	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.2	20.8	2.1	0.0	20.8

Initial raw material cost

From the calculated amount of solvents and antisolvents in Section 5.1, the initial raw material cost is estimated and listed in Table 15. Prices of solvents are quoted from *Chemical Market Reporter*. It is assumed that for all solvents except water three days supply are initially purchased and stored. These costs are included in the initial fixed capital investment.

Table 48: Initial raw material cost

Material	Mass flow (kg/day)	Price ($/kg)	Year cost($/year)
Acetone	3940	$0.389	$4,598
Ethanol	2355	$0.472	$3,334
Cyclohexane	4000	$0.476	$5,712
water	6000	$0.067	$402
Total cost			$14,046

Equipment choice and costs

On the basis of the flow diagram in Figure 61, appropriate equipment was selected for each processing step.

Tanks

Twelve tanks, which are made of stainless steel 304, were selected for the whole process. The volume of tanks depends on the total volume of solvents and polymers. It was assumed that the tanks are to be half filled. The cost of API Standard tanks was taken from Walas [1] and the formula to calculate the purchased cost of these tanks.

The equation used to estimate purchased cost of these tanks is:

$$C = 2.4\exp[2.631 + 1.3673(\ln V) - 0.06309(\ln V)^2]\,\$ \qquad (5)$$

Where,

$1300 < V < 21{,}000\,gal$ $\quad V$ is the volume of tank

The chosen tanks and their purchased equipment cost are listed in Table 49.

Table 49: Sizes and costs of tanks

No. of tanks	Calculated volume (gallon)	Capacity (gallon)	Diameter (inch)	Length (ft-in.)	Thickness (inch)	Purchased equipment Cost($)
1	1571.87	1500	64	9-0	3/16	$ 7,276
2	1599.72	1500	64	9-0	3/16	$ 7,276
3	2654.48	3000	64	18-9	3/16	$ 7,511
4	1994.03	2000	64	12-0	3/16	$ 7,447
5	144.77	280	42	4-0	3/16	$ 4,779
6	370.91	550	48	6-0	3/16	$ 6,000
7	78.73	280	42	4-0	3/16	$ 4,779
8	292.18	280	48	4-0	3/16	$ 4,779
9	1320.90	1500	64	9-0	3/16	$ 7,276
10	1585.08	1500	64	9-0	3/16	$ 7,276
11	792.54	1000	48	12-0	3/16	$ 6,873
12	1320.90	1500	64	9-0	3/16	$7,276
Total cost						$78,553

Filters

Four stationary screen separators were selected for the filtration process. In Figure 61, Filter No. 1 will be used for stream 3 and 17. Filter No. 2 is used for stream 20 and 31, and Filter No. 3 is used for stream 5 and 11. And Filter No. 4 is used for stream 23 and 26. Assuming the average bulk density of polymer is 1000kg/m^3, the volume of polymer to be treated in the filtration process per batch were calculated and assuming the depth of loading for each filter is 3 in., the filtration areas for the four different filters were obtained. Based on the filtration area and the size of polymer to be filtered, the sizes of screen for filters were decided and listed in Table 50 and the purchased equipment costs were obtained [2].

Table 50: Size and costs of vibrating screen separator

No. of filters	Mesh of screen	Clear opening(in.)	Wire diameter(in.)	Area of filtration (ft^2)	Purchased equipment cost($)
1	12	0.055	0.028	68	$ 17,600
2	12	0.055	0.028	64	$ 17,200
3	12	0.055	0.028	4	$ 5,300
4	12	0.055	0.028	4	$ 5,300
Total cost					$ 45,400

Dryer

Vacuum tray dryers are selected for three different polymers because of the lower working temperature. T he amounts of each polymer to be treated in each batch are 450 kg PC, 25 kg PS and 25 kg ABS. Dryers are selected from Walas [1] according to the capacities listed in Table 50. In Table 51, four dryers are used for 450 kg PC, two dryer are selected for 25 kg PS and 25 kg ABS. Costs of dryers were estimated from [2].

Table 51 Size and costs of Vacuum tray dryers

Capacity (kg/hr)	No. of trays	Tray spacing (cm)	Tray size (cm)	Depth of loading (cm)	No. of dryer	Unit Cost ($)	Purchased equipment Cost ($)
122	16	43	91.4 x 104	7.0	4	7,100	$28,400
27.7	24	43	85 x 98	4	2	6,700	$13,400
Total cost							$41,800

Distillation tower

A distillation tower was designed to separate acetone from water. This column will be operated continuously using feed tanks to regulate the flow from the batch process. Details of the column design are given in Table 52.

Table 52: Size and cost of distillation tower

Tower	Tower description	Tower MOC	No. of trays	Tray spacing (in.)	Height (ft)	Diameter (ft)	Purchased equipment Cost
1	20 carbon steel sieve trays	Carbon steel	20	6	12	1.4	$ 18,300

Condenser and Reboiler

Simple tubular exchangers were used for the condenser and reboilers of the column. Details of these exchangers are given in Table 53.

Table 53: Size and cost of heat exchanger

Heat exchanger	Type of exchanger	Tube pressure (barg)	MOC	Area (m^2)	Purchased equipment cost ($)	Annual utility cost ($)
1	Double pipe	2	Stainless steel /carbon steel	1.87	2,600	497
2	Double pipe	2	Stainless steel /carbon steel	1.00	2,210	20,398

Pumps

Six centrifugal pumps were chosen for the whole process as shown in Table 54.

Table 54: Pump costs

Able Pump type	No. of pump	Power (horsepower)	MOC	Purchased equipment cost	Annual utility cost
Centrifugal	6	1.4	Carbon steel	$2,460	$ 618
Total cost				$14,760	$3,708

The purchased equipment costs and annual utility costs for distillation tower, heat exchanger and pumps are quoted from Turton et al. [3].

Pervaporation equipment

The separation of organic solvent mixtures is the least developed application of pervaporation. Therefore, it is difficult to find information about equipment cost evaluation. But, in principle, pervaporation could be used as substitute or supplement to distillation process with lower cost and energy savings. This is definitely true for the separation of azeotropes and close boiling-point liquids, which are difficult to separate with conventional distillation techniques. So in this work, it was assumed that the cost of pervaporation equipment for cyclohexane/ethanol separation is at most the same as the cost of distillation tower discussed above. So, the purchased cost of this equipment is also $18,300. The main utility of pervaporation process is the energy cost to evaporate cyclohexane and ethanol. Therefore, the annual utility of this equipment is roughly estimated as follows:

Capital cost

Referring to Turton [3], the Lang Factor method was used to estimate the capital cost of the whole process. The total cost is determined by multiplying the total purchased cost for all the major items of equipment by a constant. The constant multiplier is called the Lang Factor (F_{lang}).

The capital cost calculation is determined by using the following equation

$$C_{TM} = F_{Lang} \sum_{i=1}^{n} C_{p,i} \quad (6)$$

Where, C_{TM} is the capital cost (total Module) of the process

$C_{p,i}$ is the purchased cost for the major equipment units

n is the total number of individual units

F_{lang} is the Lang factor

For a solid-fluid processing plant, F_{lang} =3.63. The purchased equipment cost was summarized in Table 55.

Table 55 Purchased equipment costs

Equipment	Purchased equipment cost
Tank (12 units)	$ 78,553
Filter (4 units)	$ 45,400
Dryer (6 units)	$ 41,800
Distillation tower (1 unit)	$ 18,300
Condenser (1 unit)	$ 2,600
Reboiler (1 unit)	$ 2,210
Pump (6 units)	$ 14,760
Pervaporation equipment (1 unit)	$ 20,700
Total	$ 221,903

Therefore, the capital cost (*FCI or* C_{TM}) including the initial raw material cost is:

$$C_{TM} = 23{,}133 + 3.63 \times \$221{,}903 = \$828{,}641 \quad (7)$$

Or,

$$P = \$\ 828{,}641 \quad (8)$$

The equivalent annuity cost, before tax, A is obtained by equation

$$\frac{A}{P} = \frac{i(1+i)^{10}}{(1+i)^{10} - 1} = \frac{0.08(1+0.08)^{10}}{(1+0.08)^{10} - 1} = 0.149 \quad (9)$$

Hence,

$$A = \$123{,}468/\text{yr} \quad (10)$$

Cost of operating labor

The operating labor requirement for this work is given by equation provided by Turton et al. [3]:

$$N_{OL} = (6.29 + 31.7P^2 + 0.23N_{np})^{0.5} \quad (11)$$

Where, N_{OL} is the number of operators per shift

P is the number of processing steps involving the handling of particular solids

$N_{np} = \Sigma Equipment$ such as compressors, towers, reactors, heaters, exchangers

For the process considered in this work, P is 1, $N_{np} = 10$. Then the number of operators required per shift is:

$$N_{OL} = (6.29 + 31.7 \times 1^2 + 0.23 \times 10)^{0.5} = 6.35 \quad (12)$$

It is assumed that the facility operates 2 eight-hour shifts per day, 340 days per year. This requires (340 days/year $\times$ 2 shifts/day) 680 shifts per year. Each operator is assumed to work 240 shifts per year (5 shifts per week and 48 weeks per year, with 2 weeks sick leave and 2 weeks vacation). The number of operators needed to provide this number of shifts is [(680 shifts/year) / (240shifts/operator/year)] about 3 operators.

Then,

$$\text{Operating Labor} = 3 \times 6.35 \approx 19 \tag{13}$$

Assume a single operator is paid $12/hr for a 2000-hours year, there is one supervisor per shift, who is paid $18/hr, and then the operation labor costs are:

$$\text{Operating labor costs} = 17 \times 12 \times 2000 + 2 \times 18 \times 2000 = \$480{,}000 / yr \tag{14}$$

Calculation of utilities

Based on data above, a utility summary for all the equipment is given in Table 56.

Table 56: Summary of the utility costs for the equipment

Equipment	Annual Utility cost
Dryer	$ 4,180
Condenser	$ 497
Reboiler	$ 20,398
pump	$ 3,708
Pervaporation equipment	$ 8,801
Total	$ 37,593

The total utilities for the whole process is

$$\text{Total utilities} = \$\ 37{,}593/\text{yr} \tag{15}$$

Cost of manufacturing

From Turton [3], the cost of manufacturing, COM , can be determined by equation as follow:

$$COM = 0.180 C_{TM} + C_{OL} + (C_{UT} + C_{WT} + C_{RW}) \tag{16}$$

The following cost information have already been obtained:

Fixed capital investment C_{TM}	$123,468/yr
Raw material cost C_{RM}	0
Utilities C_{UT}	$37,593/yr
Cost of operating labor C_{OL}	$480,000/yr
Cost of waste treatment C_{WT}	0

The cost of waste treatment is considered zero because the cost evaluation is based on the assumption of no solvent loss. Therefore, the total manufacturing cost is:

$$COM = 0.180 \times 123{,}468 + 480{,}000 + 37{,}593$$

$$COM = \$0.540 \times 10^6 / yr \tag{17}$$

According to the total manufacturing cost, the selling price required to breakdown is:

$$\$0.540 \times 10^6 / yr \div 340 day / yr \div 1000 kg / day \div 2.2 lb / kg = \$0.72 / lb \qquad (18)$$

Therefore, this result shows that solvent separation of 1000kg/day mixed plastics is expensive.

A similar economic analysis was carried out for a plant that processed 10,000kg/day of mixed plastics. The results are listed in Table 57. It was assumed that the same labor force would process 10,000kg/day as was estimated for the 1,000kg/day case.

Table 57: Equipments and costs for 10, 000kg/day plastic mixtures

Equipment	Purchased equipment cost	Annual utility cost
Tank (12 units)	$246,800	NA
Filter (4 units)	$128,500	NA
Dryer (6 units)	$112,600	$11,260
Distillation tower (1 unit)	$18,300	NA
Condenser (1 unit)	$6,580	$4,970
Reboiler (1 unit)	$3,700	$203,980
Pump (6 units)	$24,072	$37,080
Pervaporation equipment (1 unit)	$18,300	$88,010
Total	$558,852	$345,300

And the manufacturing cost is *COM* = $0.886 x 10^6/*yr*, the price required for breakeven is $0.12/lb. This result shows that the solvent-based separation of mixed plastics is economically feasible if the throughput is 10,000 kg/day. However, it should be pointed out that this data is optimistic because the current economic analysis is based on the best case, namely that there is no solvent loss anywhere in the process.

3.3.5.4 References

1. S.M. Walas, Chemical Process Equipment, McGraw-Hill, New York (1988)
2. www.matche.com.
3. R. Turton, R.C. Bailie, W.B. Whiting, J.A. Shaeiwitz, Analysis, Synthesis, and Design of Chemical Processes, 2nd ed., Prentice-Hall, Upper Sadle River, NJ 92002)

Task 3.4 Utilization and Awareness – Outreach to Users (PAZ)

The Recipient shall develop and provide outreach and education services to promote EOLE recycling. This will involve developing an outreach strategy, creating educational material that stresses the importance of returning and recycling end-of-life electronics, educating municipalities on the importance of collecting end of life electronics, and implementing the outreach strategy. These educational services shall be directed toward consumers, equipment manufacturers, non-governmental and private sector organizations about their respective roles in the recycling of end of life electronics.

The Recipient shall convene two meetings that will further Stakeholder Dialogue's work products; integrate EETP Recycled Material Guidelines into industry practice and e-

commerce; conduct a supply characterization generator survey; compile a matrix to identify "gaps" between supply and demand for recovered resins; identify and coordinate demonstration projects relating to recovered engineering thermoplastics for the Government; coordinate with Underwriters Laboratory in revising testing standards for recognition of recycled resins and developing a certification program for listed or banned plastic additives.

<u>Description of work performed, accomplishments and results:</u>

Information on activities performed for this task can be found in Appendix O.

Task 3.5 Project Master Plan and Site Issues (PAZ)

The Recipient shall update a 5-year implementation of a master plan developed under Task 2.5. The Recipient shall update financial plans developed in Task 2.5.

The Recipient shall conduct studies related to the planning for the use of the selected site as a recycling/processing site as well as studies regarding the use of the building for operations. These studies will include: boundary surveys, site assessments for location of utilities, geo-technical evaluations, Phase I site assessments.

The Recipient shall continue to identify possible candidates to participate in the electronics recycling effort. There will be a focus on selecting candidates who can utilize the output from the plastics separation operation.

<u>Description of work performed, accomplishments and results:</u>

PAZ purchased a one-fifty-six acre tract of land that had an existing 315,500 square foot building and is currently developing the tract into a state-of-the- art industrial park aptly named the Polymer Technology Park (PTP). The PTP will be the home of the Mid-Atlantic Recycling Center for End-of-life Electronics (MARCEE Project). The site will house a cluster of facilities that are dedicated to recycling, re-engineering and remanufacturing projects from end-of-life electronics. The brick and mortar portion of the project will not utilize any DOE or EPA funds. It will be entirely financed by lease income from the existing 313,500 square foot building as well as other public ($4.3 million grant from the State of WV for purchase) and private financial sources.

The long term financial success of the Polymer Technology Park and the "MARCEE Project" will be accomplished by the Polymer Alliance Zone's continued reinvestment of its' lease income (approximately $600,000 per year) from the existing 315,500 square foot building and by matching the public sectors financing programs with private sectors entrepreneurial capabilities and industry's technology. This financing will upgrade the existing facility as well as build out the infrastructure in the PTP. Once this is accomplished PAZ will step out of the project and will only be involved as requested.

PAZ contracted with Thrasher Engineering to complete the boundary surveys and create a master plan to incrementally develop the unused acreage in the PTP.

SDR Technologies and Envirocycle have been selected to develop the technologies to recycle end-of-life electronics. They were selected after an exhausting five year investigation of recyclers throughout the world. Unfortunately PAZ cannot report the results of our findings of the many companies we investigated. This is due to confidentiality agreements we signed with the many companies we investigated.

After all of the findings were in, SDR Technologies and Envirocycle were far superior in every category and came out as the obvious choice to lead the MARCEE private sector implementation portion of the recycling project.

Task 3.6 Industrial Information Exchange and Internet Trading Tools

The Recipient shall manage and support the existing suite of web-based information technology tools developed in Phase II, as well as research additional areas of the electronics recycling industry where the development of new tools can help impact the overall flow of materials. This includes evaluation of materials characteristics in regards to electronic marketplaces and the development of e-business support tools for areas such as information gathering, reporting, and analysis.

<u>Description of work performed, accomplishments and results:</u>

DN American's work focuses upon leveraging information technology tools in a way to help support the development of the electronics recycling infrastructure. This means working with different areas of information technology in order to support each of the growing electronics recycling initiatives. Efforts described in this section highlight activities based around information technologies such as: Web Development, Database Development, Data Warehousing, Web Services, XML, Content Management, and Marketplace demonstration.

Three primary areas of emphasis are based upon:

1. Information Exchange & Collaboration
2. Data Collection & Analysis
3. Electronic Marketplace support & Logistics

The following sub-task areas will highlight and describe activities that have helped position the MARCEE project into areas of support and will identify industry problems and describe MARCEE solutions.

In order to support all of the MARCEE information technology sub-task areas DN American provides technical infrastructure tasks that include:

- Provide T1 Internet connectivity for all MARCEE Project related tools.
- Provide Network Infrastructure support for Cisco Routers, Network Switches, and Firewalls.
- Provide 24/7 monitoring and support of MARCEE web and database servers.
- Maintain existing content and performed daily system maintenance.
- Responded to web site e-mail related messages.
- Perform Content Management activities including adding new contacts, adding organizations, adding content items, and maintaining web portal access.

- Performed security updates and installed operating system patches.
- Administered system databases and performed daily system maintenance.
- Compiled site statistics for all MARCEE websites
- Tested new system components.

Task 3.6.1 Development of GreenOnline Trading Network (PAZ)

The Recipient shall develop Green Online (GOL), an Internet based trading network for the rapidly growing field of environmental commerce. GOL shall offer customized transaction and Web-hosting services for business-to-business; consumer and retail based environmental commerce both in the U.S. and internationally. GOL will be designed to provide the focal point for trading all types of products and services in the environmental industry, which include, but not limited to: plastics recycling, brown-fields, green certification, renewable energy exchanges, distributed water markets, advanced emission trading, socially responsible investing, the World Bank Prototype Carbon Fund, pollution prevention technologies and market-based incentives, ecological computing and product substitution.

Description of work performed, accomplishments and results:

The original GOL platform was developed to support online commerce in the environmental community. This initial concept has been maintained throughout the MARCEE project but the emphasis has been place upon electronics recycling and the materials that are part of the recycling process for end-of-life electronics. Even though are emphasis has been squarely focused upon electronics recycling the tools and technologies developed under the MARCEE project have been created to support scalability and adaptability for other industries or support activities. The electronics recycling industry, even though it is a young and a very fragmented industry has the same basic information technology needs as other industries. These include information sharing & collaboration, data collection, data analysis, content management, and electronic marketplace support.

In order to validate the MARCEE information technology tools all of the areas developed under the GOL platform have been demonstrated in pilot project scale or full implementation scale. This includes supporting government/industry initiatives such as

- EPA Region III eCycling program,
- EPA National Plug-In to eCycling program,
- EPA Environmental Product Assessment Tool (EPEAT),
- National Center for Electronics recycling initiatives, and
- MARCEE demonstration marketplaces places to support Polymer Alliance Zone related activities including the MARCEE demonstration project with SDRT.

Task 3.6.2 Development of GreenOnline Enhancements (PAZ)

The Recipient shall develop specific enhancements to the GOL platform that will ensure its competitiveness for the latest technology design implementations, which will include but not necessarily be limited to: the software code for the overall platform upgrades and platform integration with existing exchanges, upgrades to the design as they relate to usability and market relevance, and technical performance related to reliability, speed of execution, maintainability and security, as well as useful and operational linkages to all related environmental e-commerce sites currently available.

Using the GOL tool, the Recipient shall develop an assessment management system that will provide a resource for handling, processing, and disposal of equipment; provide information to a third party organization about volumes and types of equipment being processed, and; provide feedback about its disposal both to the customer and to the original manufacturer.

Description of work performed, accomplishments and results:

This area primarily deals with enhancements to the GreenOnline platform. The original GOL system provided a platform for electronic commerce and marketplace development. However, this only supported one focus area of the MARCEE project and did not allow for support of information sharing, data collection, or content management. DN American added these additional features in an effort to better position the MARCEE information technology tools to support industry and government activities relating to electronics recycling.

1. DN American successfully migrated the old GreenOnline Active Server Page (ASP) source code over to the new Microsoft ASP.NET architecture. This allows for better control of source code updates, increased security, and XML integration.
2. DN American led the development of industry-created data standards to help provide a data standardization mechanism for all electronics recycling pilot projects. This allows for better information sharing and increased industry collaboration.
3. DN American created a robust online data collection system that allows for online data collection, data management, and data analysis.
4. DN American has also enhanced the marketplace capabilities of GreenOnline to support MARCEE efforts in electronics recycling. This provides an online mechanism for material sourcing and marketing of processed materials.
5. DN American developed a web-based content management system to work in conjunction with the MARCEE information technology platform that provides easy content management for the MARCEE web portal, MARCEE data collection tools, and the MARCEE electronic marketplaces.

Task 3.6.2.1 Continue Management of www.electronicsrecycling.org (PAZ)

The Recipient shall continue to manage the www.electronicsrecycling.org information exchange web site. In addition to website management, support for industry events, research activities under this project, and identification of potential sponsorship and teaming activities related to this Subtask will be performed.

<u>Description of work performed, accomplishments and results:</u>

The increased use of the Internet has allowed for the creation of web sites full of information relating to specific topic areas. The major drawback especially for fragmented industries like electronics recycling is that the information is scattered all over the web and it takes time to really find what you are looking for. When the MARCEE project first got established one of the common themes we heard from industry stakeholders and project participants was the lack of a centralized information resource for the electronics recycling industry. Therefore, the first aspect of information technology support was the creation of an industrial web portal.

Table 58: Themes for web portal

Industry Need: Information Sharing and Centralized Repository for electronics recycling information
MARCEE Solution: Creation of Electronics Recycling Web Portal
MARCEE – Project Related Outcomes: • Developed industry leading Web Portal to help showcase MARCEE activities. • Helped position MARCEE as a credible resource with agencies such as EPA, EIA, etc. • Created the infrastructure necessary to support a regional, national, or international electronics recycling model. • Created platform necessary to help support efforts of a National Coordinating Entity (NCE). • Created a collaborative platform for information sharing between industry stakeholders.

D.N. American set forth in the creation of the Electronic Recycling web portal and registered the domain http://www.electronicsrecycling.org/com/net. The initial focus was in the development of a centralized industry resource that could be used for sharing of information relating to electronics recycling. This web portal has grown to become one of the most recognized web resources on the Internet. There is currently over 560 pieces of industry related content accessible via the web portal. The web portal has played an instrumental part in creating a platform for industry outreach and awareness. Currently, there are over fifty web sites that maintain links back to the electronicsrecycling.org site. The electronics recycling web portal has also been mentioned in local newspaper markets such as Los Angeles, Chicago, Philadelphia, etc. as well as USA Today. It has been mentioned in magazine articles in Wired (Both U.S and Japan), CIO (Both U.S. and Asia), and Business 2.0. Microsoft also maintains 2 pages on their web site where they mention the electronicsrecycling.com site as a resource for information concerning electronics recycling.

In response to the efforts put forth under the MARCEE project in developing information technology support for the electronics recycling industry, D.N. American was invited to participate in an industry panel presentation at the RECCON ’03 conference held in Bilbao Spain. This was a first-of-its-kind conference bringing together industry stakeholders from both the United States and the European Union.

Summary Of Results -- Task 3.6.2.1

- **Industry Platform –** Content-rich web portal with over 560 pieces of content relating to electronics recycling.
- **Industry Penetration –** Electronicsrecycling.com has over 70 web sites providing referring links, currently located in top 5% of Internet search engines, and is generating over 50,000 requests per month.
- **Industry Exposure –** Mentioned in national and international newspapers, magazines, and web sites.
- **Industry Collaboration –** Integrated information with EIA consumer initiative website as well as EPA related programs such as Plug-in to eCycling.
- **International Collaboration –** Presented ideas at RECCON ’03 International Conference and IEEE ISEE Conference in 2004 and 2005.

Task 3.6.2.2 Development of Recycling Best Practices/Lessons Learned Electronic Repository (PAZ)

The Recipient shall develop a fully functional Best Practices/Lessons Learned repository utilizing the GOL platform to showcase Best Practices in electronics recycling fields such as disassembly, manufacturing, research, and plastics separation. The repository will allow public accessibility, and include data analysis and data mining tools to help disseminate the information and research findings found on the site.

Description of work performed, accomplishments and results:

Information exchange is a cornerstone for any industry and by utilizing electronic tools combined with the global connectivity of the Internet we can drastically impact the productivity of companies in today’s business environment. In order to maximize efficiencies industry needs to eliminate redundancies and streamline processes. By utilizing tools such as information web portals, electronic information repositories, and online best practice libraries, organizations can provide a value-added component to an industrial supply stream.

Sourcing in the electronics recycling industry is usually described as either post-consumer or post-industrial. The MARCEE project wanted to try and find the most up-to-date and relevant sources of information relating to the collection of materials. This opportunity presented itself within the Mid-Atlantic region in the scope of an EPA Region III supported take-back pilot program called eCycling. In support of the eCycling pilot, five individual states that make up Region III participated in over 45 electronics recycling collection events. However, the problem that surfaced was how to efficiently handle the tremendous amounts of data and analyze the data within a timely manner.

Table 59: Efficient Information Collection

Industry Need: Ability to collect electronic recycling take-back information in a cost-effective and timely manner.
MARCEE Solution: Develop a data collection system that would allow for almost real-time data collection and analysis.
MARCEE – Project Related Outcomes: • Leveraged MARCEE information technology tools to help provide faster access to data. • Provided MARCEE project with mechanism to access data in almost real-time fashion. • Utilized data to support the simulation and modeling work performed under the MARCEE project. • Provided credibility with agencies such as EPA, EIA and OEM's like Sony, Sharp, and Panasonic.

The creation of information technology infrastructure support by the MARCEE project has also initiated other agencies such as EPA to look towards the MARCEE project to help provide assistance in industry related activities. One such activity is in the creation of a standardized set of electronics recycling data elements and corresponding data collection forms.

- Data Collection elements and forms were distributed to EPA's Plug-In To eCycling pilot with Staples and the Product Stewardship Institute as well as electronics manufacturers Apple, Brother, Dell, Epson, Intel, Lexmark, Panasonic, Sharp, and Sony. This pilot involves 25 retail stores in Connecticut, Maine, New Hampshire, and Massachusetts.

- Data Collection to be performed by Office Depot's Nationwide In-store take back program

- Currently 11 localities in Virginia under the direction of Allan Lassiter of the Virginia Department of Environmental Quality are using the data collection forms.

- Data Collection forms are also being used as part of the Good Guys pilot in Pacific Northwest, Sego Jackson in Snohomish County, Washington and six electronics manufacturers

- The Florida Department of Environmental Protection recycling activities lead up by Jack Price has also provided initial feedback and has sent some preliminary data.

After performing some initial data collection from pilot projects DN American noticed that in order for this data to be effectively used there would need to be a standard reporting process that would allow similar data elements to be collected.

Table 60: Standard Reporting Process for Data Collection

Industry Need: Ability to collect electronic recycling data from multiple pilot projects in a common standardized format.
MARCEE Solution: Develop a set of industry-specific data elements that can be used by all pilot projects throughout the United States in order to collect comparable data.
MARCEE – Project Related Outcomes: • Created a mechanism so electronics recycling data could be compared in a more uniform way. • Positioned MARCEE project as an industry participate with OEM's, recyclers, etc. • Allowed MARCEE to be involved with the largest single take-back program within the US.

The MARCEE project took the lead in the development of these data elements by organizing a series of conference calls designed to flush out ideas and thoughts relating to electronics recycling data collected from take-back and pilot programs. This was a first-of-it's-kind series of conference calls where over 45 individual electronics recycling related stakeholders participated. As a result an initial set of data elements were generated and are currently being used by several pilot projects in VA, NJ, WA, and FL. In addition national retailers such as Staples, OfficeMax, and Best Buy will be utilizing these data elements and forms in support of the Plug-In To eCycling program.

Please refer to Appendix P for additional details and formats relating to the industry data guidelines.

In order to help support this need of common data elements and the ability to share data seamlessly between systems, DN American started integrating the use of Extensible Markup Language (XML) components into the MARCEE information technology tools. To understand how XML standards can integrate within an industry we first must look at the three types of standards that currently exist within the area of XML.

- Infrastructure Standards for the Web
- Interoperability Standards
- Industry / Business Specific Standards

The first area primarily deals with the development of standards that impact how the Internet functions and is currently being handled by the W3C[4]. The W3C has several working groups that concentrate on infrastructure, Internet resources, and software development. The second area is focused on how XML standards can be used to aid in interoperability between

[4] World Wide Web Consortium (W3C), (http://www.w3c.org)

systems. The OASIS[5] group is one example of a standards body working on topics such as a replacement for EDI transactions between electronic systems. The third area is the one that relates to the electronics recycling industry and leads to the development of XML standards for a specific industry. In order for the electronics recycling industry to utilize information technology tools efficiently such as online marketplaces or supply chain management tools, a commonly accepted terminology must be developed. This common terminology will ease the integration of data with existing systems and help increase the use of electronic tools, E-business platforms and other applications of evolving information technology solutions.

The electronics recycling industry is a prime example of an industry that could benefit from the use of information technology and an integrated supply chain management approach. Given the industry's historically low margins and developing status, the opportunity for cost reduction is attractive.

To demonstrate the need for a common terminology the MARCEE effort has supported several pilot or demonstration projects that have required multiple stakeholders or industry partners to communicate through the use of electronic systems. The following sections include a description of the pilot project along with a discussion as to how a common terminology or XML standards could aid in the development of additional information technology tools that support electronic commerce.

Companies can now collaboratively share ideas and concerns in a rapid and electronic format that allows for almost real-time collaboration from anywhere in the world. For example, companies in the United States can now share information with European firms on issues impacting material flow via the Internet. Electronics Recycling is a global concern as seen by the number of countries that have now enacted legislation regarding end-of-life electronics. Also, XML has the potential to become the technology enabler that allows for a dynamic information-sharing network to develop, however industry participation is vital to make this a reality.

Please refer to Appendix P for further information.

Summary Of Results – Task 3.6.2.2

- **Data Collection** - Developed primary database containing EPA Pilot Program Data results.
- **Industry Recognition** - Received EPA acknowledgement for assistance in data collection efforts at EPA annual meeting, Authored paper on "Development of XML Industry Standards For Information Exchange and Commerce" which was accepted for publication by IEEE.
- **Data Standards** - Created "first-ever" set of national data standards for electronics recycling.
- **Industry Participation** - Moderated a series of electronics recycling stakeholder conference calls with over 45 industry participants.
- **Industry Penetration** - Continued to position MARCEE as industry leader in data analysis, created centralized data repository for electronics recycling information that

[5] OASIS – Organization for the Advancement of Structured Information Standards. (http://www.oasis-open.org)

currently supports data from 19 programs, 11 states and reports on over 21,865,563 pounds of material.

- **Industry Collaboration** – Created an electronic best practices repository for information relating to electronic collection programs throughout the United States, Participated in industry discussions with National Electronics Manufacturing Initiative on development of industry XML standards.
- **R&D Collaboration –** Developed infrastructure to create best practices repository for research & development initiatives.
- **National/International Exposure –** Utilized electronicsrecycling.com platform to web-enable the best practices information in order to provide ease of use for data sharing, Presented overview of work within MARCEE project at IEEE International Symposium on Electronics in the Environment Conference.

Task 3.6.2.3 Demonstration of GOL Supply Chain Integration and Identification of R&D Efforts for Future Feedstock Supply (PAZ)

The Recipient shall utilize the GOL digital services platform to develop a feedstock locator system and a pilot marketplace for products developed from recycled EOLE components. Identification of tools that will impact different levels of the supply chain future R&D efforts for high-valued recycled composites will be accomplished under this Subtask.

Description of work performed, accomplishments and results:

The process of recycling electronics can take on many different flavors. There are several companies working in the field of recycling that use different processes and procedures in order to separate, process, and recycle the plastics, metals, and glass found in most consumer electronics. To make this a more efficient process and adaptable to electronic commerce a need for a better way to classify or characterize a challenging set of recycled materials was identified.

With financial support from the MARCEE project, industry participated in this effort in cooperation with the Gordon Institute at Tuft's University Stakeholder Dialogues on Recycling Engineering Thermoplastics from Used Electronic Equipment[6]. The Dialogue process has actively engaged companies throughout the supply chain, including major resin suppliers and original equipment manufacturers, along with plastics processors, molders, electronics recyclers, federal, state and regional government officials, and other industry experts. Over 60 organizations have participated in the Dialogue process since its inception. An industry-led Materials Characterization task force was created in order to help

focus efforts on the problem of complex material attributes. The Materials Characterization task force activities included:

- Development of standard terminology for recovered / reprocessed electronic engineering Thermoplastics (ETPs)
- Development of a classification / grading system to enhance buying / selling of recovered ETPs

[6] Stakeholder Dialogue's website– (http://www.electronicsrecycling.com/stakeholder)

- Establish / specify a set of standardized test protocols for the characterization of recovered ETPs
- Integration of classification system into plastics trading platform

As a result the EETP Recycled Material Characterization Matrix was developed. This matrix provides the necessary terminology to facilitate characterization and communication of complex recycled/recyclable plastic materials by several different attributes. The matrix was ultimately adopted as an industry standard by the Institute of Scrap Recycling Industries (ISRI) in 2003 and converted into an XML schema that is currently being utilized by GreenOnline.com™ for marketplace characterization.

Moving materials through the supply chain is a critical component of a successful recycling industry. The plastics and resins that make up the material used in plastic casings and monitor housings are very complex and they are often blended together, which makes it very difficult to recycle. Therefore, having the ability to characterize the material to some degree takes some of the guesswork out of recycling the material. To date the work performed in combining the materials characterization process with an online supply chain tool is very unique to the MARCEE project.

Table 61: Characterizing Potential Recycled Materials

Industry Need: Ability to characterize potential recycled materials to help facilitate communication of complex material attributes.
Solution: Develop an online material characterization tool built upon the EETP Matrix to aid in the processing of electronics recycling equipment.
MARCEE – Project Related Outcomes: • Building off of work performed by industry participation in Stakeholder Dialogues. • Increased MARCEE credibility by becoming involved with standards that have been adopted by ISRI. • Positioned MARCEE project to move to the forefront of support for electronic commerce. • Bringing to the attention of industry how complex a problem trading recycled materials can be.

In addition to the work mentioned in product characterization the MARCEE project is also looking at how to provide the product designers and engineers with information relating to the use of recycled polymers and resins. Without the proper information the product designers are less likely to use recycled materials. In combination with R&D work being performed at West Virginia University and materials studies performed by MBDC, D.N. American is gathering the initial requirements necessary to design a Recycled Materials Informatics System. This system would combine thousands of hours of research and product benchmarking and web-enable the results so Original Equipment Manufacturers (OEM's) can access information on the feasibility of recycling the materials. Again the

GreenOnline.com™ platform would provide the necessary information technology infrastructure necessary to support such a tool.

The use of the Internet for electronic commerce has drastically changed the way we look at marketing and selling of products in today's marketplace. However, some products are much more complex than selling books or CD's online. The MARCEE project identified this as a necessary step in the development of information technology infrastructure support. D.N. American has built off of the electronic marketplace components that were part of the original GreenOnline.com™ system and have provided several enhancements that allow electronics recycling organizations the ability to market and sell materials online. The use of online tools helps reduce the amount of overhead necessary to market goods and services via traditional salesforce methods. Industrial materials such as plastic, metals, and glass have numerous product characteristics and forms that drive a material's potential value to successfully market material online. In order to market complex materials via an online marketplace a trusted method of characterization is required. To demonstrate this concept a series of XML schemas were developed. The schemas, collectively named erXML, include a "Plastic Material" schema, which defines the basic set of information needed to describe plastic material. Other schemas go one step further and define acceptable values for certain attributes of this material. These schemas include "Loose Mixed Plastic", "Shredded Sorted Plastic", "Granulated TV Plastic", and several other schemas representing various grades of recyclable plastic material.

erXML Schemas are currently used for the GreenOnline.com™ marketplace to support an online "Material Characterization Wizard" which helps users specify exactly what type of plastic material they are posting. The wizard is made up of a series of web-based forms, which guide the user through a set of questions to determine the material type and ultimately ensure that the material specification conforms to the recycled material schema.

A software application called "Green Market Listing" makes use of the erXML "Market Listing" schema which defines the data necessary for posting a market listing on GreenOnline.com™. Also, the "Plastic Material" schema, mentioned earlier, defines the structure of the XML data being gathered and validates this data, which is then transferred via a web service to the GreenOnline.com™ marketplace. Once the XML document is received by the GreenOnline.com™ system, it is validated against a specific erXML schema and posted on the marketplace under the corresponding market category (e.g. "Loose Mixed Plastic").

Table 62: Develop Electronics Marketplace Capabilities

Industry Need: Develop electronic marketplace capabilities to help support the growth of the electronics recycling industry.
MARCEE Solution: Develop a series of demonstration marketplaces in order to market complex recycled materials throughout the supply chain.
MARCEE – Project Related Outcomes: • Provided industry support to electronics recycling processors who need to market recycled processed materials. • Showcased marketplace capabilities by utilizing several demonstrations in order to show product listings for goods and services. • Positioned MARCEE project to gain additional industry support from EIA, EPA, etc.

As part of this industry support D.N. American has developed a series of electronic marketplaces to help support the MARCEE project and the electronics recycling industry. Through the use of GreenOnline.com™, a series of specialized marketplaces were developed in order to interface with the electronics recycling industry.

In addition to the work already mentioned in regards to the information technology support for the electronics recycling industry, D.N. American has also been focused in preparing to support the MARCEE Demonstration project.

Summary Of Results – Task 3.6.2.3

- **Industry Participation** – Built solutions based around industry work in developing characterization matrix.
- **Industry Position** – Placed MARCEE project in the center of activities surrounding materials characterization.
- **Industry Demonstration –** Developed solutions that are currently being utilized to demonstrate capabilities.
- **National/International Exposure** – Presented trading platforms at national and international recycling and plastics conferences.
- **Market Penetration** – Industry participants are utilizing marketplaces to list goods and services.
- **MARCEE Demonstration Support** – Developing electronic marketing support for movement of materials in support of demonstration project in conjunction with Polymer Alliance Zone.

Task 3.6.2.4 Support of Industry-Related Projects (PAZ)

The Recipient shall utilize industry relationships to demonstrate the utility of web-enable simulation and modeling tools developed under the project. Web-enabling of simulation and modeling tools for the electronics recycling industry will be accomplished under this Subtask.

Description of work performed, accomplishments and results:

DN American has participated in several industry-led events as well as a number of government supported activities in order to maintain insight into current and future electronics recycling related projects. As MARCEE has become an industry leader in the development of an electronics recycling infrastructure so has the information technology tools developed to support the infrastructure.

EPEAT Project - As part of the information data analysis work that DN American has performed in support of the MARCEE project and the work Walter Alcorn has performed in regards to industry modeling, the MARCEE project has been asked to provide input and expertise in the creation of the EPEAT Procurement system.

EPEAT is a multi-stakeholder process to design and implement a tool for evaluating the environmental performance of electronic products. After development of the initial set of EPEAT program requirements, the EPEAT tool is being implemented by an Implementation Team of expert stakeholders. Their mission is to finalize development and implement an assessment tool for use during the procurement of electronic products and services. The EPEAT tool is intended to:

- Promote continuous improvement in the environmental performance without stifling, and while encouraging, innovation;
- Address the lifecycle of electronic products including, but not limited to, design, procurement, use, and end-of-life implications;
- Inform purchasing decisions by institutional purchasers regarding the environmental attributes of electronic products;
- Provides market advantage for companies that provide products and services that achieve improved environmental performance;
- Is low cost, user friendly, and causes minimal delay in time to market;
- Produces credible, verifiable outcomes that are accepted by relevant stakeholders and
- Provides sufficient value in the marketplace to sustain itself.

Please refer to Appendix P for additional information relating to the EPEAT program.

EPA National Meeting - DN American was recently invited to attend the 2005 EPA National Meeting on Electronics Recycling held in Washington DC. This invitation-only event was a two day conference with industry stakeholders including OEM’s, retailers, recyclers, and government officials. DN American was recognized for the work in the area of data collection, data management, and data standards development in regards to the electronics recycling projects supported by EPA.

IEEE International Symposium on Electronics and the Environment 2005 - DN American's efforts in regards to information technology solutions for the electronics recycling industry will be highlighted in a paper recently selected for publication by the IEEE. The paper entitled "Information Architecture for an Electronics Recycling National Coordinating Entity" will highlight some of the technologies supported by DN American in the areas of information sharing, data collection, data analysis, and electronic marketplace development. The paper will be presented at an upcoming International Symposium on Electronics & the Environment this spring in New Orleans LA. DN American collaborators on this paper include Jeff Tucker, Terri Linger, and Stephanie Smith.

Please refer to Appendix P for the complete IEEE 2005 paper.

IEEE International Symposium on Electronics and the Environment 2004 - Jeff Tucker of D.N. American and Walter Alcorn from EA Markets co-authored a paper on the use of XML and its impact on supply chain systems relating to e-commerce. The paper entitled "Development of XML Industry Stan-dards for Information Exchange and Commerce" was selected for publication by the IEEE and for presentation at the 2004 IEEE International Symposium on Electronics & the Environment. The conference was held in Scottsdale Arizona and was attended by several members of the MARCEE project.

Jeff and Walter received some good feedback from industry trade groups as well as major Original Equipment Manufacturers such as Cisco. The paper and correspond-ing conference presentation was used to highlight some of the work D.N. American has been doing in the areas of information technology support and the use of data standards and XML relating to application development.

Please refer to Appendix P for the complete IEEE 2004 paper.

NEMI Workshop - DN American continues its information technology support for the electronics recycling industry by participating in the development of industry data exchange standards.

On behalf of the MARCEE Project, Terri Linger attended the Material Declaration Data Exchange Workshop in Santa Clara, California at the end of August. The data exchange workshop was sponsored by the National Electronics Manufacturing Initiative (NEMI) - an industry-led consortium whose mission is to assure leadership of the global electronics manufacturing supply chain.

The workshop provided a forum for industry participants to discuss the challenges and solutions for information exchange in support of global environmental initiatives that impact the electronics industry. A special emphasis was placed on understanding the reporting requirements for the European Union's RoHS and WEEE directives.

Please refer to Appendix P for additional details of the NEMI workshop.

Attended the International Electronics Recyclers Institute sponsored Electronics Recycling Education Courses entitled **Lean Electronics Recycling and Best Management Practices for Operating Electronics Collection Programs.**

EPA Summit Meeting - This meeting was convened to discuss the agenda for the upcoming EPA Summit scheduled for early March 2005. Attendees included representatives from EIA, IAER, EPA (nationwide), University of Tennessee, Polymer Alliance Zone, state and local government officials from Minnesota and Washington. Other topics at this planning meeting were the role of the National Coordinating Entity for Electronics Recycling and the development and host organization of the EPEAT tool.

Task 3.6.3 Research and Technology Center for Plastics

Recipient shall conduct a planning /feasibility study for establishing a self-sustaining West Virginia University Polymer Research and Technology Center (WVU-PRTC) on the WVU-Parkersburg campus in Parkersburg, West Virginia that supports West Virginia's polymer and related down-stream manufacturing industries. The overall goal of the Center will be to assist the existing polymer industry in doing research that would be common to polymer producers, and to fill the technology gap for recycling of plastics from end-of-life electronics through basic and applied scientific and engineering research, technology development, and the commercialization of value-added products developed from recycled plastics. In addition, WVU-PRTC will coordinate with training facilities at WVU-Parkersburg for supplying the workforce necessary for the plastics recycling industry.

Description of work performed, accomplishments and results:

A plan has been put together to form a Polymer Research Center at West Virginia University. A director is slated to be hired to lead the Center during 2005.

Task 3.7 Project Support and Business Plan (PAZ)

The Recipient shall continue to update the plans initially developed during the Phase I, Task 1.7 effort.

The Recipient shall prepare and submit a draft topical report that covers the efforts under Tasks 3.1 – 3.7 in accordance with the Reporting Requirements Checklist after completion of Phase III. This report shall provide a comprehensive description of the results achieved and shall include tabulations of data, figures, photographs, and other bibliographic citations to support the investigations undertaken. It shall summarize all technical reports where applicable. Within thirty (30) days after submittal, the COR will accept the draft topical report or recommend changes and the Recipient shall revise the topical report and submit the final topical report with 30 days after receipt of review comments. If the Government elects not to continue with the remaining effort, the Topical Report will become the Final Report.

The Recipient shall compile the data generated and collected for this project into a final report to be submitted at the end of the project that shall be a comprehensive description of the results achieved and be consistent with the Reporting Requirements. The report shall include, supporting investigations undertaken, tabulations of data, figures, photographs, and other bibliographic citations. The final report shall summarize data from topical and field reports. The report shall include the original hypotheses of the project and present the investigative approaches used, complete with problems encountered or departures from the planned methodology, and an assessment of their impact on the project results. A draft report shall be submitted to NETL for review followed by the final report. Specific items to be included in the final report are described below:

- *Recycled polymer characterization data*
- *Methods for extrusion or injection molding of recycled plastics*
- *Estimates of capital and operating costs for production of products utilizing recycled plastics*
- *Comparisons of laboratory scale performance, pilot scale performance, and*
- *Product quality for products manufactured using recycled plastics versus virgin materials*
- *Guidelines for the establishment of an EOL electronics recycling center.*
- *List of potential recycled plastic applications, their specifications, and projected market sizes*
- *Summary of application's field test results including critiques by commercial end users*
- *Assessment of the economics of plastics recycling from End-of-Life Electronics*
- *Recommendations of applications that can utilize recycled plastics.*
- *Evaluation of the effectiveness of Internet based education and market transactions involving the trading of recycled plastics*
- *Plans for the establishment of a prototype center or group of related centers.*

Description of work performed, accomplishments and results:

A topical report that discussed many of the topics outlined was issued in August 2001.

Task 3.8 Project Management (Irwin)

The Recipient will coordinate and submit reports, integrate the polymer/electronics recycling project with other related research projects, and coordinate work statements. In addition, the Recipient will process invoices from subcontractors, assist with communication and public outreach to foster interest and project contacts and develop project exhibits for use at conferences and meetings.

Description of work performed, accomplishments and results:

All required reports were submitted to the U.S. Department of Energy, integrated the project with other research projects at West Virginia University such as the Extrusion Compounding Center, wood/polymer composites and the Industries of the Future – West Virginia program. All invoices for subcontractors were processed in a timely manner. Assisted with communication and public outreach through attending conferences, developing an exhibit of the WVU research, and contacting all necessary individuals to promote the project and to ensure that the research continued in a timely manner.

Table 63: Milestone Table

Task	Planned Start Date	Planned Finish Date	Actual Start Date	Actual Finish Date
Phase I – Business and technology assessments, supporting research, master plan development, information exchange, and work-force programs				
Task 1.0 - Phase I Program Plan	11/22/99	11/22/00	11/22/99	11/22/01
Task 1.1: Economic Feasibility Assessments, Industry Structure and Business Plan	11/22/99	11/22/00	11/22/99	12/31/00
Task 1.2: Best Available Technologies and Practices (BAT&P)	11/22/99	11/22/00	11/22/99	3/31/01
Task 1.3: Polymer Characterization, Research, and Testing	11/22/99	11/22/00	11/22/99	11/22/01
Task 1.4: Application and Product Development	11/22/99	11/22/00	11/22/99	Ongoing
Task 1.5: Project Master Plan: Site Selection, Financial Plan, Construction and Training Programs	11/22/99	11/22/00	11/22/99	11/22/02
Task 1.6: Industrial Information Exchange, Virtual Eco-park, and Internet Trading Tools	11/22/99	11/22/00	11/22/99	11/22/04
Task 1.7: Project Support, Business Plan, Environmental Impacts, Site Development, and Conferences	11/22/99	11/22/00	11/22/99	11/22/00
Task 1.8 - Topical Report	11/22/99	11/22/00	11/22/99	11/22/01
Phase II - Business Model Completion, Design of a Commercialization Project, and Integration of Recycling Technologies and Products				
2.1: Project Design and Business Model Development	3/22/01	3/22/02	3/22/01	Ongoing
Task 2.2: Continuation of Modeling Effort and Product Feasibility Study	3/22/01	3/22/02	3/22/01	Ongoing
Task 2.3: Polymer Characterization, Research, and Testing	3/22/01	3/22/02	3/22/01	3/22/02
Task 2.4: Application and Product Development	3/22/01	3/22/02	3/22/01	Ongoing
Task 2.5: Project Master Plan: Site Selection, Financial Plan,	3/22/01	3/22/02	3/22/01	Ongoing

Construction and Training Programs				
Task 2.6: Maintenance of Websites and Portals Developed in Phase I: Continue to Modify and Update the Portals and Relevant Information on Websites Developed in Phase I of the Effort.	3/22/01	3/22/02	3/22/01	Ongoing
Task 2.7: Organize and Conduct the National Electronics Stewardship Workshop	3/22/01	3/22/02	3/22/01	3/22/02
Task 2.8 - Topical Report	3/22/01	3/22/02	3/22/01	3/15/06
Phase III - Completion of Industrial Information Exchange, Technology Transfer, and Internet Trading Platform Development				
Task 3.1: Business Model Development and Industry Participation				Ongoing
Task 3.2: Process Model Validation and New Product Assessment				Ongoing
Task 3.3: Polymer Characterization, Research, and Testing				Undertaken as needed
Task 3.4: Utilization and Awareness – Outreach to Users				Ongoing
Task 3.5: Project Master Plan and Site Issues				Ongoing
3.6: Industrial Information Exchange and Internet Trading Tools				Ongoing
Task 3.7: Project Support and Business Plan				Ongoing
Task 3.8 – Project Management				Ongoing
Task 3.9 - Final Report				3/15/06

Table 64: Project Expenditures as of March 31, 2005

Organization/PI	Federal Funds		Cost Share	Total
	WVU	PAZ Subcontractors		
WVU PI				
Richard Turton	$490,767		$17,331	$508,098
Rakesh Gupta	$1,350,638		$15,262	$1,365,900
GangRao Hota	$779,251		$23,645	$802,896
Cy Logar, Tom Ponzurick	$269,357			$269,357
John Weete	$23,962			$23,962
Carl Irwin, Kathleen Cullen	$176,325		$26,384	$202,709
Overhead on WVU subcontractors	$34,500			$34,500
WVU Subcontractors				
MCC[1]	$260,753			$260,753
MBDC[1]	$98,621			$98,621
Steptoe & Johnson[1]	$6,731			$6,731
Bob Bowen[1]	$10,353			$10,353
DN American[1]	$600,000			$600,000
Polymer Alliance Zone and subcontractors[1]	$5,339,985			$5,339,985
PAZ Subcontractors				
Dillon Environmental[2]		$21,308		
Gordon Institute of Tufts[2]		$173,463		
Gregg Pitts[2]		$106,435		
University of Texas[2]		$72,222		
Wuf Technologies LLC[2]		$28,514		
Spillman, Thomas & Battle PLLC[2]		$306,445		
SAIC[2]		$816,440		
DN American[2]		$2,176,276		
MAPA Inc.[2]		$97,150		
EcoAssets[2]		$196,269		
Thrasher Engineering		$46,085		
Total Expenditures as of March 31, 2005	**$9,441,243**		**$82,622**	**$9,523,865**

1. Subcontract through WVU
2. Subcontract through PAZ

Attachments

Rakesh Gupta

Papers and presentations:

1. R.Liang and R.K. Gupta, "The effect of residual impurities on the rheological and mechanical properties of engineering polymers separated from mixed plastics," Proc. Soc. Plast. Eng. 59th Ann. Tech. Conf. (ANTEC 2001), May 6-10, 2001, Dallas, TX, pp. 2753-2757.

2. M.M.K. Khan, R.F. Liang and R.K. Gupta, "Rheological and mechanical behaviour of complex ABS/PC blends," Proc. 3rd Pacific Rim Conference on Rheology, July 8-12, 2001,Vancouver, BC, Canada (3 pages on CD ROM).

3. R.K. Gupta, "Strategies for Recycling Polymers from End-of-Life Electronics," West Virginia University, Departmental Seminar, October 5, 2001.

4. R. Liang and R.K. Gupta, "Rheological characterization of complex ABS/PC blends," presentation made at the 73rd annual meeting of the Society of Rheology, Bethesda, MD, October 21-25, 2001.

5. R.K. Gupta, "Electronics Recycling," Proc. Industry Partnerships for Environmental Sci. Technol. Conf., October 30 – November 1, 2001, NETL, Morgantown (4 pages on CD ROM).

6. R.K. Gupta, "Strategies for recycling polymers from end-of-life electronics," presentation to the American Chemical Society, Morgantown Chapter, March 18, 2002.

7. R.K. Gupta, "Strategies for recycling polymers from end-of-life electronics," presentation to the American Chemical Society, Pittsburgh Chapter, April 3, 2002.

8. R. Liang and R.K. Gupta, "Processing and characterization of recycled PC/ABS blends with high recycle content," Proc. Soc. Plast. Eng. 60th Ann. Tech. Conf. (ANTEC 2002), May 5-9, 2002, San Francisco, CA, pp. 2948-2952.

9. A.D. Drozdov, A. Al-Mulla and R.K. Gupta, "Thermo-viscoelastic response of polycarbonate reinforced with short glass fibers," Macromol. Theory Simul., 12, 354-366 (2003).

10. A.D. Drozdov, A. Al-Mulla and R.K. Gupta, "The viscoelastic and viscoplastic behavior of polymer composites: polycarbonate reinforced with short glass fibers," Computational Materials Science, 28, 16-30 (2003).

11. A.D. Drozdov, A. Al-Mulla and R.K. Gupta, "A constitutive model for the viscoplastic behavior of rubbery polymers at finite strains," Acta Mechanica, 164, 139-160 (2003).

12. A.D. Drozdov and R.K. Gupta, “Constitutive equations in finite viscoplasticity of semicrystalline polymers,” Int. J. Solids Structures, 40, 6217-6243 (2003).

13. A.D. Drozdov, A. Al-Mulla and R.K. Gupta, “The viscoelastic behavior of melts of virgin and recycled polycarbonate reinforced with short glass fibers,” Mechanics Res. Communications, 30, 595-614 (2003).

14. R.K. Gupta and C.J. Hilado, “Issues concerning flame retardants during recycling of polymers,” paper presented at the 37th Int. Conf. Fire Safety, White Sulphur Springs, WV, January 12-14, 2004.

15. R.K. Gupta, “Polymer Recycling”, presentation at the Gaiker Technical Center, Bilbao, Spain, February 12, 2004.

16. A.D. Drozdov, A. Al-Mulla and R.K. Gupta, “The effect of recycling on the time-dependent behavior of polycarbonate reinforced with short glass fibers,” Composites Sci. Technol., 64, 129-144 (2004).

17. F.D. Alsewailem and R.K. Gupta, “Effect of impact modifiers on the properties of post-industrial glass-fiber-reinforced nylon 66,” Proc. Fifth Int. Conf. Composite Sci. Technol., February 1-3, 2005, Sharjah, UAE, pp. 353-358.

18. M.M.K. Khan, R.F. Liang, R.K. Gupta and S. Agarwal, “Rheological and mechanical properties of ABS/PC blends,” Korea-Australia Rheol. J., 17, 1-7 (2005).

19. A.D. Drozdov, A. Al-Mulla and R.K. Gupta, “Finite viscoplasticity of polycarbonate reinforced with short glass fibers,” Mech. Mater., 37, 473-491 (2005).

20. D. Statler Jr., T.-W. Liu, R.K. Gupta and C.J. Hilado, “Recyclability, flame retardants and polymers: A brief look at PC and ABS,” paper presented at the 38th Int. Conf. Fire Safety, White Sulphur Springs, WV, January 10-12, 2005.

21. D. Statler Jr., “The recyclability of flame retarded polycarbonate,” Poster presented at the AIChE Pittsburgh Chapter meeting, February 10, 2005. (D. Statler is a graduate student being supervised by Dr. Gupta).

Theses/ Dissertations completed:

Adam Al-Mulla, "Glass Reinforcement of Recycled Polycarbonate", Ph.D. Dissertation, November 2002.

Jason Williams, "Wood/Polymer Composites", B.S. thesis, May 2005.

Theses/Dissertations in progress:

Tze-Wei Liu, "Flame Retardants for ABS Polymers", Ph.D. dissertaion.

Shu-kai Yeh, "Wood/Polymer Composites", Ph.D. dissertation.

David Statler, "Flame Retardants for Polycarbonate", Ph.D. dissertation.

GangaRao Hota

Theses/Dissertations:

Aditham R., Manufacturing and Evaluation of Structural Products with Recycled Polymers (Advised By Vijay P.V. and Gangarao H.V.S.), MS Thesis, Dept. of Mechanical and Aerospace Engineering, 2004

Basto R.J.M., Mechanical Characterization Of Aged Recycled Polymers And Applications (Advised by Vijay P.V. and GangaRao H.V.S.), MS Thesis, Dept. of Civil and Environmental Engineering, 2002

DN American & Walter Alcorn Presentations

- J. Tucker, W. Alcorn, J. Linnell, "*Information Architecture For an Electronics Recycling National Coordinating Entity*", 2005 IEEE International Symposium on Electronics in the Environment Conference Proceedings.
- J. Tucker and W. Alcorn, "*Development of XML Industry Standards for Information Exchange and Commerce*", 2004 IEEE International Symposium on Electronics in the Environment Conference Proceedings.
- RECONN '03 International Conference on Recycling Information Exchange and Industrial Practices – Bilbao Spain (Speaker / Panel Discussion Member on Industry Information Exchange Initiatives)
- J. Tucker, W. Alcorn, "*Prototype for National Electronics Website and Plastics Trading Platform*", The Gordon Institute - Stakeholder Dialogues, Tufts University, Bedford MA. September 2000. (Presentation)

Appendices

Appendix A: Task 1.1

Break-Even Results – Scenarios

Break-even can be more than a simple tool. It can be an approach for dealing intelligently with uncertainty. Keep in mind that break-even is no panacea. It does not indicate if costs are out-of-line. It only shows the level of sales required to cover fixed and variable operating costs. The results of this break-even analysis will indicate the feasibility of the proposed project in terms of what level of revenues will be required to cover costs.   Break-even does not determine if sufficient supply or demand is available to generate the required revenue.

To this end, not knowing what supply is available in terms of quantity, quality, location and the cost associated with acquiring it, the business planning group has provided the PAZ and MARCEE decision-makers various options or scenarios from which to analyze this project. Five (5) scenarios are presented and discussed here. These scenarios consider the operation from Professor Turton's base case and in each instance analyze the break-even point from both a profit and not-for profit perspective using a ten (10) year payback projection for breaking-even. Two additional scenarios included in the body of the report are MARCEE paying versus not paying for inbound transportation for the supply and whether the supply is single or double stacked in the inbound motor carrier. Both are analyzed without considering a federal subsidy. The fourth scenario assumes no refurbishing on the part of the MARCEE demanufacturing facility and the high-end federal subsidy of $8.00 per unit handled or eight million dollars per year (one million units x $8.00 per unit). The fifth scenario assumes no refurbishing and no subsidy.

<u>Break-Even Scenario One</u>

Scenario One addresses break-even of the MARCEE demanufacturing facility from a base case perspective. That is, receiving one million computer electronic devices a year, checking 70 percent, refurbishing 20.6 percent and dismantling the rest. The dismantled material will be sold as recycled output (metal, glass and plastic) to buyers in each of the respective markets at the assumed prices. Working capital must be borrowed and a rate of 9 percent was used. The amount to be borrowed is $7,011,308.00 in Year One and $5,132,225.00 Year Two. The net present value of this money is included in the analysis. Under this scenario, it is assumed that the supplier is responsible for all costs associated with delivering the supply to Wood County, West Virginia and no federal subsidy is included.

In this base case analysis, the MARCEE project would reach the break-even point in YEAR ELEVEN if operated as a for-profit organization. It would break-even in YEAR NINE if operated in a not-for-profit manner. The complete results of the base case break-even scenario are displayed in Table 66. The reader must address at this point whether or not the parameters in the base case scenario are achievable. If not, the remaining scenarios provide for some flexibility. However, the outcome may not be favorable unless subsidies are in place.

Table 65 – Break-Even Scenario One

BASE Case

Demanufacturing Facility - Breakeven Economics Summary

Monitors		
Total Number of Monitors		1,000,000 per year
Percent-refurbished	20.6 %	
Percent-Checked	70 %	

Net Present Value	
With Tax	$ 605,592
Without Tx	$ 4,894,972

Computers		
Total Number of Computers		1,000,000 per year
Percent-refurbished	20.6 %	
Percent-Checked	70 %	

Subsidy
Per computer subsidy
$0

Capital Costs										
Warehouse Cost per Square Foot	42 $/ft²									
Warehouse Footprint	113,036 ft²									
Engineering Fees, Contractor Fees										
Transportation Percent	0 %									
Total Cost of Warehouse	$ 4,719,419									
		Shredder	Baler	Conveyors	Mag Separator	Eddy Separator	Glass Saw	Fork Lifts	Ring Mill	
Total Cost of Equipment	$ 2,291,889	585,268	195,842	799,047	40,543	334,535	20,000	112,800	203,855	
Total Capital Cost	$ 7,011,308									

Operating Costs		Labor	Electricity	Natural Gas	OB TRANS	Waste Disposal	Haz Waste	Maint.	Op. Suppl	Water
Total Operating Costs	$ 10,264,450	8,249,950	308,522	357,756	691,200	111,457	237,616	252,441	50,488	5,020
		80.4	3.0	3.5	6.7	1.1	2.3	2.5	0.5	0.0

Revenue		Refurbishing	Prec Metals	Aluminum	Steel	Plastic	Glass	Subsidy
Revenue Obtained	$ 12,748,559	6,427,200	2,600,327	2,595,352	562,387	117,811	445,482	0
		50.4	20.4	20.4	4.4	0.9	3.5	-

BASE Case

Net Present Value Calculations

Deprec'n MACRS	5 years	
Project life	10 years after start up	
Land Cost	0	assume that this is minimal
Rate of Return	9 % p.a.	
Working Capital	5,132,225	Based on 6 months of operating costs
Construction Pd	1 year	
Taxation rate	45 %	

Net Present Value Calculations as a For-Profit Organization
Taxation Rate 45

Year (end of year investment)	Investment	Revenue (R)	COM	Depreciation (d)	Taxable Profit (R-C-d)	After tax profit (R-C-d)(1-t)+d	Cash Flow (CF)	Discounted CF	Running BE
0	($7,011,308)						($7,011,308)	($7,011,308)	
1	($5,132,225)						($5,132,225)	($4,708,463)	($11,719,771)
2		$12,748,559	$10,264,450	$1,402,262	$1,081,848	$1,997,278	$1,997,278	$1,681,069	($10,038,702)
3		$12,748,559	$10,264,450	$2,243,619	$240,491	$2,375,888	$2,375,888	$1,834,622	($8,204,080)
4		$12,748,559	$10,264,450	$1,346,171	$1,137,938	$1,972,037	$1,972,037	$1,397,041	($6,807,040)
5		$12,748,559	$10,264,450	$807,703	$1,676,407	$1,729,726	$1,729,726	$1,124,203	($5,682,836)
6		$12,748,559	$10,264,450	$807,703	$1,676,407	$1,729,726	$1,729,726	$1,031,379	($4,651,457)
7		$12,748,559	$10,264,450	$403,851	$2,080,258	$1,547,993	$1,547,993	$846,805	($3,804,652)
8		$12,748,559	$10,264,450	$0	$2,484,109	$1,366,260	$1,366,260	$685,680	($3,118,972)
9		$12,748,559	$10,264,450	$0	$2,484,109	$1,366,260	$1,366,260	$629,064	($2,489,908)
10		$12,748,559	$10,264,450	$0	$2,484,109	$1,366,260	$1,366,260	$577,123	($1,912,785)
11		$12,748,559	$10,264,450	$0	$2,484,109	$1,366,260	$6,498,485	$2,518,376	$605,592
				$7,011,308		$16,817,689		$605,592	
Net Present Value	$605,592								

Net Present Value Calculations as a Non-Profit Organization
Taxation Rate 0

Year (end of year investment)	Investment	Revenue (R)	COM	Depreciation (d)	Taxable Profit (R-C-d)	After tax profit (R-C-d)(1-t)+d	Cash Flow (CF)	Discounted CF	Running BE
0	($7,011,308)						($7,011,308)	($7,011,308)	
1	($5,132,225)						($5,132,225)	($4,708,463)	($11,719,771)
2		$12,748,559	$10,264,450	$1,402,262	$1,081,848	$2,484,109	$2,484,109	$2,090,825	($9,628,946)
3		$12,748,559	$10,264,450	$2,243,619	$240,491	$2,484,109	$2,484,109	$1,918,188	($7,710,758)
4		$12,748,559	$10,264,450	$1,346,171	$1,137,938	$2,484,109	$2,484,109	$1,759,806	($5,950,952)
5		$12,748,559	$10,264,450	$807,703	$1,676,407	$2,484,109	$2,484,109	$1,614,501	($4,336,452)
6		$12,748,559	$10,264,450	$807,703	$1,676,407	$2,484,109	$2,484,109	$1,481,193	($2,855,259)
7		$12,748,559	$10,264,450	$403,851	$2,080,258	$2,484,109	$2,484,109	$1,358,893	($1,496,366)
8		$12,748,559	$10,264,450	$0	$2,484,109	$2,484,109	$2,484,109	$1,246,691	($249,675)
9		$12,748,559	$10,264,450	$0	$2,484,109	$2,484,109	$2,484,109	$1,143,753	$894,078
10		$12,748,559	$10,264,450	$0	$2,484,109	$2,484,109	$2,484,109	$1,049,315	$1,943,392
11		$12,748,559	$10,264,450	$0	$2,484,109	$2,484,109	$7,616,334	$2,951,580	$4,894,972
				$7,011,308		$24,841,092		$4,894,972	
Net Present Value	$4,894,972								

Table 66 – Break-Even Scenario One, continued

Break-Even Scenario Two

Scenario Two addresses break-even of the MARCEE demanufacturing facility using the base case scenario but considering MARCEE would have to pay for the inbound supply and that supply would be double stacked in the inbound trailer. The facility would again be receiving one million computer electronic devices a year, checking 70 percent, refurbishing 20.6 percent and dismantling the rest. The dismantled material would still be sold as recycled output (metal, glass and plastic) to buyers in each of the respective markets at the assumed prices. Working capital would be borrowed utilizing a 9 percent rate and the amount borrowed is again $7,011,308.00 in Year One and $5,132,225.00 Year Two. The net present value of this money is also included in the analysis. No federal subsidy is included in this scenario analysis.

In this inbound-double stacked analysis, the MARCEE project would not reach the break-even point in the first eleven years of operation either operating as a for-profit or not-for-profit organization. The complete results of the inbound-double stacked break-even scenario are displayed in Table 68. Under this scenario is the concern of whether the EOL computer electronics can be double stacked such that there will be no transportation damage to the computers to prevent them from being refurbished and resold. Understanding the transportation related costs associated with acquiring the supply of EOL computer electronics is critical to the success of this project. These costs could be extremely high requiring an additional subsidy.

Table 67 – Break-Even Scenario Two

IB Stacked Case

Demanufacturing Facility - Breakeven Economics Summary

Monitors		
Total Number of Monitors	1,000,000	per year
Percent-refurbished	20.6	%
Percent-Checked	70	%

Computers		
Total Number of Computers	1,000,000	per year
Percent-refurbished	20.6	%
Percent-Checked	70	%

Net Present Value		
With Tax	$	(2,206,698)
Without Tx	$	(44,259)

Subsidy	
Per computer subsidy	0

Capital Costs			
Warehouse Cost per Square Foot		42	$/ft²
Warehouse Footprint		113,036	ft²
Engineering Fees, Contractor Fees transportation Percent		0	%
Total Cost of Warehouse	$	4,719,419	
Total Cost of Equipment	$	2,291,889	
Total Capital Cost	$	7,011,308	

Equipment	Shredder	Baler	Conveyors	Mag Separator	Eddy Separator	Glass Saw	Fork Lifts	Ring Mill
Cost	585,268	195,842	799,047	40,543	334,535	20,000	112,800	203,855

Operating Costs			Labor	Electricity	Natural Gas	OB TRANS	Waste Disposal	Haz Waste	Maint.	Op. Suppl	IB TRANS	Water
Total Operating Costs	$	11,067,223	8,249,950	308,522	357,756	691,200	111,457	237,616	252,441	50,488	802,774	5,020
			74.5	2.8	3.2	6.2	1.0	2.1	2.3	0.5	7.3	0.0

Revenue			Refurbishing	Prec Metals	Aluminum	Steel	Plastic	Glass	Subsidy
Revenue Obtained	$	12,748,559	6,427,200	2,600,327	2,595,352	562,387	117,811	445,482	0
			50.4	20.4	20.4	4.4	0.9	3.5	-

Table 68 – Break-Even Scenario Two, continued

IB Stacked Case

Net Present Value Calculations

Deprec'n MACRS	5 years	
Project life	10 years after start up	
Land Cost	0	assume that this is minimal
Rate of Return	9 % p.a.	
Working Capital	5,533,612	Based on 6 months of operating costs
Construction Pd	1 year	
Taxation rate	45 %	

Net Present Value Calculations as a For-Profit Organization

Taxation Rate 45

Year (end of year investment)	Investment	Revenue (R)	COM	Depreciation (d)	Taxable Profit (R-C-d)	After tax profit (R-C-d)(1-t)+d	Cash Flow (CF)	Discounted CF	Running BE
0	($7,011,308)						($7,011,308)	($7,011,308)	
1	($5,533,612)						($5,533,612)	($5,076,708)	($12,088,016)
2		$12,748,559	$11,067,223	$1,402,262	$279,074	$1,555,752	$1,555,752	$1,309,446	($10,778,570)
3		$12,748,559	$11,067,223	$2,243,619	($562,283)	$1,934,363	$1,934,363	$1,493,683	($9,284,887)
4		$12,748,559	$11,067,223	$1,346,171	$335,165	$1,530,512	$1,530,512	$1,084,253	($8,200,634)
5		$12,748,559	$11,067,223	$807,703	$873,633	$1,288,201	$1,288,201	$837,242	($7,363,392)
6		$12,748,559	$11,067,223	$807,703	$873,633	$1,288,201	$1,288,201	$768,112	($6,595,280)
7		$12,748,559	$11,067,223	$403,851	$1,277,484	$1,106,468	$1,106,468	$605,276	($5,990,004)
8		$12,748,559	$11,067,223	$0	$1,681,336	$924,735	$924,735	$464,093	($5,525,911)
9		$12,748,559	$11,067,223	$0	$1,681,336	$924,735	$924,735	$425,774	($5,100,137)
10		$12,748,559	$11,067,223	$0	$1,681,336	$924,735	$924,735	$390,618	($4,709,519)
11		$12,748,559	$11,067,223	$0	$1,681,336	$924,735	$6,458,346	$2,502,821	($2,206,698)
				$7,011,308		$12,402,435		($2,206,698)	
Net Present Value	($2,206,698)								

Net Present Value Calculations as A Non-Profit Organization

Taxation Rate 0

Year (end of year investment)	Investment	Revenue (R)	COM	Depreciation (d)	Taxable Profit (R-C-d)	After tax profit (R-C-d)(1-t)+d	Cash Flow (CF)	Discounted CF	Running BE
0	($7,011,308)						($7,011,308)	($7,011,308)	
1	($5,533,612)						($5,533,612)	($5,076,708)	($12,088,016)
2		$12,748,559	$11,067,223	$1,402,262	$279,074	$1,681,336	$1,681,336	$1,415,147	($10,672,869)
3		$12,748,559	$11,067,223	$2,243,619	($562,283)	$1,681,336	$1,681,336	$1,298,300	($9,374,569)
4		$12,748,559	$11,067,223	$1,346,171	$335,165	$1,681,336	$1,681,336	$1,191,101	($8,183,469)
5		$12,748,559	$11,067,223	$807,703	$873,633	$1,681,336	$1,681,336	$1,092,753	($7,090,716)
6		$12,748,559	$11,067,223	$807,703	$873,633	$1,681,336	$1,681,336	$1,002,526	($6,088,190)
7		$12,748,559	$11,067,223	$403,851	$1,277,484	$1,681,336	$1,681,336	$919,748	($5,168,442)
8		$12,748,559	$11,067,223	$0	$1,681,336	$1,681,336	$1,681,336	$843,806	($4,324,637)
9		$12,748,559	$11,067,223	$0	$1,681,336	$1,681,336	$1,681,336	$774,134	($3,550,503)
10		$12,748,559	$11,067,223	$0	$1,681,336	$1,681,336	$1,681,336	$710,214	($2,840,288)
11		$12,748,559	$11,067,223	$0	$1,681,336	$1,681,336	$7,214,947	$2,796,029	($44,259)
				$7,011,308		$16,813,357		($44,259)	
Net Present Value	($44,259)								

Break-Even Scenario Three

Scenario Three addresses break-even of the MARCEE demanufacturing facility using the base case scenario but considering MARCEE would have to pay for the inbound supply and that supply would be single stacked in the inbound trailer. Single stacked in this case would mean the inbound material would be only one pallet high the in the trailer. Research into this subject has indicated that single stacking of the computer electronics supply may be required since the material is not palletized in such a manner that the contents would not be damaged. Since MARCEE is refurbishing as well as dismantling, receiving undamaged compute electronics that can be refurbished and resold is critical to the financial success of this project. Therefore, there is the need to analyze the inbound transport of supply from a single stacked perspective.

In Scenario Three, the MARCEE facility would still be receiving one million computer electronic devices a year, checking 70 percent, refurbishing 20.6 percent and dismantling the rest. The dismantled material would still be sold as recycled output (metal, glass and plastic) to buyers in each of the respective markets at the assumed prices. Working capital would again be borrowed utilizing a 9 percent rate and the amount borrowed is again $7,011,308.00 in Year One and $5,132,225.00 Year Two. The net present value of this money is also included in the analysis. No federal subsidy is included in this scenario analysis.

In this inbound-single stacked analysis, the MARCEE project would not reach the break-even point in the first eleven years of operation either operating as a for-profit or not-for-profit organization. The complete results of the inbound-single stacked break-even scenario are displayed in Table 69. The issues that apply to scenario two above apply here as well but to a greater degree.

Table 69 – Break-Even Scenario Three

IB Unstacked Case

Demanufacturing Facility - Breakeven Economics Summary

Monitors			
Total Number of Monitors		1,000,000	per year
Percent-refurbishe	20.6 %		
Percent-Checked	70 %		

Computers			
Total Number of Computers		1,000,000	per year
Percent-refurbishe	20.6 %		
Percent-Checked	70 %		

Net Present Value		
With Tax	$	(5,018,988)
Without Tx	$	(4,983,491)

Subsidy
Per computer subsidy
0

Capital Costs										
Warehouse Cost per Square Foot	42 $/ft²									
Warehouse Footprint	113,036 ft²									
Engineering Fees, Contractor Fees transportation Percent	0 %									
Total Cost of Warehouse	$ 4,719,419									
		Shredder	Baler	Conveyors	Mag Separator	Eddy Separator	Glass Saw	Fork Lifts	Ring Mill	
Total Cost of Equipment	$ 2,291,889	585,268	195,842	799,047	40,543	334,535	20,000	112,800	203,855	
Total Capital Cost	$ 7,011,308									

Operating Costs		Labor	Electricity	Natural Gas	OB TRANS	Waste Disposal	Haz Waste	Maint.	Op. Suppl	IB TRANS	Water
Total Operating Costs	$ 11,869,997	8,249,950	308,522	357,756	691,200	111,457	237,616	252,441	50,488	1,605,547	5,020
		69.5	2.6	3.0	5.8	0.9	2.0	2.1	0.4	13.5	0.0

Revenue		Refurbishing	Prec Metals	Aluminum	Steel	Plastic	Glass	Subsidy
Revenue Obtained	$ 12,748,559	6,427,200	2,600,327	2,595,352	562,387	117,811	445,482	0
		50.4	20.4	20.4	4.4	0.9	3.5	-

Table 69 – Break-Even Scenario Three, continued

IB Unstacked Case

Net Present Value Calculations

Deprec'n MACRS	5 years	
Project life	10 years after start up	
Land Cost	0	assume that this is minimal
Rate of Return	9 % p.a.	
Working Capital	5,934,998	Based on 6 months of operating costs
Construction Pd	1 year	
Taxation rate	45 %	

Net Present Value Calculations as a For-Profit Organization

Taxation Rate 45

Year (end of year investment)	Investment	Revenue (R)	COM	Depreciation (d)	Taxable Profit (R-C-d)	After tax profit (R-C-d)(1-t)+d	Cash Flow (CF)	Discounted CF	Running BE
0	($7,011,308)						($7,011,308)	($7,011,308)	
1	($5,934,998)						($5,934,998)	($5,444,953)	($12,456,260)
2		$12,748,559	$11,869,997	$1,402,262	($523,699)	$1,114,227	$1,114,227	$937,822	($11,518,438)
3		$12,748,559	$11,869,997	$2,243,619	($1,365,056)	$1,492,838	$1,492,838	$1,152,744	($10,365,693)
4		$12,748,559	$11,869,997	$1,346,171	($467,609)	$1,088,986	$1,088,986	$771,465	($9,594,228)
5		$12,748,559	$11,869,997	$807,703	$70,860	$846,675	$846,675	$550,281	($9,043,947)
6		$12,748,559	$11,869,997	$807,703	$70,860	$846,675	$846,675	$504,845	($8,539,102)
7		$12,748,559	$11,869,997	$403,851	$474,711	$664,942	$664,942	$363,746	($8,175,356)
8		$12,748,559	$11,869,997	$0	$878,562	$483,209	$483,209	$242,506	($7,932,850)
9		$12,748,559	$11,869,997	$0	$878,562	$483,209	$483,209	$222,483	($7,710,367)
10		$12,748,559	$11,869,997	$0	$878,562	$483,209	$483,209	$204,113	($7,506,254)
11		$12,748,559	$11,869,997	$0	$878,562	$483,209	$6,418,208	$2,487,266	($5,018,988)
				$7,011,308		$7,987,181		($5,018,988)	
Net Present Value	($5,018,988)								

Net Present Value Calculations as A Non-Profit Organization

Taxation Rate 0

Year (end of year investment)	Investment	Revenue (R)	COM	Depreciation (d)	Taxable Profit (R-C-d)	After tax profit (R-C-d)(1-t)+d	Cash Flow (CF)	Discounted CF	Running BE
0	($7,011,308)						($7,011,308)	($7,011,308)	
1	($5,934,998)						($5,934,998)	($5,444,953)	($12,456,260)
2		$12,748,559	$11,869,997	$1,402,262	($523,699)	$878,562	$878,562	$739,468	($11,716,792)
3		$12,748,559	$11,869,997	$2,243,619	($1,365,056)	$878,562	$878,562	$678,411	($11,038,381)
4		$12,748,559	$11,869,997	$1,346,171	($467,609)	$878,562	$878,562	$622,396	($10,415,985)
5		$12,748,559	$11,869,997	$807,703	$70,860	$878,562	$878,562	$571,005	($9,844,980)
6		$12,748,559	$11,869,997	$807,703	$70,860	$878,562	$878,562	$523,858	($9,321,122)
7		$12,748,559	$11,869,997	$403,851	$474,711	$878,562	$878,562	$480,604	($8,840,519)
8		$12,748,559	$11,869,997	$0	$878,562	$878,562	$878,562	$440,921	($8,399,598)
9		$12,748,559	$11,869,997	$0	$878,562	$878,562	$878,562	$404,514	($7,995,084)
10		$12,748,559	$11,869,997	$0	$878,562	$878,562	$878,562	$371,114	($7,623,969)
11		$12,748,559	$11,869,997	$0	$878,562	$878,562	$6,813,561	$2,640,479	($4,983,491)
				$7,011,308		$8,785,622		($4,983,491)	
Net Present Value	($4,983,491)								

Break-Even Scenario Four

Scenario Four examines the break-even of the MARCEE demanufacturing facility using the base case scenario but considering MARCEE would do no computer refurbishing and receive a federal subsidy of $8.00 per unit handled. MARCEE would still receive one million computer electronic devices a year but would dismantle (rather than refurbish) all one million units. As noted earlier this subsidy to MARCEE would amount to eight million dollars annually (1,000,000 units x $8.00 per unit subsidy). The dismantled material would still be sold as recycled output (metal, glass and plastic) to buyers in each of the respective markets at the assumed prices. Working capital must be borrowed and a rate of 9 percent was used. The amount to be borrowed is $7,011,308.00 in Year One and $5,132,225.00 Year Two. The net present value of this money is included in the analysis. Under this scenario, it is assumed that the supplier is responsible for all costs associated with delivering the supply to Wood County, West Virginia.

In this federally subsidized base case analysis, the MARCEE project would reach the break-even point in YEAR NINE if operated as a for-profit organization. It would break-even in YEAR SIX if operated in a not-for-profit manner. The complete results of the base case break-even scenario with an $8.00 federal subsidy are shown in Table 70.

Table 70 – Break-Even Scenario Four

BASE Case

Demanufacturing Facility - Breakeven Economics Summary

Monitors		
Total Number of Monitors	1,000,000	per year
Percent-refurbished	0.0	%
Percent-Checked	70	%

Net Present Value	
With Tax	$ 3,844,516
Without Tx	$ 11,029,612

Computers		
Total Number of Computers	1,000,000	per year
Percent-refurbished	0.0	%
Percent-Checked	70	%

Subsidy	
Per computer subsidy	$8

Capital Costs		
Warehouse Cost per Square Foot	42	$/ft²
Warehouse Footprint	115,528	ft²
Engineering Fees, Contractor Fees		
Transportation Percent	0	%
Total Cost of Warehouse	$ 4,823,454	
Total Cost of Equipment	$ 2,458,521	
Total Capital Cost	$ 7,281,974	

Equipment	Shredder	Baler	Conveyors	Mag Separator	Eddy Separator	Glass Saw	Fork Lifts	Ring Mill
Total Cost of Equipment	602,198	207,131	901,053	41,813	342,432	25,000	131,600	207,295

Operating Costs		Labor	Electricity	Natural Gas	OB TRANS	Waste Disposal	Haz Waste	Maint.	Op. Suppl	Water
Total Operating Costs	$ 11,118,435	8,936,350	319,683	365,642	769,300	124,033	249,064	290,748	58,150	5,466
		80.4	2.9	3.3	6.9	1.1	2.2	2.6	0.5	0.0

Revenue		Refurbishing	Prec Metals	Aluminum	Steel	Plastic	Glass	Subsidy
Revenue Obtained	$ 14,728,875	-	2,725,855	2,720,640	589,536	131,784	561,060	8000000
		-	18.5	18.5	4.0	0.9	3.8	54.3

Table 70 – Break-Even Scenario Four, continued

BASE Case

Net Present Value Calculations

Deprec'n MACRS	5 years	
Project life	10 years after start up	
Land Cost	0	assume that this is minimal
Rate of Return	9 % p.a.	
Working Capital	5,559,217	Based on 6 months of operating costs
Construction Pd	1 year	
Taxation rate	45 %	

Net Present Value Calculations as a For-Profit Organization

Taxation Rate 45

Year (end of year investment)	Investment	Revenue (R)	COM	Depreciation (d)	Taxable Profit (R-C-d)	After tax profit (R-C-d)(1-t)+d	Cash Flow (CF)	Discounted CF	Running BE
0	($7,281,974)						($7,281,974)	($7,281,974)	
1	($5,559,217)						($5,559,217)	($5,100,199)	($12,382,174)
2		$14,728,875	$11,118,435	$1,456,395	$2,154,046	$2,641,120	$2,641,120	$2,222,978	($10,159,196)
3		$14,728,875	$11,118,435	$2,330,232	$1,280,209	$3,034,347	$3,034,347	$2,343,072	($7,816,123)
4		$14,728,875	$11,118,435	$1,398,139	$2,212,302	$2,614,905	$2,614,905	$1,852,465	($5,963,659)
5		$14,728,875	$11,118,435	$838,883	$2,771,557	$2,363,240	$2,363,240	$1,535,944	($4,427,715)
6		$14,728,875	$11,118,435	$838,883	$2,771,557	$2,363,240	$2,363,240	$1,409,123	($3,018,592)
7		$14,728,875	$11,118,435	$419,442	$3,190,999	$2,174,491	$2,174,491	$1,189,521	($1,829,071)
8		$14,728,875	$11,118,435	$0	$3,610,441	$1,985,742	$1,985,742	$996,577	($832,494)
9		$14,728,875	$11,118,435	$0	$3,610,441	$1,985,742	$1,985,742	$914,291	$81,797
10		$14,728,875	$11,118,435	$0	$3,610,441	$1,985,742	$1,985,742	$838,799	$920,596
11		$14,728,875	$11,118,435	$0	$3,610,441	$1,985,742	$7,544,960	$2,923,920	$3,844,516
				$7,281,974		$23,134,312		$3,844,516	
Net Present Value	$3,844,516								

Net Present Value Calculations as a Non-Profit Organization

Taxation Rate 0

Year (end of year investment)	Investment	Revenue (R)	COM	Depreciation (d)	Taxable Profit (R-C-d)	After tax profit (R-C-d)(1-t)+d	Cash Flow (CF)	Discounted CF	Running BE
0	($7,281,974)						($7,281,974)	($7,281,974)	
1	($5,559,217)						($5,559,217)	($5,100,199)	($12,382,174)
2		$14,728,875	$11,118,435	$1,456,395	$2,154,046	$3,610,441	$3,610,441	$3,038,836	($9,343,338)
3		$14,728,875	$11,118,435	$2,330,232	$1,280,209	$3,610,441	$3,610,441	$2,787,923	($6,555,415)
4		$14,728,875	$11,118,435	$1,398,139	$2,212,302	$3,610,441	$3,610,441	$2,557,727	($3,997,688)
5		$14,728,875	$11,118,435	$838,883	$2,771,557	$3,610,441	$3,610,441	$2,346,539	($1,651,149)
6		$14,728,875	$11,118,435	$838,883	$2,771,557	$3,610,441	$3,610,441	$2,152,788	$501,638
7		$14,728,875	$11,118,435	$419,442	$3,190,999	$3,610,441	$3,610,441	$1,975,035	$2,476,673
8		$14,728,875	$11,118,435	$0	$3,610,441	$3,610,441	$3,610,441	$1,811,958	$4,288,632
9		$14,728,875	$11,118,435	$0	$3,610,441	$3,610,441	$3,610,441	$1,662,347	$5,950,979
10		$14,728,875	$11,118,435	$0	$3,610,441	$3,610,441	$3,610,441	$1,525,089	$7,476,068
11		$14,728,875	$11,118,435	$0	$3,610,441	$3,610,441	$9,169,658	$3,553,544	$11,029,612
				$7,281,974		$36,104,407		$11,029,612	
Net Present Value	$11,029,612								

Break-Even Scenario Five

Scenario Five examines the break-even of the MARCEE demanufacturing facility using the base case scenario but considering MARCEE would do no computer refurbishing and receive no federal subsidy per unit handled. MARCEE would still receive one million EOL computer electronics per year but would dismantle (rather than refurbish) all one million units. As noted, there would be no federal subsidy. The dismantled materials would be sold as recycled output (metal, glass, and plastic) to buyers in each of the respective markets at the assumed prices. Working capital must be borrowed and a rate of 9 percent used. The amounts to be borrowed will remain unchanged. It is also assumed that the supplier is responsible for all costs associated with delivering the supply to Wood County, West Virginia.

In this scenario the MARCEE project could not reach the break-even point if operating either as a for-profit or a not-for-profit organization. Profitability is contingent upon either having a specific volume of the EOL computer electronics refurbished or having in place a federal subsidy program that would cover the costs. The complete results of this scenario are displayed in Table 71.

Table 71 – Break-Even Scenario Five

BASE Case

Demanufacturing Facility - Breakeven Economics Summary

Monitors		
Total Number of Monitors		1,000,000 per year
Percent-refurbished	0.0 %	
Percent-Checked	70 %	

Computers		
Total Number of Computers		1,000,000 per year
Percent-refurbished	0.0 %	
Percent-Checked	70 %	

Net Present Value	
With Tax	$(22,061,625)
Without Tx	$(36,072,463)

Subsidy
Per computer subsidy
$0

Capital Costs		
Warehouse Cost per Square Foot		42 $/ft²
Warehouse Footprint		115,528 ft²
Engineering Fees, Contractor Fees		
Transportation Percent		0 %
Total Cost of Warehouse	$	4,823,454
Total Cost of Equipment	$	2,458,521
Total Capital Cost	$	7,281,974

Shredder	Baler	Conveyors	Mag Separator	Eddy Separator	Glass Saw	Fork Lifts	Ring Mill
602,198	207,131	901,053	41,813	342,432	25,000	131,600	207,295

Operating Costs			Labor	Electricity	Natural Gas	OB TRANS	Waste Disposal	Haz Waste	Maint.	Op. Suppl	Water
Total Operating Costs	$	11,118,435	8,936,350	319,683	365,642	769,300	124,033	249,064	290,748	58,150	5,466
			80.4	2.9	3.3	6.9	1.1	2.2	2.6	0.5	0.0

Revenue			Refurbishing	Prec Metals	Aluminum	Steel	Plastic	Glass	Subsidy
Revenue Obtained	$	6,728,875	-	2,725,855	2,720,640	589,536	131,784	561,060	0
			-	40.5	40.4	8.8	2.0	8.3	-

Table 71 – Break-Even Scenario Five, continued

BASE Case

Net Present Value Calculations

Deprec'n MACRS	5 years	
Project life	10 years after start up	
Land Cost	0	assume that this is minimal
Rate of Return	9 % p.a.	
Working Capital	5,559,217	Based on 6 months of operating costs
Construction Pd	1 year	
Taxation rate	45 %	

Net Present Value Calculations as a For-Profit Organization

Taxation Rate 45

Year (end of year investment)	Investment	Revenue (R)	COM	Depreciation (d)	Taxable Profit (R-C-d)	After tax profit (R-C-d)(1-t)+d	Cash Flow (CF)	Discounted CF	Running BE
0	($7,281,974)						($7,281,974)	($7,281,974)	
1	($5,559,217)						($5,559,217)	($5,100,199)	($12,382,174)
2		$6,728,875	$11,118,435	$1,456,395	($5,845,954)	($1,758,880)	($1,758,880)	($1,480,414)	($13,862,588)
3		$6,728,875	$11,118,435	$2,330,232	($6,719,791)	($1,365,653)	($1,365,653)	($1,054,535)	($14,917,123)
4		$6,728,875	$11,118,435	$1,398,139	($5,787,698)	($1,785,095)	($1,785,095)	($1,264,606)	($16,181,729)
5		$6,728,875	$11,118,435	$838,883	($5,228,443)	($2,036,760)	($2,036,760)	($1,323,754)	($17,505,483)
6		$6,728,875	$11,118,435	$838,883	($5,228,443)	($2,036,760)	($2,036,760)	($1,214,453)	($18,719,937)
7		$6,728,875	$11,118,435	$419,442	($4,809,001)	($2,225,509)	($2,225,509)	($1,217,430)	($19,937,366)
8		$6,728,875	$11,118,435	$0	($4,389,559)	($2,414,258)	($2,414,258)	($1,211,634)	($21,149,001)
9		$6,728,875	$11,118,435	$0	($4,389,559)	($2,414,258)	($2,414,258)	($1,111,591)	($22,260,592)
10		$6,728,875	$11,118,435	$0	($4,389,559)	($2,414,258)	($2,414,258)	($1,019,809)	($23,280,401)
11		$6,728,875	$11,118,435	$0	($4,389,559)	($2,414,258)	$3,144,960	$1,218,775	($22,061,625)
				$7,281,974		($20,865,688)		($22,061,625)	
Net Present Value	($22,061,625)								

Net Present Value Calculations as a Non-Profit Organization

Taxation Rate 0

Year (end of year investment)	Investment	Revenue (R)	COM	Depreciation (d)	Taxable Profit (R-C-d)	After tax profit (R-C-d)(1-t)+d	Cash Flow (CF)	Discounted CF	Running BE
0	($7,281,974)						($7,281,974)	($7,281,974)	
1	($5,559,217)						($5,559,217)	($5,100,199)	($12,382,174)
2		$6,728,875	$11,118,435	$1,456,395	($5,845,954)	($4,389,559)	($4,389,559)	($3,694,604)	($16,076,778)
3		$6,728,875	$11,118,435	$2,330,232	($6,719,791)	($4,389,559)	($4,389,559)	($3,389,545)	($19,466,323)
4		$6,728,875	$11,118,435	$1,398,139	($5,787,698)	($4,389,559)	($4,389,559)	($3,109,675)	($22,575,998)
5		$6,728,875	$11,118,435	$838,883	($5,228,443)	($4,389,559)	($4,389,559)	($2,852,912)	($25,428,910)
6		$6,728,875	$11,118,435	$838,883	($5,228,443)	($4,389,559)	($4,389,559)	($2,617,351)	($28,046,261)
7		$6,728,875	$11,118,435	$419,442	($4,809,001)	($4,389,559)	($4,389,559)	($2,401,239)	($30,447,500)
8		$6,728,875	$11,118,435	$0	($4,389,559)	($4,389,559)	($4,389,559)	($2,202,972)	($32,650,472)
9		$6,728,875	$11,118,435	$0	($4,389,559)	($4,389,559)	($4,389,559)	($2,021,075)	($34,671,547)
10		$6,728,875	$11,118,435	$0	($4,389,559)	($4,389,559)	($4,389,559)	($1,854,197)	($36,525,744)
11		$6,728,875	$11,118,435	$0	($4,389,559)	($4,389,559)	$1,169,658	$453,281	($36,072,463)
				$7,281,974		($43,895,593)		($36,072,463)	
Net Present Value	($36,072,463)								

Appendix B: Task 1.2

Report on Spreadsheet Model of Demanufactring Facility

Demanufacturing Process

A spreadsheet-based model has been developed to simulate an end-of-life (EOL) electronics recycling/demanufacturing process. This model takes into account the fixed capital investments associated with the construction of a warehouse to house the demanufacturing facility as well as all equipment required for the demanufacturing processes. In addition, all operating costs including, operating labor, utilities, transportation, and hazardous materials disposal are estimated. Finally, revenues from recycling materials such as glass, metal containing scrap, and plastics are estimated, as are the revenues from the sale of refurbished/recycled components that still have a useful life. All these costs and revenues are combined using the appropriate cost of capital to yield a Net Present Value (NPV) for the process. Each section of the spreadsheet model is described below in the following sections.

1. Estimation of Material Balance

In order to estimate the flow of goods through the facility, it is necessary to complete a material balance to correctly account for the feed and product flows and to insure that all material flows are correctly accounted. The composition of the "average" computer is very difficult to estimate since the time, age, and type of computer is changing and there is little information available about typical PC composition. The composition used in the current study was modified from the article "Just say no to E-Waste" [1]. The composition and assumptions used in closing the material balance for this study are listed in Table 72 below.

Table 72: Composition of a "typical" PC used in the current research (modified from [1])

Material	Weight % in Computer	Weight in Computer (lb)	Assumed Distribution between computer case and monitor
Glass	24.9 %	14.928	100% in Monitor
Plastic	23.1 %	13.872	50% in Monitor - 5% goes to shredder with electronics
Lead	6.3 %	3.774	100% in Monitor
Aluminum	14.2 %	8.502	20% in Monitor
Iron and Steel	20.5 %	12.282	20% in Monitor
Tin	1.0 %	0.600	20% in Monitor
Copper	6.9 %	4.152	20% in Monitor
Nickel	0.9 %	0.510	20% in Monitor
Zinc	2.2 %	1.323	20% in Monitor
Gold	0.0 %	0.001	20% in Monitor
Battery	0.1 %	0.044	20% in Monitor
Mercury	0.0 %	0.001	20% in Monitor
Silver	0.0 %	0.011	20% in Monitor
Total	**100.0 %**	**60.0 lb**	

The hazardous waste stream is assumed to comprise all the batteries from the computers plus all the mercury (in the form of mercury switches). The glass stream is assumed to comprise all of the glass and all the lead from the recycled monitors. The plastic stream is calculated from the plastic recovered from recycled monitors and the plastic in the computer cases. It is further assumed that 5% of this plastic will be lost with the shredded electronics and this leaves with the metals stream from the shredder. Of the remaining plastic, it is assumed that 50% of this can be sold to a plastics refiner/separator and the remainder has no value and must be disposed of as waste (municipal landfill). The weight of refurbished computer parts is estimated to be 0.5 lb for each drive (hard, CD, SCCI) and 0.05 lb for a CPU. Finally, a waste stream from the facility of 0.5wt% of the throughput is assumed to account for miscellaneous foam, paper, and other un-recyclable material.

2. Estimation of Size of Warehouse

It is assumed that this facility will handle a supply stream of computer cases (boxes containing CPU, mother board, hard drives, etc.) and associated monitors. A portion of these monitors are eligible for refurbishing and a portion of the components from the computers can be recycled to the computer industry as functioning, albeit somewhat older generation, components. In order to estimate the size of the warehouse, the logistics of the flow of material handled by the facility must be formulated. Based on site visits to a demanufacturer (DMC), a glass/monitor recycler (Envirocycle), and several plastics separation and handling facilities (MBA Polymers, Butler-McDonald, and SDR Plastics) the following assumptions about the material flow through the facility have been made. A general view of the floor plan for the demanufacturing facility proposed here is shown below in Figure 62.

2.1 Storage

It is assumed that monitors entering the facility arrive on pallets containing 27 monitors to a pallet (3x3x3). These pallets will be stored in rows of 20 pallets length and 2 pallets width. The pallets have a footprint of $16ft^2$ (4 ft by 4 ft) and each pallet will be separated from its neighbor by 6 inches. Due to the uneven surface of the monitors these pallets will not be stacked. For both the monitors and computers a total 10 days inventory will be stored at the facility. Each double row of pallets is separated by subsequent double rows by an aisle 4 ft wide to allow a forklift vehicle to maneuver and pick up the pallets.

It is assumed that computer cases entering the facility arrive on pallets containing 36 computer cases to a pallet (4x4x3). Each pallet has a footprint of $16ft^2$ (4 ft by 4 ft) and these pallets will be arranged in the same way as the pallets discussed above, which contain the monitors.

2.2 Initial Inspection

The term recycle is used here to describe the process by which a unit is dismantled into basic materials (glass, metals, plastics, etc.) and each material is sold to an external broker/recycler for its "scrap" value. The term refurbished is defined as the process by which

Figure 62: Warehouse Facility to Handle One Million Units Per Year Stream Flows Indicated by Arrows

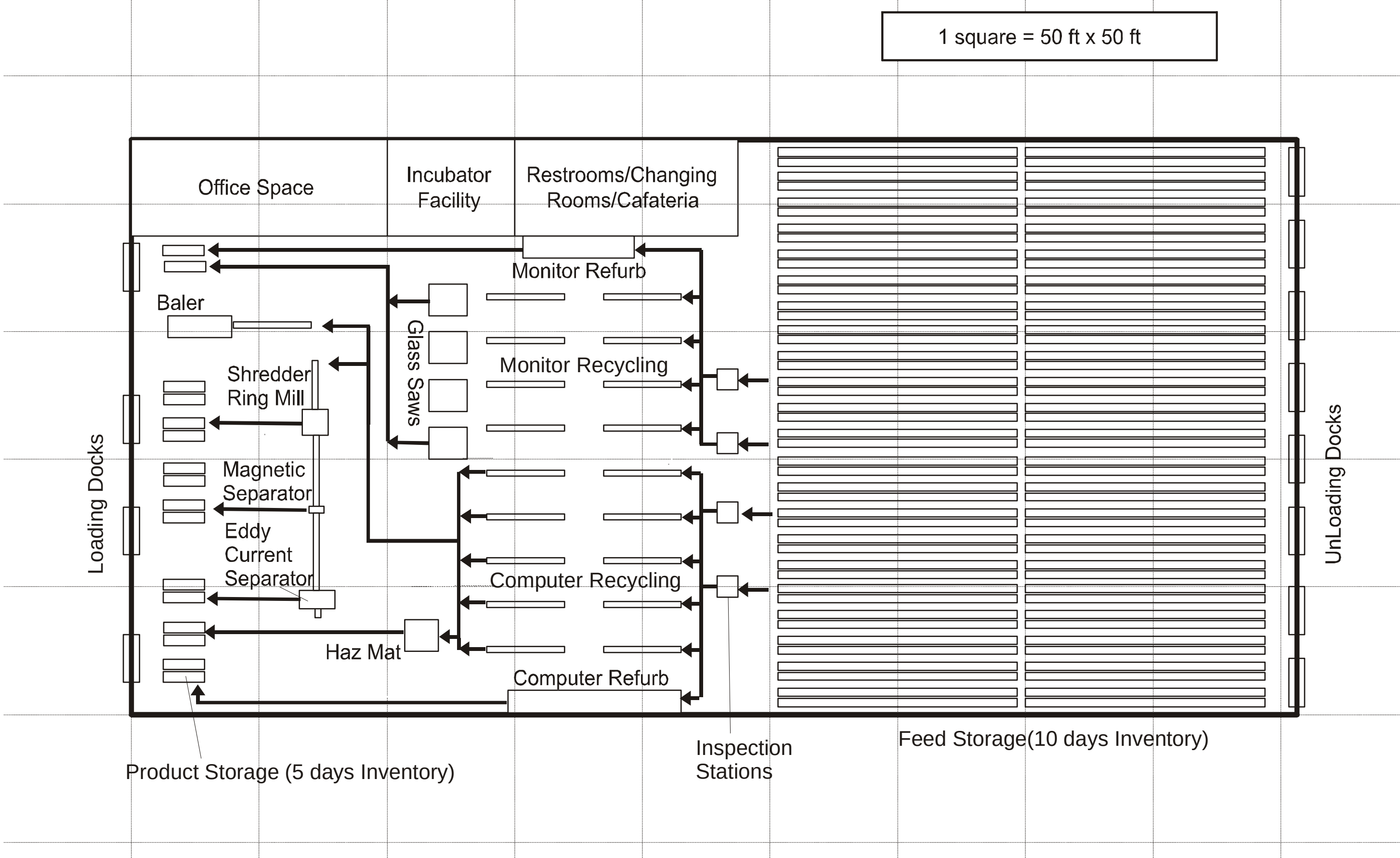

Figure 1: Warehouse Facility to Handle One Million Units per Year, Stream Flows Indicated by Arrows

a monitor is reconditioned in to a working unit that can be sold or the process by which components such as CPUs, hard drives, CDs and SCCi drives are removed and resold. The handling of computer cases and monitors differs depending on whether the unit can be refurbished or recycled. In order to assess whether a monitor or computer can be refurbished it is necessary to complete an initial inspection of the unit and make a determination of where the unit should go (to the recycling station or the refurbishing station). It is assumed that 70% of all units entering the facility will be candidates for this initial inspection, the remaining 30% of the units are considered to be so old or damaged that they will go directly to the recycling station. The initial inspection takes approximately 1 minute per unit. The refurbishable units are then sent to the refurbishing station while the remaining units are sent to the recycling stations.

2.3 Recycling Stations

The recycling stations consist of a set of parallel conveyor belts onto which the units are placed. These conveyors are approximately 2 ft wide and 30 ft long. There is a 15 ft aisle between conveyors. Since the demanufacturing/disassembling processes are different for monitors and computer boxes, separate conveyors will handle each feed. During the recycling of the units, it is necessary to remove and account for all hazardous waste materials. These consist mainly of batteries and mercury switches found in the computer boxes. Although, the monitor glass contains high levels of lead, the lead is chemically bound into the glass and for the sake of this analysis it is not considered to be a hazardous waste material. It should be noted that the handling and definition of hazardous wastes is a contentious issue and the characterization of monitor glass depends upon the State in which the facility is located. A small office is located within the facility to handle and track these hazardous wastes.

2.4 Testing and Refurbishing Stations

Each monitor refurbishing station consists of a table 3ft wide and 12 ft long on which is located test equipment and onto which monitors are placed, powered-up, and allowed to run for a period of time to allow assessment of their condition. The computer refurbishing stations are the same size as the monitor stations. The testing equipment is used to determine the operability of the different drives. All hard drives are reformatted. The CPUs are simple removed and placed in a box of like generation chips.

2.5 Equipment for Recycling

The equipment required in the demanufacturing facility for the processing of recycled materials is listed below in Table 73. The equipment is sized based on the throughput of material through the given equipment. Based on the size of the equipment a footprint is estimated for the equipment.

2.6 Office Space, Restrooms/Cafeteria/Showers/Changing Facilities, and Incubator Facility

After the estimation of the total number of Operators has been made, it is assumed that a support staff equal to 15% of the operations work force will be required. This staff will be responsible for sales, supply chain management, human resources, accounting, etc. Office space is allocated at a rate of 180 ft^2 per person plus an additional 10% for hallways. An incubator facility consisting of 10 offices with hallways is also allocated.

Based on the size of the total workforce estimates are made for restrooms, cafeteria, showers, and changing facilities.

Table 73: Equipment used in Recycling facility and the function that it performs.

Equipment	Function
Baler	Used to compress and compact plastics from computer and monitor casing
Shredder	Used to reduce the size of printed circuit boards, metallic casing chasses, etc.
Magnetic Separator	Used in conjunction with the shredder to remove shredded ferromagnetic material.
Eddy Current Separator	Used in conjunction with the shredder to remove shredded paramagnetic material.
Ring Mill	Used as an alternative to the shredder. It is capable of reducing the size of all streams to the 1-3 mm range and can deal with very tough and hard materials
Glass Saw	Used to remove the 3 different glass sections (panel, neck, and funnel) of the monitor.
Conveyors	Used to transport monitors and computer cases through recycling stations
Forklifts	Used to move pallets and boxes of feed and product materials through the facility

2.7 Product Storage

It is assumed that 5 days of product inventory will be stored at the facility. All products from the refurbishing and recycling lines are stored either on pallets (4ft by 4ft) or in Gaylord boxes (4ft by 4ft by 4ft). The Gaylord boxes are stacked 2 high while the pallets (containing refurbished monitors) are not stacked. The pallets/boxes are arranged in rows two storage units wide with a 4ft aisle between each row of two. The footprint for the product storage is considerably smaller than for the feed storage because there is a large reduction in volume during the recycling process and also the product inventory is only 5 days compared to 10 days for feed material.

2.8 Safety/Ergonomic Factor

The total footprint for the warehouse facility is taken to be the sum of all the factors listed above multiplied by 1.25. This 25% increase is used as a safety factor to take into account that additional space will probably be required for ergonomic considerations plus this gives a safety margin for future expansion.

2.9 Cost Estimation of Warehouse

The cost estimation of the warehouse facility was done by following the guidelines and costs given in reference [2]. These costs were adjusted from national averages for industrial warehouse facilities using factors specific to the geographical location, thus prices were adjusted to Charleston, WV averages. It is assumed that costs in Wood County, WV will be equivalent. Based on observations at several demanufacturing and recycling facilities, the height of the warehouse was taken to be 32 ft to account for clearance of tall equipment such as the shredder. Costs from reference [2] were based on a standard height of 28 ft. These costs were further adjusted on a wall surface area basis using information given in Reference [3]. The costs of office space were also taken from reference [2]. Averaged costs for the warehouse facility plus office space are in the range of $40-50/sq ft.

3. Estimation of Demanufacturing Equipment

Several vendor quotes were obtained for equipment needed for this facility. From these cost estimates, correlations for equipment cost as a function of throughput were made and these were used to estimate the purchased cost of equipment. These correlations along with the installation factors are listed below in Table 74.

Table 74: Equations for the Purchased Equipment Cost and installation factors used for the Demanufacturing Facility

Equipment	Cost Equation	Installation Factor
Baler	$C = \$65,000(F/2000)^{0.50}$	3
Shredder	$C = \$125,000(F/2000)^{0.586}$	3
Magnetic Separator	$C = \$8,000(F/2000)^{0.633}$	3
Eddy Current Separator	$C = \$75,000(F/2000)^{0.479}$	3
Ring Mill	$C = \$70,000(F/2000)^{0.344}$	3
Glass Saw	C = $5,000	1
Conveyors	C = $5,670	3
Forklifts	C = $18,800	1

The total cost of equipment is taken as $C_{total} = \sum_{i=1}^{all\ equip} C_{purchased,i} F_{installation}$

4. Estimation of Revenues

Revenues are generated from all recycled materials (glass, plastic, metals, precious metals) and refurbished materials (monitors, CPUs, hard drives, CD drives, SCCI drives). The unit values for each product and the source for this information is given below in Table 75.

Table 75: Basis for Estimation of Revenues for Demanufacturing Products

Refurbished Product	Unit Cost	Source for Cost
Refurbished Monitor	$ 35	www.electronic-recycling.ie
CPU	$ 30	www.electronic-recycling.ie
Hard Drive	$ 30	www.electronic-recycling.ie
CD Drive	$ 15	www.electronic-recycling.ie
SCCI Drive	$ 15	www.electronic-recycling.ie
Recycled Product		
Precious Metals from Computer Boards gold silver copper	95% of market price - $5.00 per oz – ½ oz per ton of scrap - $700 lot charge 95% of market price - $0.60 per oz – 2 oz per ton of scrap - $700 lot charge 80% of market price - $0.15 per lb – 55 lb per ton of scrap - $700 lot charge	These are standard rates obtained from Charles Beckmann Noranda. Transportation charges are included separately in the section on operating costs.
Aluminum	$ 0.32 per lb transportation not included in price	From Texas Recycler Market News at http://grn.com/grn/prices/tx-prices.htm
Steel	$ 0.048 per lb	http://metalprices.com/
Plastic	$ 0.02 per lb transportation included in price	Average value from Envirocycle
Glass	$ 0.03 per lb transportation not included in price	Average value for separated glass from Envirocycle.

5. Estimation of Operating Costs

5.1 Labor Costs

Labor costs are estimated using the wage schedule outlined in Table 76 below.

The fringe rate was estimated at 25% of total labor costs and includes social security tax, health insurance, and sick leave and vacation for salaried employees. The estimation of office staff was based on typical supervisor/operator ratios seen at similar facilities. The estimation of office staff was also done on this basis. No costs have been included for personnel involved in the incubator facility.

It is assumed that the facility operates 2 eight-hour shifts per day, 365 days per year. Each operator is assumed to work 240 shifts per year (5 shifts per week and 48 weeks per year, with 2 weeks sick leave and 2 weeks vacation).

Table 76: Wage and Salary Schedule for Operating Labor and Office Staff

Employee	Wage/Salary Rate	Comments
Operating Labor	$12.00 /hr	
Operations Supervisor	$ 14.00 /hr	Estimated at 10% of labor force
Office Staff	$ 15.00 /hr	Estimated at 15% of labor force
Human Resources Director	$ 35,000 /yr	
Plant Manager	$ 60,000 /yr	

In order to estimate the operating labor force, it was necessary to assign times to different recycling and refurbishing tasks. These tasks are given below in Table 77 along with the assumed time for completion.

Table 77: Completion Times for Recycling and Refurbishing Tasks

Task	Time to Complete Task	Comments
Initial Inspection of Monitors	1 minute	Number of operators = number of monitors to be inspected per hour/60 [rounded up to next integer)
Initial Inspection of Computer Boxes	1 minute	Number of operators = number of boxes to be inspected per hour/60 [rounded up to next integer)
Monitor Dismantling	10 minutes	Number of operators = number of monitors to be dismantled per hour/60 [rounded up to next integer)
Computer Box Dismantling	6 minutes	Number of operators = number of boxes to be dismantled per hour/60 [rounded up to next integer)
Equipment Operation	1 operator per equipment	
Time to check Refurbished Monitor	5 minutes per monitor	Number of operators = number of monitors to be refurbished per hour/12 [rounded up to next integer)
Time to check Refurbished Computer Components	3 minutes per component	Number of operators = number of computer components to be refurbished per hour/20 [rounded up to next integer)
Hazardous Storage Area	1 operator	

5.2 Electricity

Power consumption was estimated from equipment specifications, lighting and air conditioning requirements. The lighting requirements for the warehouse area were estimated at 200W per 100 ft^2. The air conditioning requirements were taken as 1 ton of refrigeration per 1000 ft^2 obtained from reference [4]. The cost of electricity was obtained from Allegheny Power and was taken to be $0.0758/kW-h.

5.3 Water

Water requirements were obtained based on restroom and shower usage for all the employees. A rate for water of $1.44 per 1000 gals was obtained from reference [5].

5.4 Hazardous Waste Disposal

It was assumed that each computer contains a single battery and the cost of disposing of the battery was obtained from reference [6] as $5.65 per lb. The cost of disposal of mercury, contained in mercury switches, was estimated from reference [7] at $0.35 per lb.

5.5 Municipal Waste Disposal

It is assumed that approximately 0.5wt% of the total throughput of the facility will be waste material such as paper, foam, scrap cardboard, etc. In addition, it is assumed that 50 wt% of the plastic will not be suitable for further separation and recycle. Both these streams will be disposed of in a local Municipal landfill at a cost of $36 per ton, reference [8]. This price is assumed to include local transportation.

5.6 Transportation

The transportation costs for the aluminum, steel, shredded computer boards containing precious metals, and glass were all assumed to be $600 per truckload (42,000 lb).

5.7 Natural Gas

Natural gas costs for heating the facility were estimated at 23,000 BTU/h per 1000ft^2 of warehouse floor area. The cost of natural gas was taken as $0.00299 per standard ft^3, from reference [9].

5.8 Equipment Maintenance

This was assumed to be equal to 10% of the installed cost of the equipment per year, from reference [10].

5.9 Operating Supplies

This was assumed to be equal to 20% of the annual equipment maintenance cost, from reference [10].

6. Breakeven Price Calculations

Both before tax (non-profit) and after tax (for profit) net present value calculations were performed for the demanufacturing facility. The assumptions used for these calculations are given in Table 78 below.

Table 78: Economic Parameters used in Evaluating the Net Present Value of the Facility

Depreciation Method	MACRS over 5 years
Project life	10 years after start up
Land Cost	Assumed to be negligible
Rate of Return	9.0 % per year.
Working Capital	6 months of operating costs
Construction Pd	1 year
Taxation rate	45%

7. Results

Using the spreadsheet model outlined above a number of simulations was performed for the manufacturing facility. These results are displayed in Figures 63-68 below. For all of the cases run, it is clear that without refurbishing or some form of subsidy, or a combination, the facility cannot be made to operate profitably.

Figure 63 shows the relationship between the percentage of refurbished units (1 unit = 1monitor + 1 computer) required for the facility to breakeven (NPV=0) as a function of the number of units fed to the facility and with subsidies of $0, $2, $4, $6, and $8 per unit. For a given subsidy, the larger the number of units processed, the smaller the percentage that must be refurbished. This trend reflects the economy of scale that occurs as the facility increases in size. However, the dominant cost for these facilities is due to the operating labor and thus for a given subsidy, there will exist a limiting refurbishing rate at which the facility must operate in order to breakeven. In Figure 64, the case for a not-for-profit facility is illustrated. The same basic trends as shown in Figure 64 are illustrated, except all the curves are shifted to the left reflecting the lower refurbishing rates required when taxation is not included.

Figure 65 shows how the subsidy must change as a function of throughput for the case when refurbishing is not included. This case represents the situation when only true EOL computers, having zero residual value, are processed. The results indicate that a subsidy of between $5 – 10 per unit covers the costs to recycle the units for all facilities processing more than about 300,000 units per year.

Figures 66 and 67 show a breakdown of the operating costs and revenues for a base case facility (for-profit) processing 1,000,000 units per year without a subsidy. The largest operating cost is clearly the labor (including supervisory and office staff) accounting for nearly 81% of the total, transportation costs are a distant second accounting for only 6.7 % of the total. The three largest revenues are sales from refurbishing (49.9%), precious metals (20.6%), and Aluminum (20.6%).

Finally, Figure 68 shows, for the base case in Figures 66 and 67, the sensitivity of the percentage of refurbished units required to breakeven to changes in key parameters. The results indicate that changes in the cost of labor (the biggest operating cost) and the revenue generated from refurbishing (generally the largest revenue) have the greatest effect on the percentage of refurbished computers required for the facility to breakeven. The effects of revenue from precious metals and the costs associated with transportation are significantly smaller.

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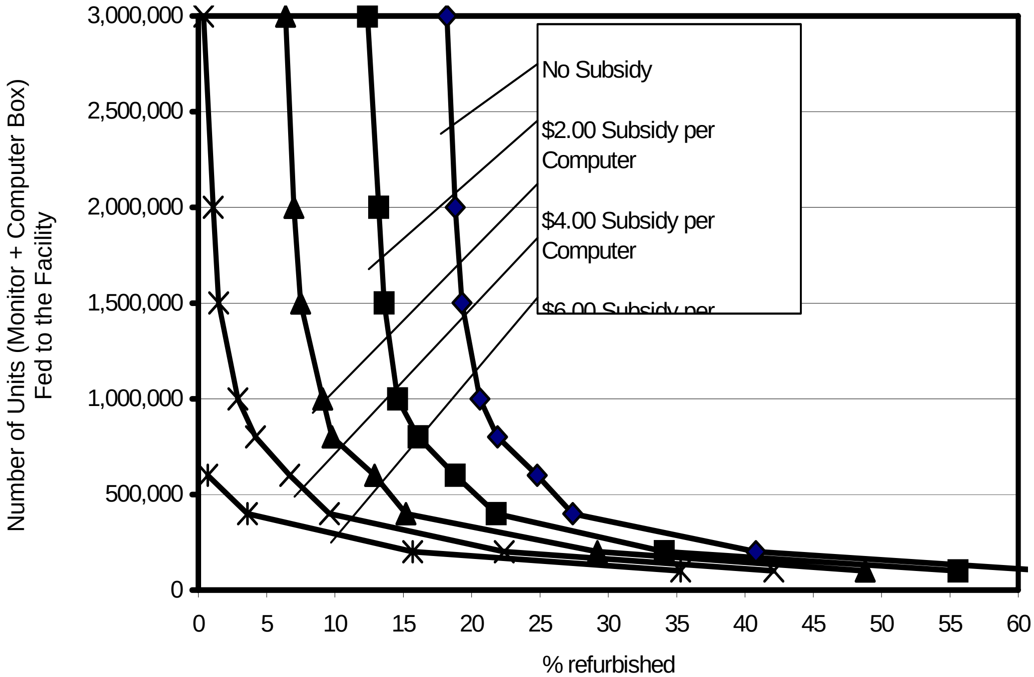

Figure 63: The Effect of Subsidy on the Amount of Refurbishing Required to Breakeven (For-Profit Case)

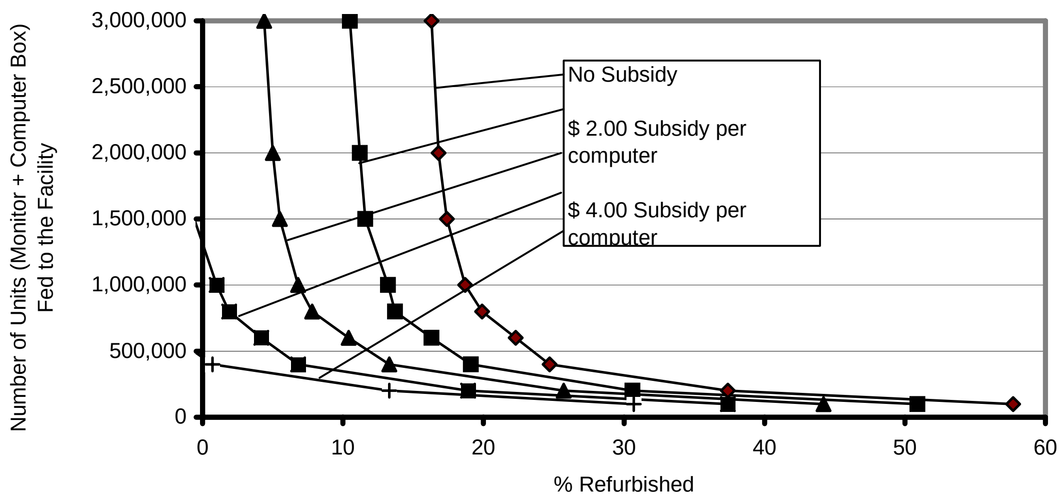

Figure 64: The Effect of Subsidy on the Amount of Refurbishing Required to Breakeven (Not-for-Profit Case)

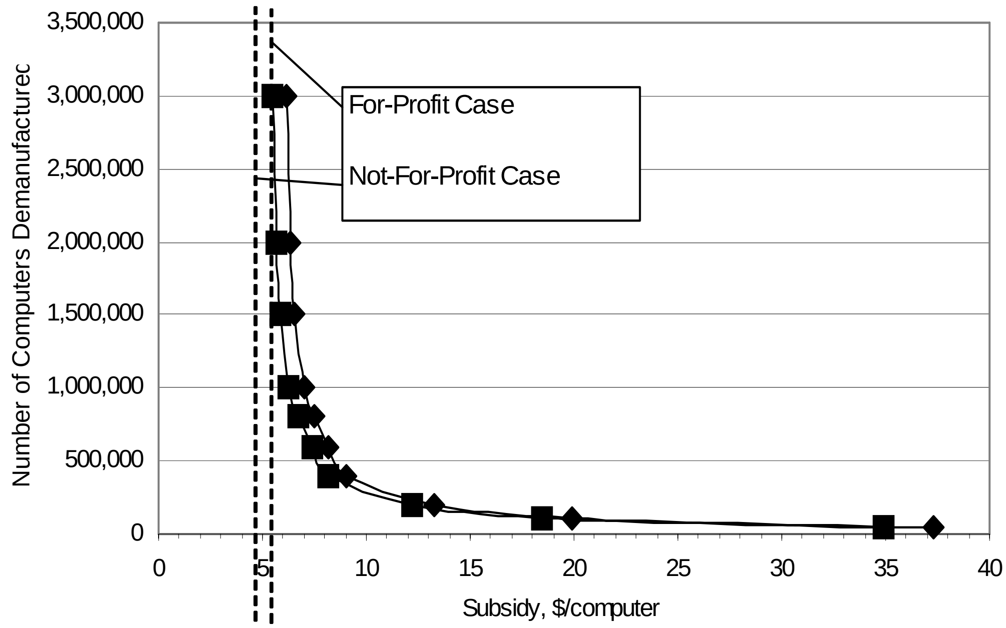

Figure 65: Subsidy vs Number of Computers Processed (No Refurbishing)

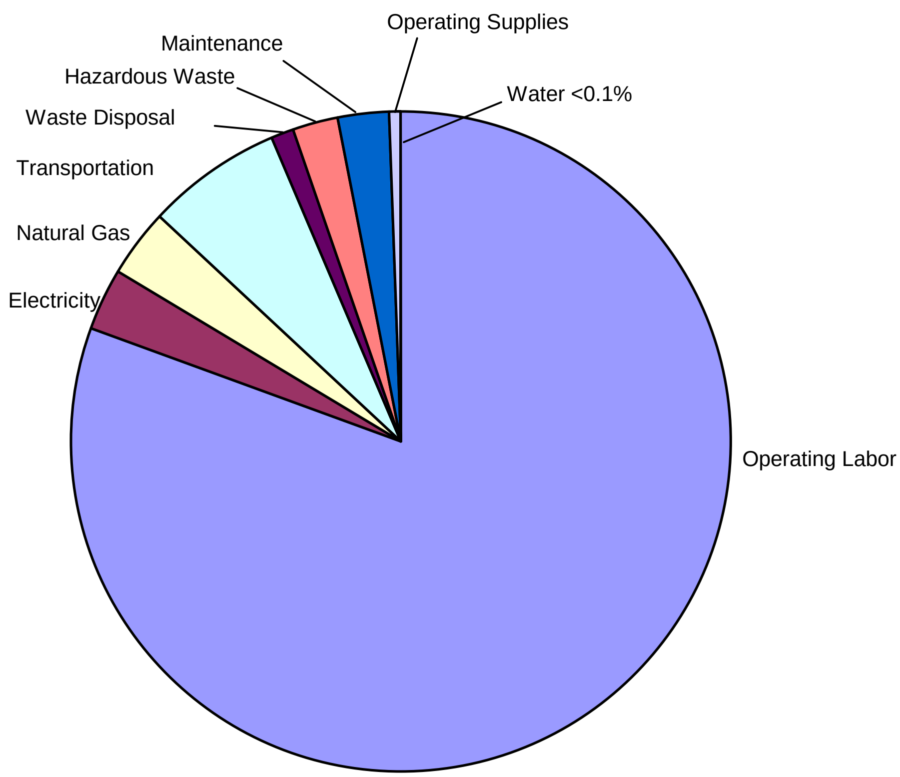

Figure 66: Breakdown of Operating Costs (total = $10.3 million)

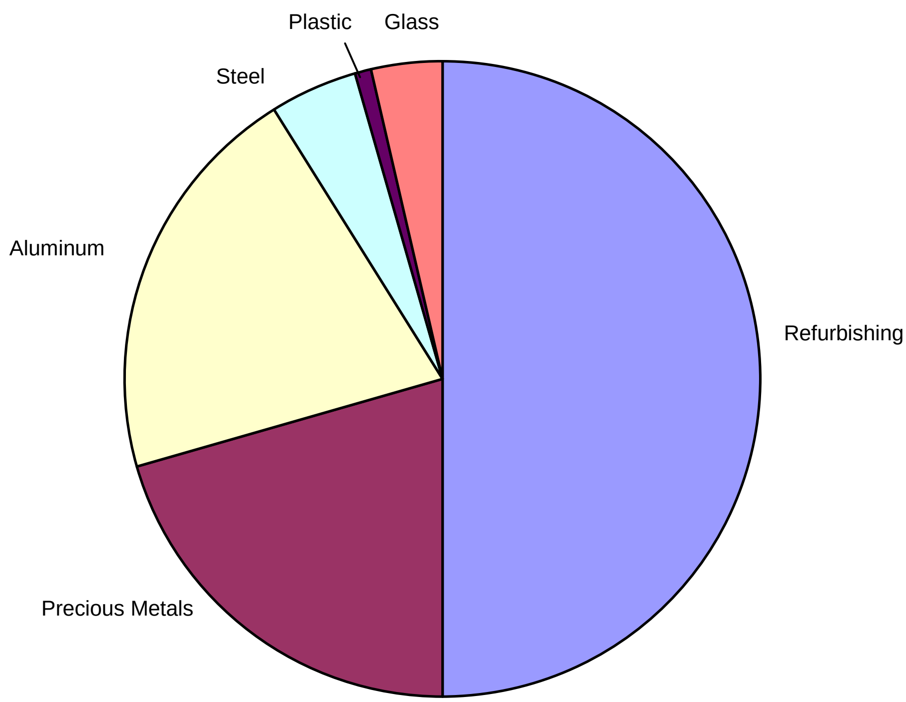

Figure 67: Breakdown of Revenues (total = $ 12.6 million)

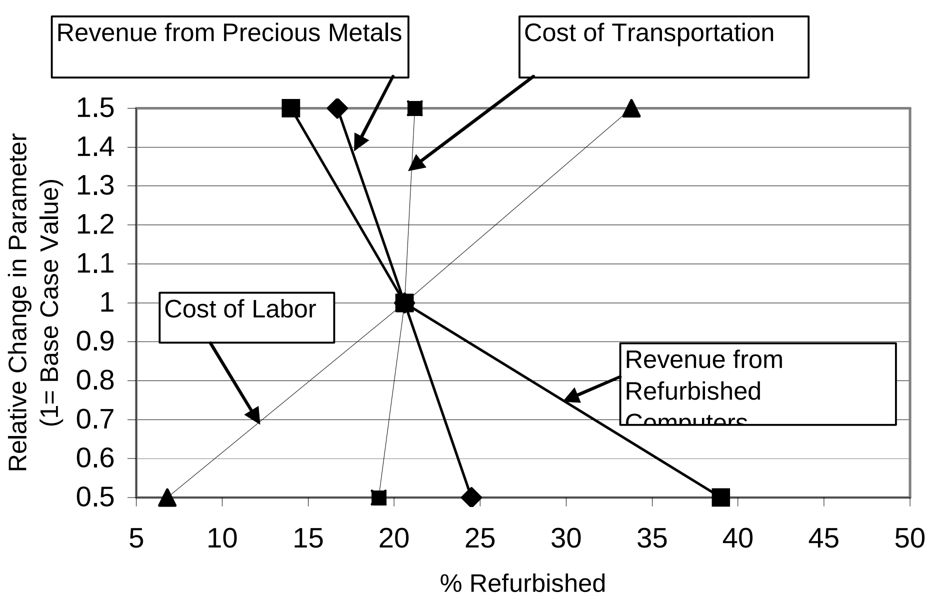

Figure 68 Sensitivity Analysis for Input Key Variables
(Base Case = 1 million units - No Subsidy)

Addendum

Demanufacturing Process for the Zero-Refurbishing Case

A spreadsheet-based model has been developed to simulate an end-of-life (EOL) electronics recycling/demanufacturing process. This model takes into account the fixed capital investments associated with the construction of a warehouse to house the demanufacturing facility as well as all equipment required for the demanufacturing processes. In addition, all operating costs including, operating labor, utilities, transportation, and hazardous materials disposal are estimated. Finally, revenues from recycling materials such as glass, metal containing scrap, and plastics are estimated, as are the revenues from the sale of refurbished/recycled components that still have a useful life. All these costs and revenues are combined using the appropriate cost of capital to yield a Net Present Value (NPV) for the process.

Each section of the spreadsheet model has been explained in a previous report, see 3rd Quarterly report for period July 1 – September 30, 2000. The basic differences in the new case are that no revenues are obtained for refurnished computers, and that the labor and warehouse space required for the refurbishing stations are eliminated. Currently, equipment costs and operating costs for the dryers, screens and hydroclones are being sought. The movement of computers through the warehouse is shown below in Figure 69.

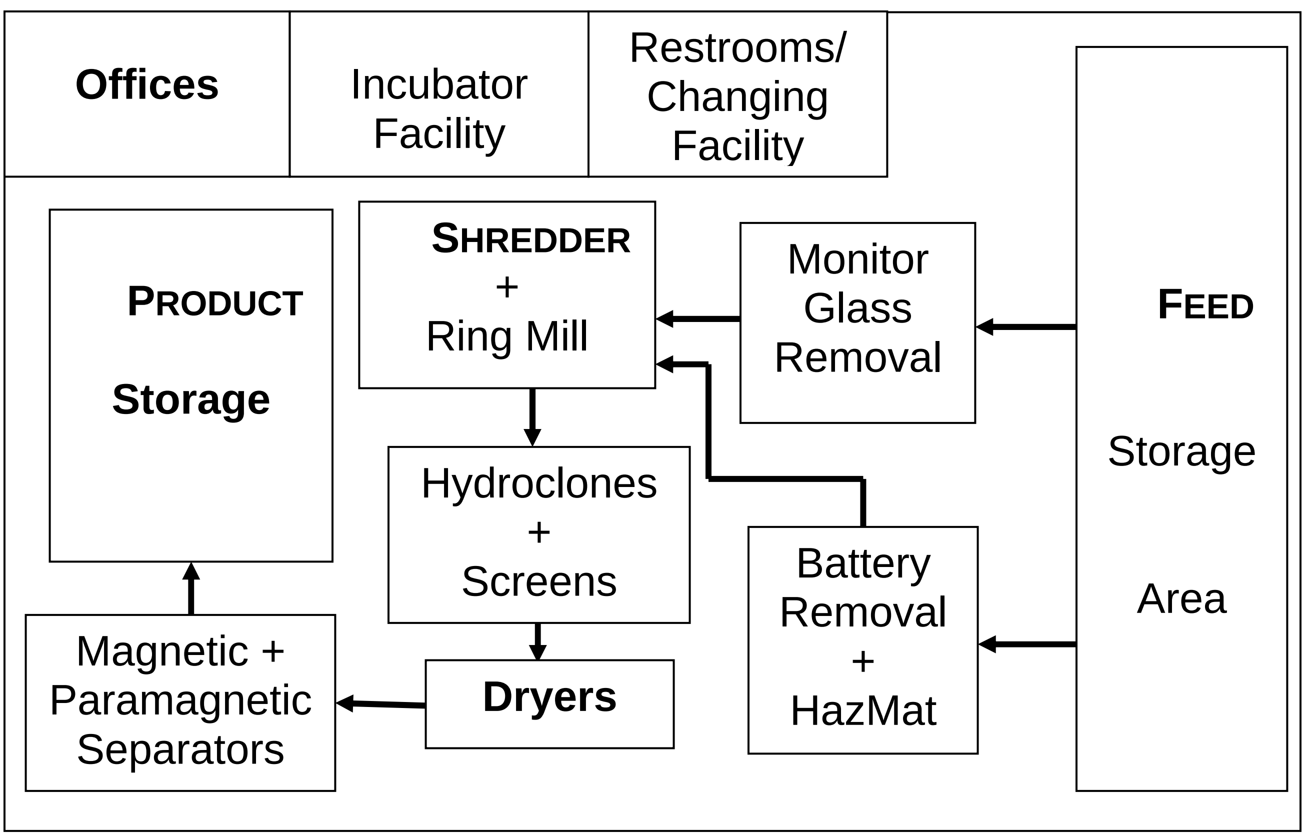

Figure 69: Material Flow through Warehouse for Zero-Refurbishing Case

A comparison of operating costs and revenues for two cases, each processing 1 million computers per year, is shown Table 79. The two cases that are compared differ in the quality of the feed material. In Case 1, approximately 20 % of the computers can be refurbished and generate revenue from post recycling sales. In Case 2, the computers cannot be refurbished and no attempt is made to separate components except for the HAZMATs and monitor glass.

Table 79: Operating Cost Comparison for Case 1 (refurbishing) and Case 2 (No Refurbishing)

Operating Costs (All costs in $/yr)	Case 1 (1 million units - approx. 20% refurbished)	Case 2 (1 million units - 0% refurbished)
Operating Labor	8,336,400	4,614,000
Electricity	293,400	308,400
Natural Gas	357,800	328,300
Transportation Costs (nom)	693,000	769,300
Waste Disposal	111,700	5,400
HAZMAT Disposal	237,800	237,800
Equipment Maintenance	252,500	243,400
Operating Supplies	50,500	48,700
Water	5,100	2,800
Total	**10,338,200**	**6,558,100**

From Table 79 it is clear that that major savings for Case 2 come from the reduction in the labor force. This reduction is due to the fact that no inspection or refurbishing stations are required since all equipment, after HAZMAT (battery) and Monitor Glass removal, are sent directly to the shredder.

The overall economic summary for the zero-refurbishing case (Case 2) show that this case may be profitable depending on the labor cost and the revenue from the plastics. A sensitivity study was performed for both these costs, and the results are shown below in Figure 70. It should be noted that these results are preliminary, since the equipment and operating costs for the dryers, hydroclones, and screens have not been included. Nevertheless, the results are encouraging from the point of view being able to operate a profitable facility using old EOL equipment as a feed source. The results also show the importance of efficient ergonomic design of the recycling facility, vis-à-vis the role of labor costs on the overall profitability of the facility. At the base conditions, which correspond to those shown in Table 72, for a for-profit facility, the plastic stream must be sold for approximately 13.6¢/lb in order for the facility to breakeven. The effect of reducing labor costs on the required selling price of plastic for the facility to break even is shown in the figure. A reduction in the operating labor cost of approximately 28% would yield a situation where by the required selling price of plastic drops to 0¢/lb.

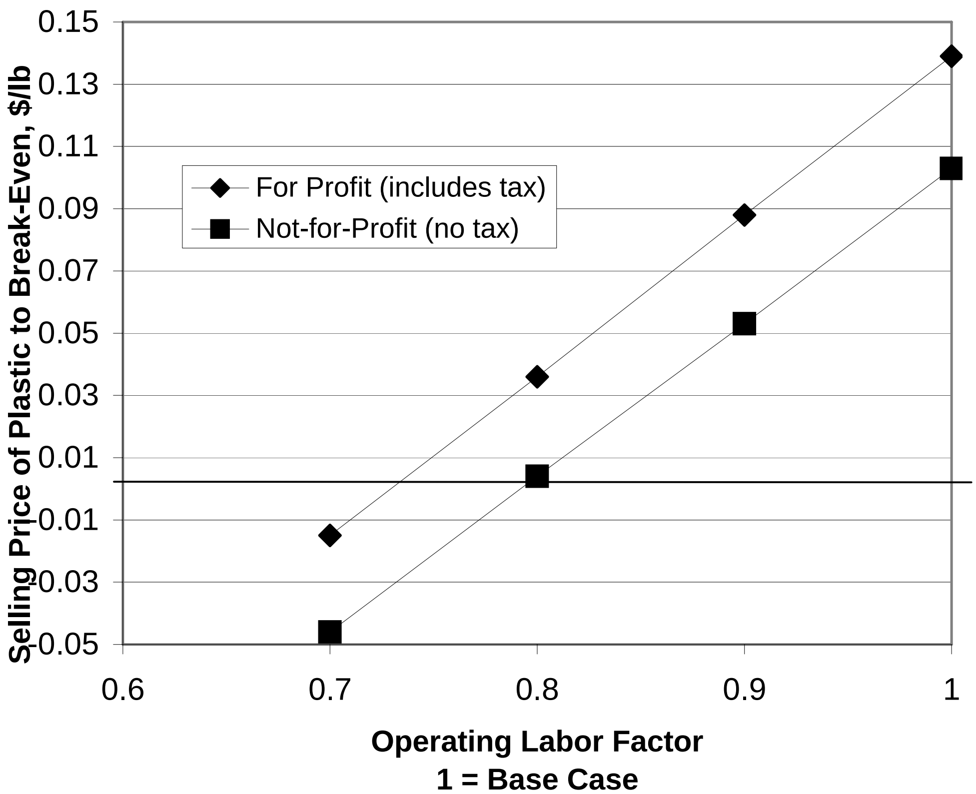

Figure 70: Sensitivity of Plastic Selling Price to Labor Costs

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Summary

From the results shown above, it is clear that the cost of operating labor is by far the most important operating cost in an EOL electronics demanufacturing facility. On the revenue side of the equation, the value of the plastics stream is the most difficult to evaluate. In the zero-refurbishing case described here, the plastics stream probably has a very low value, since no attempt has been made to refine it. Nevertheless, by keeping operating labor costs low there may be "window of profitability " open for a process fed with old EOL devices.

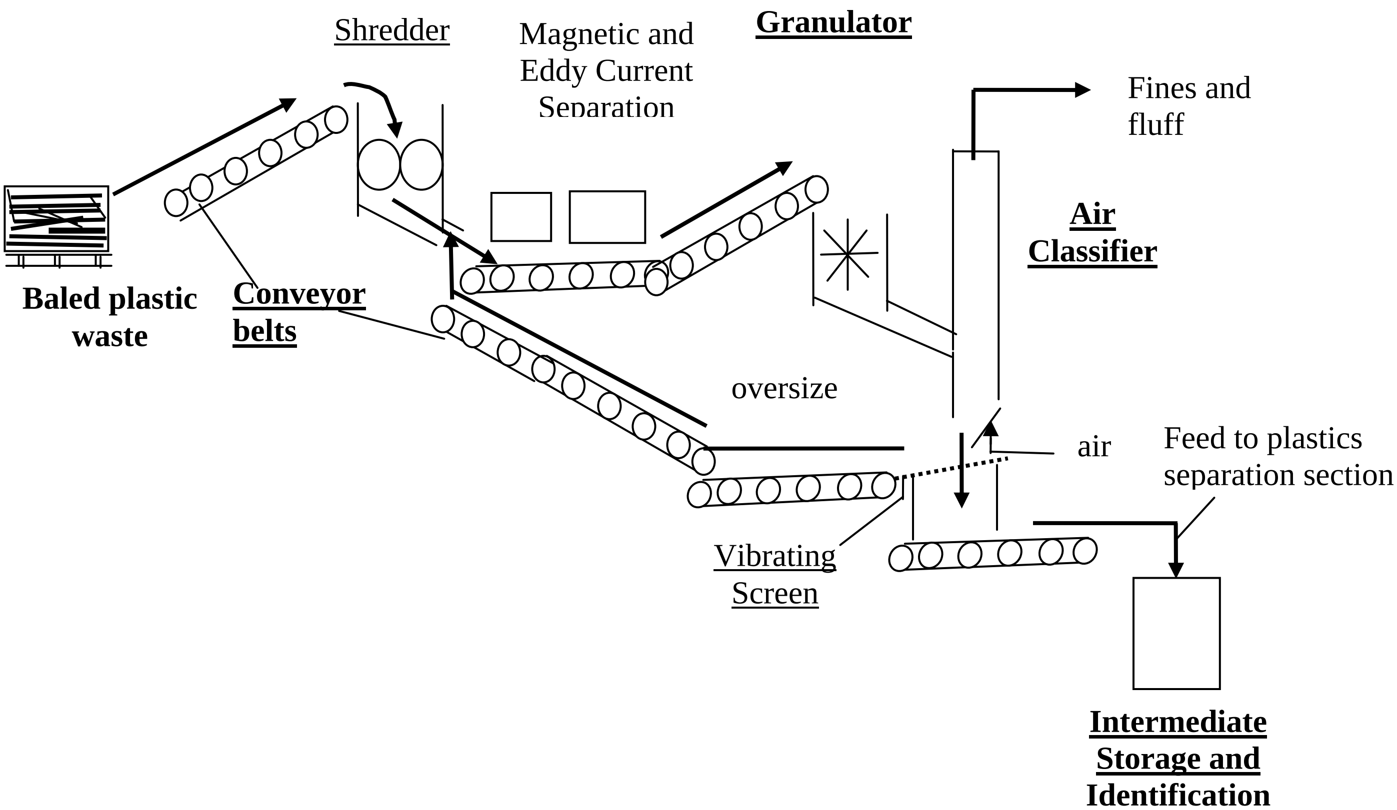

Figure 71: Primary Separation and Size Reduction Process

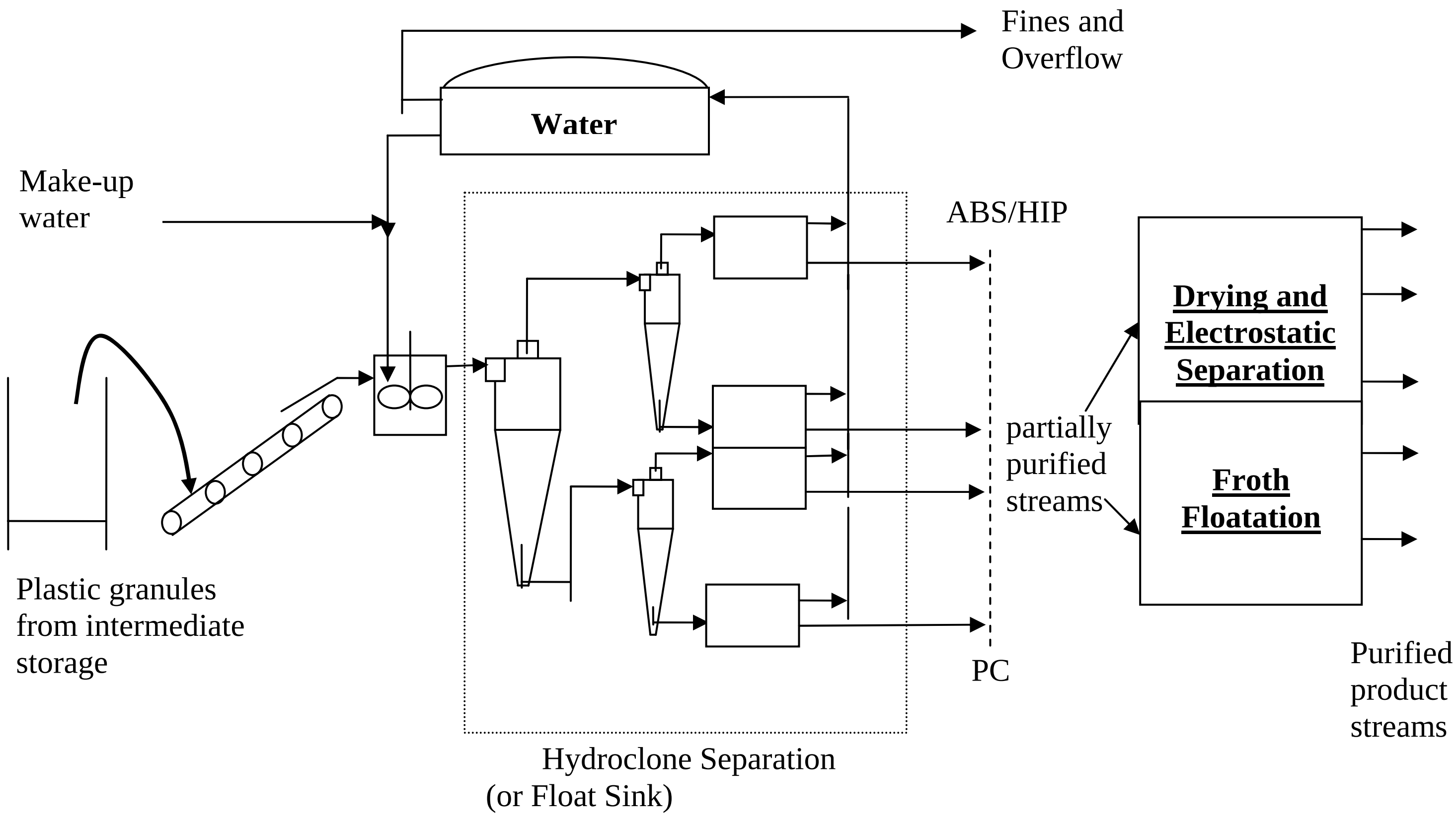

Figure 72: Secondary Separation Processes

Table 80: Equipment Estimates for Demanufacturing and Recycling Process

Equipment	Price	Company	Address	Notes
Shredder	$45,000-$50,000	Jacobson Companies	Minneapolis	20"x30" inlet throat opening,
			Minnesota	20-30 hp, 2 counter rotating
				shafts with control panel
	2000 lb/hr--$120,000	SSI Shredding Systems	Oregon	Quad shaft shredder
	8500 lb/hr---$280,000			5-30 rpm
	$189,000	American Pulverizer	St. Louis	Model 5440
			Missouri	
Magnetic	$10,000	Ding's Magnetics		Only a very ball park figure
Separator				
	$7,750	Magnetics Division		Mastermag 8
		Global Marketing Inc.		Pcb 5 K EL, Permanent Self
				Cleaning Crossbelt Magnetic
				Separator
				30" conveyor and 4" material
	2000 lb/hr--$8000	Eriez Magnetics	Erie	
	8500 lb/hr--20,000		PA	
	2000 lb/hr--$500-1,500	Bunting Magnetics	Cleveland	
	8500 lb/hr--$650-2000		OH	
Eddy-Current	$78,275 x 2	Magnetics Division		Rare Earth Eddy Current
Separator	$156,550	Global Marketing Inc.		Separator
				ECS 100 would need 2
				for 8500 lb/hr
	$96,167	Magnetics Division		Rare Earth Eddy Current
		Global Marketing Inc.		Separator
				ECS 150
				Can only handle 6600 lb/hr
	$40,000	Ding's Magnetics		Only a very ball park figure
	2000 lb/hr--$75,000	Eriez Magnetics	Erie	
	8500 lb/hr--$150,000		PA	
Granulator	2000 lb/hr--$50-75,000	Cumberland Engineering	Atteboro	With loading and exiting
	8500 lb/hr--$155,000		Mass.	conveyors and control system
				2000 lb/hr--$70-85,000
				8500 lb/hr--$250,000

Table: (Continued)				
Granulator	2000 lb/hr--$35,000	Rotogran International	Concord	With a Fines Separator
	4000 lb/hr--$100,000		Ontario	System Add:
				2000 lb/hr--$8,000
				4000 lb/hr--$10,000
	2000 lb/hr--$40,000	American Pulverizer	St. Louis	
	8500 lb/hr--$55,000		Missouri	
Extruder	$7-8,000	Cierra Industries		Also Gave a Package Price
Pelletizer	$8-9,000	Cierra Industries		Also Gave a Package Price
Screens	2000 lb/hr--$8,000	Witte Company	Washington	Single Screened
	8500 lb/hr--$20,000		NJ	
Air	2000 lb/hr--$35,000	Witte Company	Washington	Three Parts
Classification	8500 lb/hr--$54,000		NJ	Classifier-2000 lb/hr--$15,000
System				8500 lb/hr--$24,000
				Air Supplier-2000 lb/hr--$5,000
				8500 lb/hr--$10,000
				Air Exhust-2000 lb/hr--$15,000
				8500 lb/hr--$20,000

Table 81: Cost/Price Schedule for Treating Recycled CRT Glass

Description of Glass	Price or Cost (fob)* per ton
Dirty sorted funnel glass from CRT	$ 80.00
Dirty broken panel glass from CRT	$40.00
Dirty whole panels from CRT	$60.00
Broken color dirty mix monitors – w & w/o metals	($100.00) & ($60.00)
Broken color dirty mixed glass w & w/o metals	($110.00) & ($60.00)
Whole Bare CRTs	($2.50) ea - approx. 130CRT/ton

Table 82: Calculated Values from Spreadsheet Model for Demanufacturing Facility

Net Present Value	Capital Cost of Warehouse	Capital Cost of Equipment	Revenues	Operating Costs
• with tax • without tax	Size of Warehouse • footprint of storage area • footprint of processing line • footprint of equipment • footprint of testing and refurbishing center • footprint of office space • footprint of incubator facility • footprint of restrooms/changing rooms/cafeteria • footprint of product storage • footprint of hazardous area	• baler • shredder • conveyor • forklifts • magnetic separator • eddy current separator	Refurbishing Center • monitors • computer parts Shredded Material • precious metals • glass • aluminum • steel • plastic	• labor (+ fringe) • electricity • natural gas • water • hazardous waste disposal • waste disposal • maintenance • operating supplies • transportation

Appendix C: Task 1.3

Korea-Australia Rheology Journal
Vol. 17, No. 1, March 2005 pp. 000-000

Rheological and mechanical properties of ABS/PC blends

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(Received June 19, 2002; final revision received February 1, 2005)

Abstract

Acrylonitrile-Butadiene-Styrene (ABS), polycarbonate (PC) and their alloys are an important class of engineering thermoplastics that are widely used for automotive industry, computer and equipment housings. For the process of recycling mixtures of ABS and PC, it is desirable to know how sensitive the blend properties are to changes in compositions. It was for this reason that blends of virgin ABS and virgin PC at five different compositions, namely, 15%, 30%, 50%, 70% and 85% by weight of ABS were prepared and characterised by rheological and mechanical measurements. Rheological properties of these blends in steady, oscillatory and transient step shear and mechanical properties, namely, tensile strength, elongation-at-break and Izod impact strength are reported. The results show that PC behaves in a relatively Newtonian manner, but ABS exhibits significant shear thinning. The ABS-rich blends show a trend that is similar to that of ABS, while PC-rich blends, namely 0% and 15%, exhibit a nearly Newtonian behaviour. However, at a fixed shear rate or frequency, the steady shear or the dynamic viscosity varied respectively in a non-monotonic manner with composition. Except for 15% blend, the viscosities of other blends fall into a narrow band indicating a wide-operation window of varying blend ratio. The blends exhibited a lower viscosity than either of the two pure components. The other noticeable feature was that the blends at 70% and 85% ABS content had a higher G' than pure ABS, indicating an enhancement of elastic effect. The tensile yield strength of the blends followed the 'rule of mixtures' showing a decreasing value with the increase of ABS content in PC. However, the elongation-at-break and the impact strength did not appear to obey this 'rule of mixtures,' which suggests that morphology of the blends also plays a significant role in determining the properties. Indeed, scanning electron micrographs of the fracture surfaces of the different blends validate this hypothesis, and the 15% blend is seen to have the most distinct morphology and correspondingly different behaviour and properties.

Keywords : ABS/PC blends, oscillatory and steady shear, heterogeneous morphology, mechanical properties

1. Introduction

ABS, PC and their blends are high impact resistant materials with good ductility, durability and high dimensional stability. They are widely used in the automotive industry and also for making computer and equipment housings. With continuous improvement in computer and electronic equipment, a large volume of plastic is discarded when the equipment is replaced, and this ends up in landfills. These materials are not biodegradable and since no viable recycling process appears to exist for these materials, they pose an environmental hazard. While recycling of single thermoplastic polymeric materials, particularly high density polyethylene (HDPE) used in milk containers, low density polyethylene (LDPE) used in garbage bags and polyethylene terephthalate (PET) used in beverage bottles, has developed to a reasonable level, recycling of ABS/PC thermoplastics has not progressed to the same extent and has remained somewhat unattractive. This is partly because the volume of these materials was not very large and partly because these materials are made from more than one polymer. The supply situation is now changing, but these plastics are still mixed with other polymers and materials. Generally, mixed recycled polymers exhibit poor mechanical properties compared to the pure components and show unpredictable rheological properties. They have, therefore, traditionally been used in low-value applications such as flower pots and park benches where mechanical property requirements are not very stringent. For a recycle process to be economically successful, though, the recycled materials need to be employed in high value applications or sold

[redacted]

at a premium.

In their earlier work, Liang and Gupta (2000) studied the rheological and mechanical properties of a recycled PC blended with virgin PC; these authors reported that separated PC could be added to pure PC up to the 15% level without significantly altering the properties of pure PC.

This study is aimed at characterising alloys of ABS and PC with a view to developing commercially viable products through blending these two materials. The ultimate objective is to develop alloys containing as much recycled plastics as feasible. The study of the properties of the blends of virgin ABS/PC plastics provides a useful basis for realising and maximising product development from recycled materials.

2. Experimental procedure

2.1. Preparation of ABS/PC blends

A Brabender Twin Screw was used for the blending. In terms of process conditions, though, one has to contend with the fact that PC has a glass transition temperature of 150°C while that for ABS is 95°C. Thus, the nominal extrusion temperatures for PC is 300°C but that for ABS is only 200°C. Getting the correct extrusion temperature for the preparation of ABS/PC blends between this range was important so that blends were neither under-plasticised due to low temperature nor degraded due to high temperature. Consequently, different temperature profiles were used for extrusion followed by tests on the properties of the blends for thermal, mechanical and rheological stability. After a careful trial and error check, an optimised temperature profile was chosen for the preparation of the blends. Five different compositions of ABS/PC blends, namely, 15%, 30%, 50%, 70% and 85% by weight of ABS and virgin ABS (100%) and virgin PC (0%) were prepared for rheological and mechanical testing.

Lexan 101, a commercial grade virgin PC, and *Cycolac GPM 5500-1000*, a virgin ABS, both supplied by GE Plastics were used for this study. The relative densities of PC and ABS were 1.2 and 1.05 respectively. The PC had a molecular weight (MW) of 33050 and a polydispersity index (P.I.) of 2.3. Before extrusion, the PC and ABS pellets were dried at 90°C in a vacuum oven overnight.

It should be noted that PC is a homogeneous, single-phase polymer while ABS is a heterogeneous, two-phase terpolymer consisting of a dispersed rubbery phase made up of polybutadiene (PB) rubber grafted with styrene-acrylonitrile (SAN) and then dispersed in a continuous plastic phase of more SAN. Blending PC into ABS changes the ratio of plastic and rubber phase components, altering the structural morphology of the system and yielding different rheological and mechanical properties.

2.2. Test specimen preparations

The blends were extruded into a water bath, and the extruded strands were pelletized by a C.W. Brabender pelletizer; the pellets were then dried in the vacuum oven overnight. They were compression moulded into sheet specimens by a hydraulic press at a temperature of 200°C under a load of 15 tons for 2.5 minutes. Circular disks of 25 mm diameter and 1 mm thickness were cut from the sheets for rheological tests.

The appropriate specimens for mechanical testing, namely tensile test and impact tests, were also compression moulded using the hydraulic press. Moulds for the test sample were designed and fabricated as per the standard specimen dimensions. Dried pellets were pressed under a load of 15 tons for 5 minutes for tensile specimens and 7 minutes for the impact test specimens.

The moulded specimen for tensile tests was a dog-bone shaped with a total length of 110 mm, an effective length of 35.56 mm with an end width of 25 mm and test width of 6.5 mm. The impact specimen had a length of 63.5 mm with a width of 4.8 mm, a thickness of 12.7 mm and a notch at the one side centre in the direction of width with a residual thickness of 10.1 mm at the notch.

2.3. Scanning electron microscopy

Moulded specimens for impact testing were notched and then fractured at room temperature by the impact tester. The fractured surface was gold coated using a sputterer. A Hitachi S 4700 model scanning electron microscope was then used to study the fractured surfaces.

3. Rheological characterisation

Rheological measurements on these blends were carried out on a Rheometrics Mechanical Spectrometer, model RMS800 at a temperature of 225°C. The test modes included strain sweep at a 1 rad/s frequency to establish the linear strain range; dynamic frequency sweep at a strain of 10% to determine dynamic linear viscoelastic moduli G' G''; steady shear rate and transient (unsteady) step shear rate to evaluate viscous and elastic response; and dynamic time sweep in the linear range (at a frequency of 1 rad/s and a strain rate of 10%) to determine the build up or breakdown of network structure. Prior to testing, the samples were heated to 225°C for duration of 15 to 20 minutes until the residual stress was released and sample thermal equilibrium was attained.

3.1. Linear viscoelasticity

The response from the strain sweep test showed that all the blends exhibited a linear behaviour up to a strain magnitude of 100%; so both the storage modulus and the loss modulus and the dynamic viscosity are independent of strain amplitude in this region.

The linear viscoelastic data are viewed to be important as they provide much useful information to help understand the more difficult non-linear properties. Besides, it should not be forgotten that for any type or magnitude of deformation all materials should satisfy the linear viscoelastic response in the limit of small deformation.

The properties of pure PC or ABS depend on the molecular weight and their structures. The properties of the blends however are likely to be different, and we focus on their behaviour and attempt to explain how these properties depend on or differ from those of the pure materials.

Fig. 1 presents the response of storage and loss moduli against frequency. As far as the loss modulus G'' is concerned, it is seen that pure PC (0%) has a much higher modulus indicating higher energy dissipation compared to the various blends. With the addition of 15% ABS, the blend exhibits the lowest modulus at lower frequencies but rises above the corresponding data for the other blends to attain the highest magnitude at higher frequencies. Both the 15% and 30% blends deviate from the ABS-rich samples at high frequencies and show a higher modulus. The responses for 50%, 70% and 85% are ABS dominant and similar to pure ABS (100%), and they converge into a narrow band in the frequency range of 0.2 to 2 rad/s.

Fig. 1 also shows the storage modulus response. Pure PC (0%) appears to be much more elastic than pure ABS,

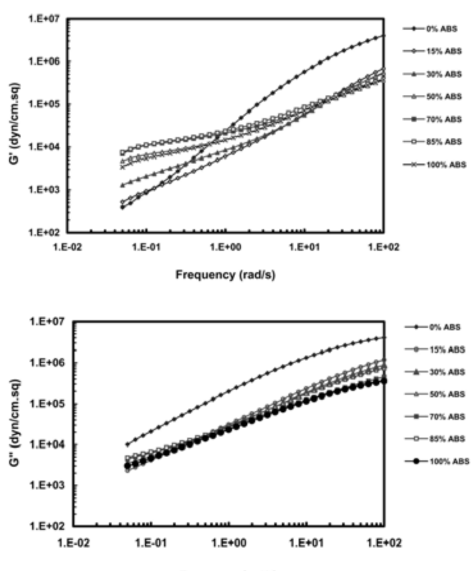

Fig. 1. Storage (G') and loss (G'') moduli vs. Frequency at 10% strain and 225°C.

showing the lowest storage modulus at low frequencies but then reaching the highest value at higher frequencies. All other blends behave similar to pure ABS showing a near plateau at low frequencies and falling into a narrow band at high frequencies. The plateau height is higher than the G'' value at the same frequency and is seen to increase with increasing ABS content. However, the 70% and 85% blends show the highest modulus at low frequencies indicating that they are capable of storing more energy than pure ABS. Exhibition of this solid-like behaviour at low frequency is not uncommon for heterogeneous systems although such behaviour has not been completely explained (Marie-Pierre Bertin, 1995).

These dynamic mechanical responses of ABS/PC blends do not appear to be systematic deviations from the behaviour of either pure PC or pure ABS. In other words, the behaviour does not follow the 'rule of mixtures', which should show a predictable increasing or decreasing trend with increasing or decreasing blend content. Quite clearly, the addition of PC into ABS changes the ratio of the plastic phase component (PS, AS) to the rubbery phase component (PB, BS, BA), altering the interaction between these phases. This, in turn, changes the structural morphology of the system, resulting in varying rheological and mechanical properties. Previous works by Yuji Aoki (1986) and Marie-Pierre Bertin *et al.* (1995) indicate that the viscoelastic behaviour of ABS depends strongly on the rubber phase or more precisely on the degree of grafting of the rubber particles. Therefore, the responses of the ABS/PC blends are likely to be influenced by the changed rubber phase as well as the plastic phase of the blends.

In order to verify the above hypothesis, the morphology of the ABS/PC blends was examined with the help of a scanning electron microscope. Fig. 2 shows micrographs of the fractured surfaces with respect to composition of the various blends. The difference between the ABS rich phases and PC rich phases is clear. For blends containing 15% ABS up to 50% ABS, we can see that the ABS phase appears as spherical inclusions in the PC phase matrix. Also, at the fracture surface, there seems to be slippage between the PC and ABS phases as these two phases are not bonded together, especially at low ABS content. However, ABS-rich blends look more uniform and the micrographs resemble the fracture surface of pure ABS. Thus, it is not surprising that the 15% ABS blend seems to stand out the most from the other blends.

The ratio of the loss modulus to the storage modulus, known as the loss tangent value, provides a useful measure of the relative magnitudes of energy storage and dissipation of energy. From Fig. 3, it can be determined that PC has the highest loss tangent at nearly all frequencies; this is not surprising considering that this polymer is known for its excellent impact strength. Conversely, the 70% and 85 % blends have the lowest loss tangent, and thus the lowest impact strength.

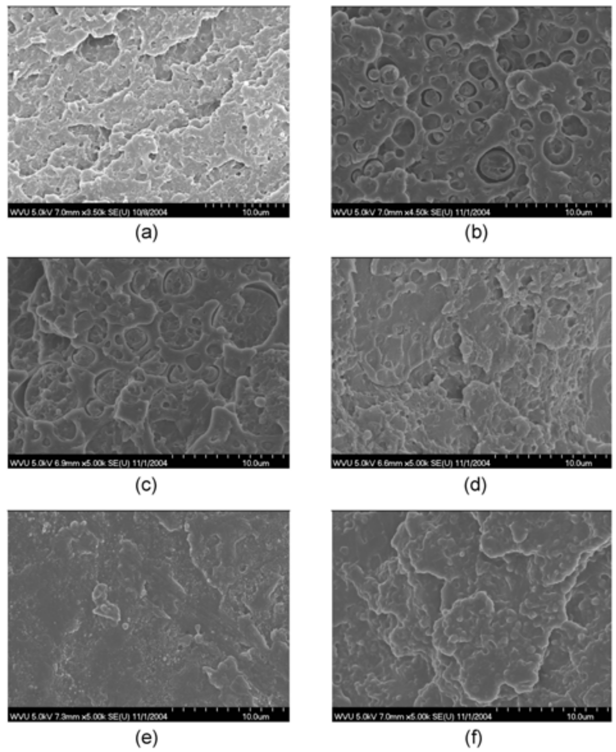

Fig. 2. Scanning electron micrographs of fracture surfaces of PC/ABS blends: (a) ABS (b) 15% ABS (c) 30% ABS (d) 50% ABS (e) 70% ABS and (f) 85% ABS.

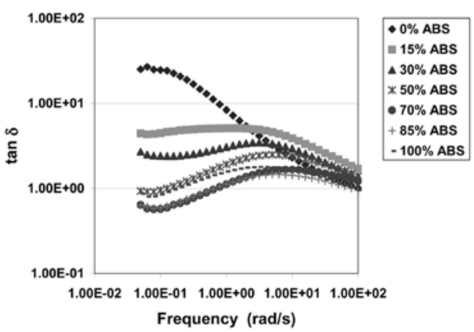

Fig. 3. tan δ vs. Frequency at 10% strain and 225°C.

3.2. Complex viscosity and shear viscosity

Results for the absolute value of the complex viscosity against frequency are presented in Fig. 4. Pure PC has the highest viscosity, and, as is known, it shows a weak shear thinning effect while ABS shows a significant shear thinning behaviour. The shear-thinning viscosity behaviour of ABS carries over to the blends, and their viscosity is seen to decrease substantially with the addition of ABS into PC. The only exception is the 15% sample, which shows a relatively constant viscosity behaviour that is similar to pure PC; however, the magnitude of the viscosity is significantly lower than that of pure PC, and, in fact, the 15% blend has the lowest zero shear viscosity among all the blends. The response of the 30% ABS sample is seen to represent a transition from weak shear thinning (PC) to strong shear thinning (ABS). The decrease in η_0 (zero shear rate viscosity) upon adding 30% and 50% ABS is about 38% and 27% respectively. Thus, processability would seem to improve leading to a power saving when ABS is added to PC. A possible reason for the decrease of viscosity with addition of ABS may be solvation of the

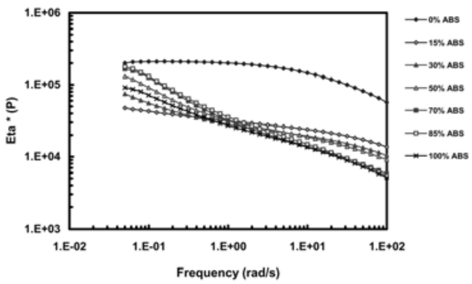

Fig. 4. Dynamic viscosity vs. Frequency.

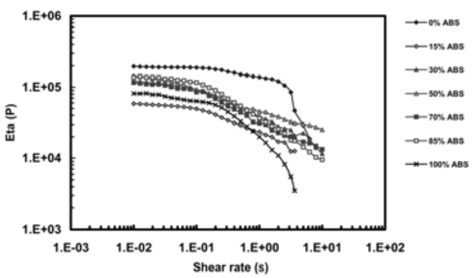

Fig. 5. Shear viscosity for ABS/PC blends at 225°C.

highly entangled structure of molecules of PC by the ABS molecules (Babbar and Mathur, 1994).

The steady shear viscosity responses are shown in Fig. 5. From these data and the data in Fig. 4, it is seen that the magnitude of the complex viscosity for some blends nearly equals the steady shear viscosity at corresponding values of low frequency and small shear rate. From continuum mechanics, it is known that both complex and shear viscosity approach η_0 as the frequency (ω) and the shear rate ($\dot{\gamma}$) approach zero. This is seen to be true for most blends, although some difference in their values is noticeable. It then can be said that the Cox-Merz rule ($\eta(\dot{\gamma}) = \eta^*(\omega)$) is loosely followed by nearly all the blends. It is also known that the rate of decrease in dynamic viscosity at large frequency is different from the rate of decrease of shear viscosity at large shear rates (Bird *et al*., 1987). For example, unlike in dynamic tests, 15% sample exhibits a significant shear thinning behaviour in steady shear viscosity. This is, however, expected and plausible as these deformations appear to occur beyond the linear range and also these blends were found to show some time-dependent properties discussed later in Section 3.3. It is however not obvious if some discrepancy in magnitude observed can be attributed to this effect.

The viscosity data from Fig. 5 can be used to further

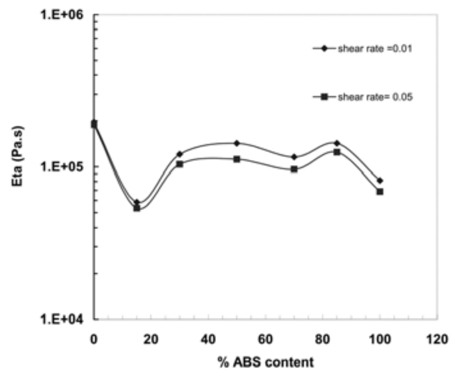

Fig. 6. Steady shear vs. ABS content at different shear rate.

analyse the shear steady state behaviour of the complex ABS/PC blends. In particular, steady state viscosity data at lower shear rate were plotted against ABS content as shown in Fig. 6. The shear viscosity data exhibit a wave-like response as the ABS content increases showing two maximum peaks at 50% and 85% composition. The viscosity of the blends falls with the addition of ABS composition reaching a minimum at 15% composition. It then increases monotonically with the increase of ABS content showing a maximum peak at 85%. This inconsistent feature is not totally unexpected and may be attributed to the complex ABS/PC system and their multiphase morphology.

3.3. Dynamic time sweep

The dynamic viscosity tests were conducted against time for sample stability. It was found that pure PC and pure ABS appear quite stable over a test period of more than one hour. With an increase of the ratio of the mix (PC or ABS), the blends exhibited material softening over time. This effect was seen to be the most pronounced in 30% and 50% blends. This feature illustrates some potential difficulty in conducting valid rheological tests over an extended period of time.

3.4. Step shear rate transient response

A transient step-shear-rate test was conducted to determine the viscoelastic linear and non-linear responses over time from a start up deformation. Tests were conducted for a range of shear rates. The most important feature of these data was the existence of stress overshoot followed by an eventual plateau, which would indicate a steady state value. It is however, noted that for some blends the steady value appeared to give way to a decaying trend which can be attributed to sample distortion. Pearson and Kiss (1987) suggested that the overshoot occurs because polymer strands are stretched during brief period after start-up of shearing. The maximum overshoot appeared to occur at a roughly constant value of the imposed strain, $\dot{\gamma}t$ of about 2. This appears to satisfy the Doi-Edwards equation (Larson, 1988). The magnitude of the overshoot was seen to be increasing with the increase of ABS content in pure PC. This can be attributed to the fact that ABS exhibits more elastic than viscous behaviour (Marie-Pierre Bertin, 1995).

4. Mechanical properties

The mechanical properties evaluated were tensile strength, elongation-at-break and Izod impact strength. Tensile tests were conducted on an Instron machine model 8501 at room temperature. The specimen was stretched at a constant rate of 0.2 in/min. The results for yield strength and fracture strength are presented in Fig. 7, and results for elongation-at-break are given in Fig. 8 as a function of ABS content. The results in Fig. 7 show that the strength properties nearly follow the rule of mixtures, with strength decreasing with increasing ABS content in PC. However, Fig. 8 demonstrates that the elongation-at-break is non-

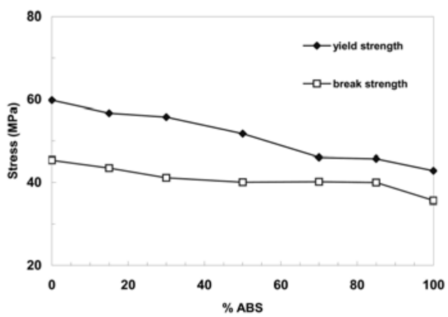

Fig. 7. Yield strength and break strength as a function of ABS content.

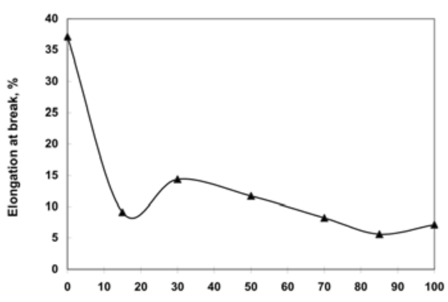

Fig. 8. Effect of ABS content on elongation at break.

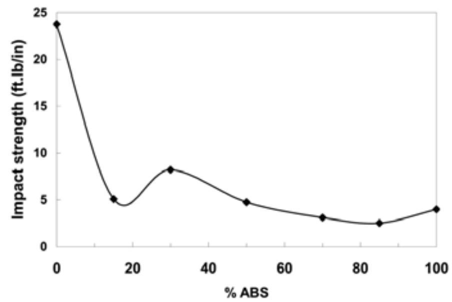

Fig. 9. Effect of ABS content on impact strength.

monotonic with ABS content, and, overall, ABS/PC blends have a much smaller elongation compared to pure PC.

The Izod impact test was conducted on Satec Impact Testing Machine equipped with a 2 fl-Ib Izod pendulum and the specimen holder. The test calculates the energy required to break a specimen when the pendulum hits the specimen on impact. The impact tests were carried at room temperature of 25°C, and their results are presented in Fig. 9.

The result of the Izod impact testing shows the same features as shown by elongation-at-break. While PC and blends with lower ABS content exhibit high impact strength, ABS rich blends have much smaller impact strength than PC.

5. Conclusions

Rheological and mechanical properties of the ABS/PC blends are evaluated here to developing a strategy of recycling these materials. A recycling process is viable if these materials can be employed in high value applications or in new product development. The results of this study show that the processability of PC can be improved by the addition of ABS. The shear thinning effect of ABS rich blends provides a significant power saving in the processing of these blends. Furthermore, except for the 15% blend, the viscosities of other blends fall into a narrow band which offers a wide range of operation window and room to mask possible variations in properties of recycled polymers. The results of the tensile and impact tests also indicate an improvement in the processability of PC by adding ABS. The tensile yield strength results for the blends follow the 'rule of mixtures' showing a decreasing value with the increase of ABS content. However, neither the impact strength nor the elongation-at-break obeys this rule, and they both show much lower magnitudes than that of virgin PC. These results are important as they indicate the possibility of reusing recycled polymers at a much higher percentage through blending ABS/PC.

Acknowledgements

The authors wish to thank Mr. Robert Wildi for his valuable comments during the course of this study. The experimental work was done while M.M.K. Khan was on sabbatical leave at West Virginia University. This work was funded, in part, by the US Department of Energy.

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Appendix D: Task 1.4

MECHANICAL CHARACTERIZATION OF RECYCLED THERMOPLASTIC POLYMERS FOR INFRASTRUCTURE APPLICATIONS

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ABSTRACT

Reuse of engineering thermoplastics retrieved from discarded computers, monitors and printers called as electronic shredder residue are described in this paper. Mechanical characterization of virgin, blend of virgin and recycled, and 100% recycled polymers such as acrylonitrile butadiene styrene (ABS) is carried out as a part of this research. Tension, bending, compression, impact and creep properties of the virgin, blend and recycled polymers are focused in this research. It was found that the recycled polymers retain at least 85% and in most cases over 90% of the tension, bending and compression strength and stiffness properties compared to virgin polymers. Based on test results it is concluded that recycled polymers have significant potential for high-volume infrastructure and automotive applications.

INTRODUCTION

The research results described in this paper focus on the evaluation of mechanical properties of ABS thermoplastics obtained as electronic shredder residue (ESR) from computer and monitor housings in three forms, i.e., virgin, blend of virgin and recycled, and 100% recycled polymers. Since resins alone often do not have the strength or stiffness to meet the requirements of certain infrastructure and/or automobile applications, the polymers in this research are studied by adding fibers during the manufacturing process. Test samples were manufactured with and without glass fibers by special collaboration between CFC-WVU and Owens Corning Company and PPG Industries.

OBJECTIVES

Objectives of this research are to:

- o Characterize the strength, stiffness of recycled polymers obtained from electronic shredder residue (ESR) under tension, compression and bending.
- o Characterize virgin polymers, which are identical to the ESR polymers and compare the strength, stiffness of recycled polymers and their blends with virgin polymers under tension, compression and bending.
- o Establish the impact properties and creep behavior of recycled and virgin polymers.
- o Evaluate the potential of recycled polymers and blends for infrastructure and automotive applications.

SCOPE

Recycled ABS and PC were considered for evaluation purposes based on their availability as electronic shredder residue (ESR), suitability for mass production and cost consideration. Over 150 ABS samples manufactured by Owens Corning were tested in tension, bending, compression, impact and creep. This paper focuses only on the results of ABS specimens. Testing and analysis of PC sample is continuing at CFC-WVU. In the following sections material selection, results of different tests and conclusions are provided.

MATERIALS AND MANUFACTURING

Virgin and Recycled Polymers

Cycolac-GPM5500 ABS virgin resins evaluated in this study are manufactured by GE Plasitcs and have excellent impact strength, hardness, rigidity, and toughness properties. The resin grades of Cycolac ABS consist of elastomeric blends of polybutadiene or a butadiene copolymer and an amorphous thermoplastic component of styrene and acrylonitrile (SAN) and are easy to process (GE Plastics User's Guide, 1999).

ABS recycled polymers were received as granulated shredded pellets and flakes with a size of 0.25" or less with a purity level above 95% from sources such as computer, monitor and printer housings. These were made available to the CFC-WVU research team by the MBA polymers, USA.

Glass Fibers

The 408A-14C CRATEC chopped strands supplied by Owens Corning with a length of 4mm, diameter of 14 μ and suitable sizing were blended with ABS. The 408A CRATEC strands have proven compatibility with many thermoplastic resins including ABS. The characteristics of the 408A CRATEC strands include optimized strand integrity, good glass dispersion, excellent mechanical properties, and excellent coupling with polymer systems.

Injection Molding

Injection molding of the ABS samples was performed by Owens Corning. Six types of specimens as shown in Table 1 were manufactured. Polymer pellets were uniformly blended by means of a screw extruder having L/D ratios of 24:1 and a compression ratio of 3.75:1) to achieve melt homogeneity and avoid material degradation and discoloration at transition sections. Melt temperature used for both the extrusion process and the injection molding was 530^o to 535^{o}F. Molding was performed on a Cincinnati Milacron injection-molding machine with a 200-ton press.

Table 1. Description of Different Types of ABS Specimens

Specimens	Description of Different Specimens
A1	Virgin ABS polymer without fibers
A2	Virgin ABS polymer with 25% (wt. %) chopped fibers
A3	100% recycled ABS polymer without fibers
A4	100% recycled ABS polymer with 25% (wt. %) chopped fibers
A5	Recycled ABS/virgin ABS (20%/80%) blend without fibers
A6	Recycled ABS/virgin ABS (20%/80%) blend with 25% (wt. %) fibers

Coupon specimens manufactured through injection molding allowed the researchers to conduct six types of tests, i.e., tension, compression, bending, impact, hardness and creep. In this paper, results of hardness tests are not included.

TEST SPECIMENS AND TEST PROCEDURES

Test Specimens

The tension, bending, compression and impact test specimens were manufactured to the dimensions as per ASTM D638-94b (Type I specimen), ASTM D790-92, ASTM standards D695-91 and ASTM D256-93a: method A, respectively. Dimensions of the 0.125” thick tension specimen are shown in Fig. 1. Bending specimens were rectangular with a length of 5", width of 0.5", and a thickness of 0.125". The compression specimens were rectangular with a cross-section of 0.5"x 0.25". Height of the specimens was 0.5”. Additional samples with heights 1" and 1.5" were also tested to establish the optimum height for minimizing and eliminating bending effects. Based on pilot testing, height of 0.5” was chosen, which provides an aspect ratio of 2. Dimensions of the impact test specimen including the notch are shown in Fig. 2. For creep test, tension test specimens were drilled with holes and the sustained load was applied by suspending known dead weights.

Each specimen was labeled according to the type of test conducted and the test number. For example, a specimen designated as TA1-2 represents, tension test (T), group of 100% virgin sample without fibers (A1, refer Table 1), and the specimen test number (2). Similarly letters (B), (C) and (I) stand for bending, compression and Impact, respectively.

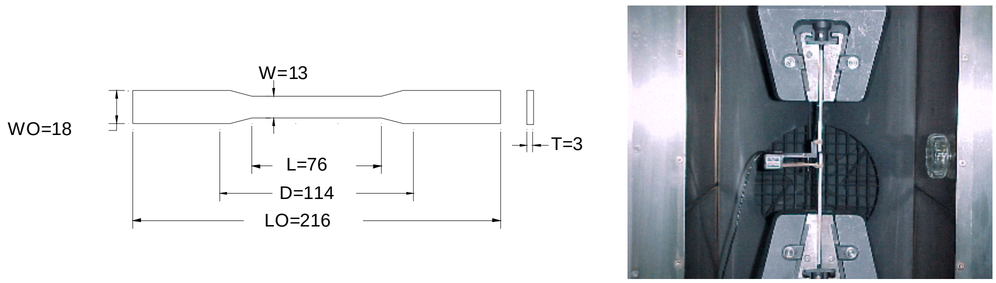

Fig. 1 Tension Testing

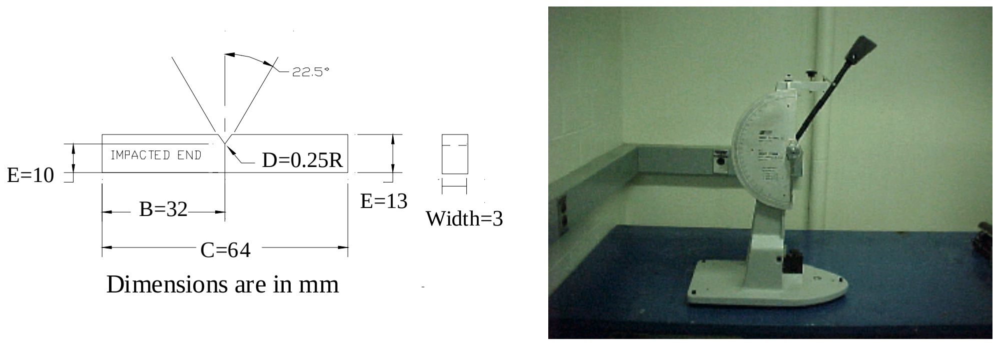

Fig. 2 Impact Testing

Test Set-up and Procedure

Each of the tension specimens was tested using an Instron Series 8500 Two-Column Load Frame as per ASTM D638-94b as shown in Fig. 1. The test was computer controlled at a rate of 300 lbs./min using the 'wavemaker' software and the strains were automatically recorded with the use of extensometer having a gage length of one inch. For three-point bending tests, the rate of cross-head motion was set at 0.25 in./min. Tensile and compressive strains were recorded using a strain indicator at predetermined load intervals. The specimens were loaded to failure or until significant deflections in excess of 1/3 of the span were observed. For compression tests rate of cross-head motion was set at 0.05 in./min. The strains were recorded at predetermined load intervals. Each specimen was loaded to maximum load and beyond the yield zone. Maximum load, strain and reduction in length were recorded. The impact testing was conducted by using a BLI Series impact-testing machine at laboratory temperature of 72^0F. The final impact energy was obtained from the pointer reading and the type of break (i.e. H-hinge or C-complete) was recorded. The results were calibrated for pendulum friction and windage. For creep test, creep strains were recorded at regular intervals from the strain gages.

Results and Analysis of Tension, Bending, Compression, Impact and Creep Tests

Strength and stiffness results of the tension, bending, compression, and impact tests are summarized in Table 2. Each result is an average of at least five specimens. Virgin polymers and recycled polymers without fibers showed elongations in excess of 10%. Extensometer used in this study had a limit of 10% on strain measurements and hence the strain readings were discontinued at about 8% strain. Comparison of stress and stiffness in tension, bending, and compression is shown in Fig. 3.

Table 2 Tension, Bending, Compression and Impact Test Results

Type	Maximum Stress (MPa)			Stiffness (GPa)			Impact Strength
	Tension	Bending	Comp.	Tension	Bending	Comp.	(N-m/ m)
A1	42.54	62.56	61.78	2.21E+06	2.76E+06	2.34E+06	186.29
A2	70.96	122.44	90.50	6.72E+06	7.03E+06	6.27E+06	84.34
A3	38.44	63.30	60.58	2.29E+06	2.76E+06	2.89E+06	115.83
A4	60.64	115.34	102.60	6.64E+06	7.44E+06	6.34E+06	51.24
A5	40.76	65.86	61.82	2.47E+06	2.76E+06	2.82E+06	127.04
A6	61.40	113.75	95.91	6.48E+06	7.65E+06	7.03E+06	64.05

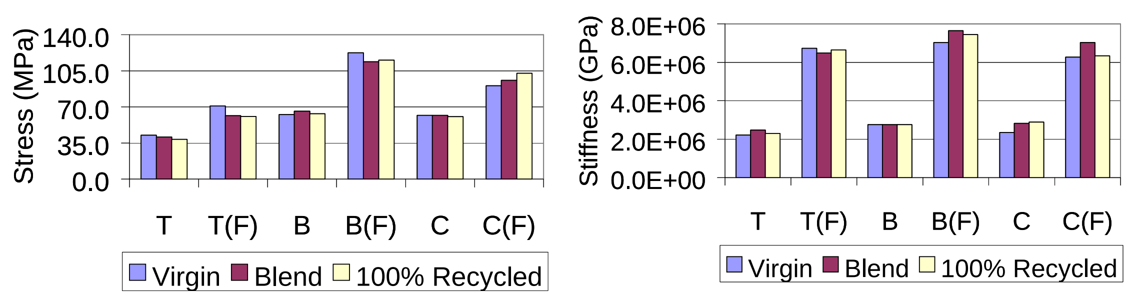

Fig. 3 Comparison of Tension, Bending and Compression Stresses and Stiffnesse in Different ABS Polymers without and with Fibers (F)

Typical tensile stress-strain curves for virgin ABS without and with fibers and bending load-deflection curves for ABS blend with and without fibers are shown in Fig.4. Tensile stiffness of the specimens was evaluated through regression analysis by providing best-fit curve to the linear portion of the stress-strain curve. Bending and compressive stiffness were obtained from the strain-gages attached to the specimens. Bending stiffness values calculated from load vs. deflection diagram or compressive stiffness calculated from the load vs. height-reduction diagrams provided lower values than those by strain gages. As expected, addition of chopped fibers to the polymers resulted in reduction of impact strength. Analysis of test results and effect of recycling and addition of fibers are shown in Table 3.

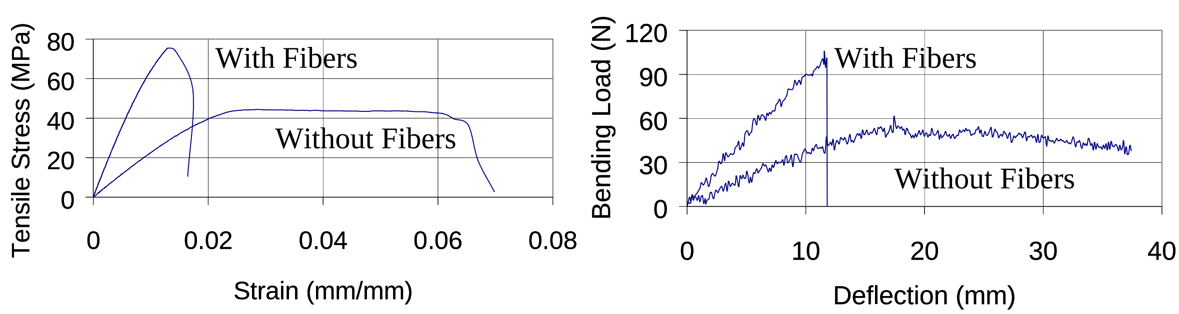

Figure 4 Load-Deflection Curve in Bending for Polymer Blend Specimen with Fibers

Table 3 Effect of Recycling and Fiber Addition on Tension, Bending Compression strength and stiffness and Impact Strength (% Increase/Decrease)

Effect of	ABS Type	Compared With	Stress (Tension, Bending, Comp.)			Stiffness (Tension, Bending, Comp.)			Impact Strength
			T	B	C	T	B	C	
			%	%	%	%	%	%	%
Recycling (No Fibers)	**A3 (R)**	**A1 (V)**	-9.6	+1.2	-1.9	+3.7	0.0	+23.5	-37.8
	A5 (B)		-4.2	+5.3	+0.1	+11.8	0.0	+20.6	-31.8
Recycling (With Fibers)	**A4 (R-F)**	**A2 (V-F)**	-14.6	-5.8	+13.4	-1.2	+5.9	+1.1	-39.2
	A6 (B-F)		-13.5	-7.1	+6.0	-3.6	+8.8	+12.1	-24.1
Fiber Addition	**A2 (V-F)**	**A1 (V)**	+66.8	+95.7	+46.5	+204.0	+155.0	+167.6	-54.7
	A4 (R-F)	A3 (R)	+48.8	+75.1	+66.0	+168.5	+170.0	+124.4	-59.7
	A6 (B-F)	A5 (B)	+50.6	+72.7	+55.1	+162.1	+177.5	+148.8	-49.6

Note: A-ABS; V-Virgin; R-100% Recycled; B (represented within brackets)-Blend (80% virgin and 20% Recycled); F-Fiber; +ve sign -Increase; -ve sign- Reduction. Refer to Table 2 for absolute values.

At 50% of sustained loading, ABS specimens with recycled polymer blend and 100% recycled polymer without fibers failed at 17 days. Both these specimens were connected in series. Virgin polymer specimen at the same stress level and without fibers failed at 47 days. These are single specimen results and further tests are being conducted at CFC-WVU laboratories with different specimens and 20% stress level. It is to be noted that the specimens with fibers are performing well under sustained loads as high as 50%. In practice, sustained stress on the fiber-reinforced polymers is limited to less than 20%. At 45 days the creep coefficient (ratio of creep to initial strain) for virgin, blend and 100% recycled polymers with fibers was found to be 0.255, 0.281 and 0.423, respectively. Typical 27 day creep curves for ABS specimen are shown in Fig. 5.

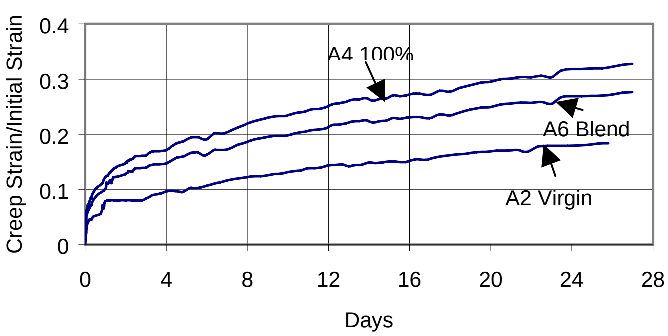

Fig. 5 Creep Curves with Fibers for ABS (≈50% Ultimate Load)

Discussion of Tension, Bending, Compression, Impact and Creep Test Results

Stress

- Compared to virgin polymers without fibers, maximum tensile stress reductions in the blend and 100% recycled polymers were 4.2% and 9.6% respectively. However, bending stresses of blends and recycled polymers showed an increase of up to 5.3%, whereas, compressive stresses showed a maximum reduction of 1.9%.
- Compared to virgin polymers with fibers, maximum tensile stress reductions in the blend and 100% recycled polymers with fibers were found to be between 13.5 and 14.6%, respectively. Similarly, blend and 100% recycled polymer stiffness reductions in bending were found to be 7.1 and 5.8%, respectively, whereas, the compression stresses increased by 6.0 and 13.4%, respectively.
- Addition of 25% by weight of randomly oriented and chopped glass fibers to virgin, blend and 100% recycled polymers resulted in a tensile stress increase of 66.8, 50.6, and 48.8% respectively. Similarly, bending stress increases were 95.7%, 72.7% and 75.1% respectively, and compressive stress increases were 46.5%, 55.1% and 46.5%, respectively.

Stiffness

- Compared to virgin polymers without fibers, maximum tensile stiffness increases in the blend and 100% recycled polymers were 11.8% and 3.7% respectively. However, bending stiffness was the same for blends and recycled polymers, whereas, compressive stiffness showed a maximum increase of 20.6% and 23.5%, respectively.
- Compared to virgin polymers with fibers, maximum tensile stiffness reductions in the blend and 100% recycled polymers were 3.6% and 1.2%, respectively. Bending stiffness for the blends and recycled polymers increased by 8.8% and 5.9%, respectively, whereas, compressive stiffness showed a maximum increase of 12.1% and 1.1%, respectively.
- Addition of 25% by weight randomly oriented and chopped glass fibers to virgin, blend and 100% recycled polymers resulted in a tensile stiffness increase of 204.0, 162.1 and 168.5%, respectively. Bending stiffness increases were found to be 155.0, 177.5 and 170.0%, respectively, for the virgin, blend and 100% recycled polymers. Similarly, compressive stiffness increases were found to be 167.6, 148.8 and 124.4%, respectively.

Strain

- Virgin polymers without fibers showed significant elongation in excess of 10%. Extensometer available with the Instron machine had a maximum capacity of 10% and hence the readings were discontinued. Strain values of recycled and blend specimens were less than the virgin polymers. Addition of fibers increased the strength and stiffness including reduction in the maximum tensile strain values in virgin, blend and 100% recycled polymers to 1.35, 1.18 and 1.12%, respectively. Bending specimens without fibers showed significant deflections that exceeded 1/3rd of the 3.75" test span. Compressive strains in all the polymers with and without fibers were considerably high and virgin polymers showed strains in excess of 10%.

Impact

- Compared to virgin polymers, impact strength of the blend and 100% recycled polymers decreased by 31.8% and 37.8% respectively. Compared to virgin polymers with fibers, maximum impact strength reductions in the blend and 100% recycled polymers with fibers were found to be 24.1 and 39.2%, respectively. Addition of 25% by weight of randomly oriented and chopped glass fibers to virgin, blend and 100% recycled polymers resulted in impact strength reduction of 54.7, 49.6, and 59.7%.

Creep

- Polymers alone without glass fibers are not suitable for high-sustained load applications. Creep of polymers is limited by the use of fibers. Recycled polymers and their blends showed creep-life of about 40% of those of virgin polymers without fibers at a high-sustained load of 50%. These results are based on single specimen tests and further tests need to be carried out with additional samples.

CONCLUSIONS

Use of 100% recycled polymers resulted in tensile, bending and compressive strength and stiffness reduction within 10% and a maximum of 15% in some cases. Bending strength and stiffness values were found to be higher than the corresponding tensile values for all three types of polymers considered in this study. Among different mechanical properties, reduction in impact strength of the blend and recycled polymers was more than the reductions in tensile, bending and compressive stresses. Compared to virgin polymers with and without fibers, impact strength of the blend with and without fibers was less by 24.1 and 31.8%, respectively. Maximum impact strength reductions up to 39.2% were observed in 100% recycled polymer. Use of fibers is essential to control the creep of different types of ABS virgin and recycled polymers for sustained load applications. Use of unidirectional fibers and increase in fiber volume content are expected to further increase the strength, stiffness and other mechanical properties of recycled polymers.

Based on the test results, recycled polymers were found to retain at least 85% of their tensile, bending and compressive strength and stiffness properties. Proper design of recycled polymer blends with and without glass fibers has significant potential for primary and secondary infrastructure and automotive applications.

ACKNOWLEDGEMENTS

The authors would like to acknowledge and thank Dr. Carl Irwin of NRCCE, West Virginia University, Dr. Darren Arola of MBA Polymers, Dr. Kwan Hongladarom of GE Plastics, Mr. Bob Schweizer of Owens Corning Company and Mr. Bill Ferrell of PPG industries for their support during different phases of this ongoing research.

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2. Powelson, D., Powelson, M. (1992), "The recycler's manual for business, government, and the environmental community," Van Nostrand Reinhold, New York.
3. Tall, S., Karlsson, S., Albertson, A. (1998), "Improvements in the properties of mechanically recycled thermoplastics," Polymer & Polymer Composites, Vol. 6, No. 5, 1998.

Appendix E: Task 1.5

Statistics furnished by West Virginia Development Office

Erickson Site

Location

City :	Parkersburg
County :	Wood
Miles To Nearest Interstate Or 4 Lane Highway:	0.0
Miles To Nearest Commercial Airport:	12.0
Rail Access :	½ mile
Navigable Waterways:	Little Kanawha River

Size and Utilities

Site Acreage :	60.0
Electric :	Allegheny Power
Water :	City of Parkersburg
Gas :	Hope Gas, Inc.
Sewer :	Parkersburg Sanitary Board

MARCEE INDUSTRIAL PARK
Site Evaluation Criteria

CITY: COUNTY: STATE:

1. **Name of the Site:**

2. **Size of the Total Site:**

3. **Location of the Site Relative to the City Proper**

4. **Owner of the Site and Authorized Representative:**

   Name
   Address
   Telephone
   Facsimile
   Contact

5. **General Topography of the Site:**

   ____ level ____ rolling ____ gently rolling (less than 5% slope)

6. **Is the site within the corporate city limits: ____ yes _ no**

   Is the site subject to annexation: ____ yes no

7. **Is the site subject to flooding: ____ yes ____ no**

   Elevation range of the site: ___________________

Established 100-year flood level elevation at the site:

8. **Surrounding Contiguous Areas:**

   East

   West

   North

   South

9. **Previous Land Use:**

10. **Has an environmental audit of the site been conducted:___ yes ____ no**

    Company and contact who performed the work:

11. Have any archeological studies been performed on the site:
___ yes ____ no

Company and contact who performed the work:

12. Transportation Accessibility:

Highway:

A. Nearest general aviation airport

1. Name

2. Location

3. Distance

B. Railroad:

13. Easements:

A. Utility

B. Roads

C. Railroad

D. Other

14. Present Zoning:

Will zoning change be required: yes _____no _____

Normal length of time required to obtain zoning changes: _____

15. Applicable Protective Covenants and/or Zoning Regulations:

16. Soil Consistency:
A. **Type**

B. Bearing pressure

C. Water table

D. Rock elevation

17. Ownership of Mineral Rights:

18. Utilities Available:
A. Water:

1. Source of supply

2. Line size ___ inch

3. Location of line

4. Current pressure and flow test at the site

__psi static; __psi residual; _ gpm flow

5. Is there a storage tank on the site-- ____ yes _ no

B. Sewer

1. Source of supply

2. Line size

3. Location of line

4. Limitations on use

_ domestic only _ pre-treated process

5. Storm drainage

__ surface and storm drainage

C. Electric Power

1. Source of supply

2. Specifications of power available

___ Volts ____ phase

D. Natural Gas

1. Source of supply

2. Service Line ___ psi ____

3. Location Of Line

19. Other Services at the Site:

A. Telephone (name)

B. Refuse collection-- ____ city ____ county ___ private

C. Police protection-- ____ city __ county ____ private

D. Fire protection-- ____ city ____

E. Fire insurance class rating at the site

F. Applicable Total Tax Rate of this Site:

20. Property Costs: Price Per Acre

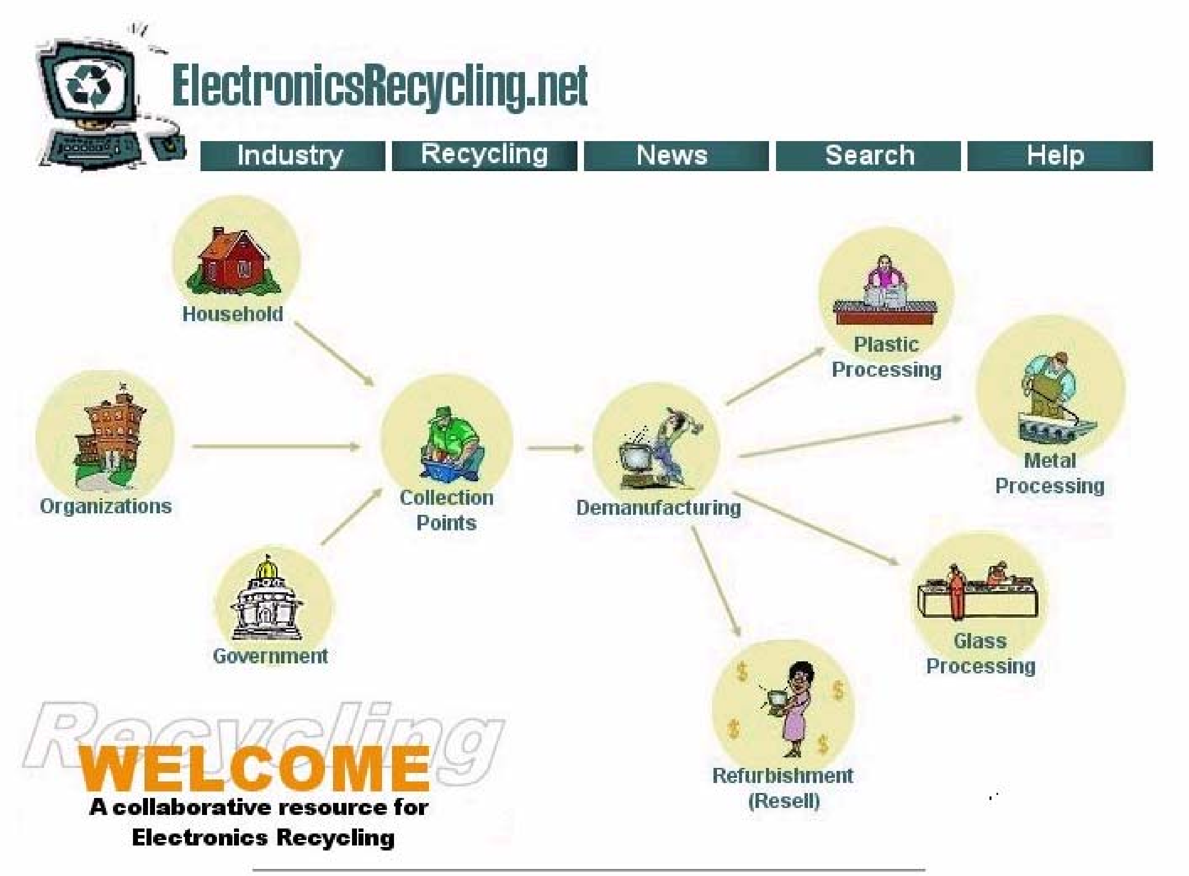
21. Other Comments:

Other information needed (Attachments):

1. **Boundary survey of the site**
2. **U.S.G.S., or better, topographical survey of the site (on disc's)**
3. **ASCS Aerial photograph, or better, with the site outlined (pending)**
4. **Applicable covenants and/or zoning regulations**
5. **Environmental Narrative**
6. **Soil boring data**

Tax table

Appendix F: Task 1.6



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Search Results brought to you by:

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You searched the Collection Organizations Directory for Organizations in

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Anaheim Goodwill Store Donation Center	Anaheim	CA
Silicon Salvage	Anaheim	CA
Neighborhood Computers Project (Berkeley)	Berkeley	CA
Urban Ore	Berkeley	CA
Salvage 1 Recycling	Brea	CA
Excess Quality New and Used Computers	Campbell	CA
Buyer's Consultation Service (BCS)	Canoga Park	CA
MonitorGuy.com	Commerce	CA
Costa Mesa Goodwill Store Donation Center	Costa Mesa	CA
StRUT Alliance, California StRUT	Folsom	CA
Tri-Cities Waste Management	Fremont	CA

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Industry Projects

Federal | State / Local | Academia | International

Federal Government Programs and Sponsored Activities

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Chelsea Center for Recycling and Economic Development

The Chelsea Center initiative launched by the Commonwealth of Massachusetts in 1995 serves to increase the use of recyclables by manufacturers.

Computers for Learning

The "Computers for Learning" program is designed to donate surplus federal computer equipment to schools and educational nonprofits, giving special consideration to those with the greatest need. The Computers for Learning web site allows schools and educational nonprofits to register quickly and easily to request surplus federal computer equipment. Federal agencies will then use the web site to donate computers to schools and educational nonprofits based upon indications of need.

Cross Roads

A collection of reports put out by National Safty Council dealing with electronics recycling.

DEER2

DEER2 is the Demanufacturing of Electronic Equipment for Reuse and Recycling project that encourages electronic equipment reuse and recycling. The Department of Defense initiated the project to research, test and deploy technology upgrades in the public and private sectors. DEER2 is a task under the National Defense Center for Environmental Excellence.

End-of-Life Computer and Electronics Recovery Policy Options for the Mid-Atlantic States 2nd Edition

Thos document provides a summary of major technology and environmental policies regarding the recycling and reuse of obsolete computers and other electronic device

Extended Product Responsibility: A New Principle for Product-Oriented Pollution Prevention

This report state that all actors along the product chain share responsibility for the life-cycle environmental impacts of products.

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Plastic Recycling

[home] [household] [organization] [government] [collection points] [demanufacturing] [refurbishment]

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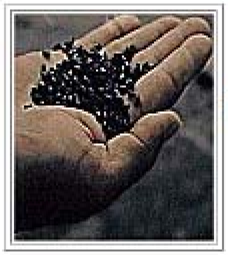

Plastic News

Computer Plastics for Paving Highway/Pothole Filler

25,000 lbs/day, 13 Million lbs/year recycled - Give new meaning to "Information Highway"

Modern Plastics

Site provides general industry news.

Plastics from Electronics Update, Fall 2000

American Plastics Council keeping you informed of the latest developments in plastics from end-of-life electronics.

Plastics Hit the Road, January 2001

Recycled plastics used for highway projects.

Plastics News

Site provides general industry news.

Recycled Plastic "Timbers" Hold Up Under Field Conditions

University of Massachusetts reports on timber made from recycled mixed plastic.

Recycling is Your Business

Don't be misled by the numbers and arrows stamped on plastics.

What's new with plastic lumber? Resource Recycling, October 1998

The plastic lumber industry has unassumingly come of age in the past few years, and many people would be surprised by the high-quality recycled plastic lumber products being used in a variety of demanding applications.

ElectronicsRecycling.net

Stakeholder Dialogues on Recycling Engineering Thermoplastics from Used Electronic Equipment

Meetings | Task Forces | Publications | About Us

Overview

In May 1999 the **Gordon Institute at Tufts University** initiated a series of Stakeholder Dialogues on Recycling Engineering Thermoplastics from Used Electronic Equipment. The Stakeholder Dialogues bring together the plastics supply chain to discuss barriers and opportunities in recycling electronic engineering thermoplastics (EETPs), and to develop collaborative industry strategies to advance recycling of plastic resins from used electronic equipment.

The Stakeholder Dialogue process has identified major challenges to the successful and sustained recycling of engineering thermoplastics, including cost-effective collection & processing of resins and the development of adequate markets, particularly for mixed resins. Several **Task Forces** have been established to develop strategies for overcoming these challenges, utilizing the collective expertise of this unique multi-stakeholder process.

The Dialogue process has actively engaged **companies** throughout the supply chain, including major resin suppliers and original equipment manufacturers, along with plastics processors, molders, electronics recyclers, federal, state and regional government officials, and other industry experts. Over 60 organizations have participated in the Dialogue process since its inception.

National Electronics Stewardship Workshop

DOD -- DOE -- DOI -- EPA -- USPS

National Electronics Stewardship Workshop

National Conservation Training Center

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Workshop Agenda

Travel Info

National Electronics Stewardship Workshop

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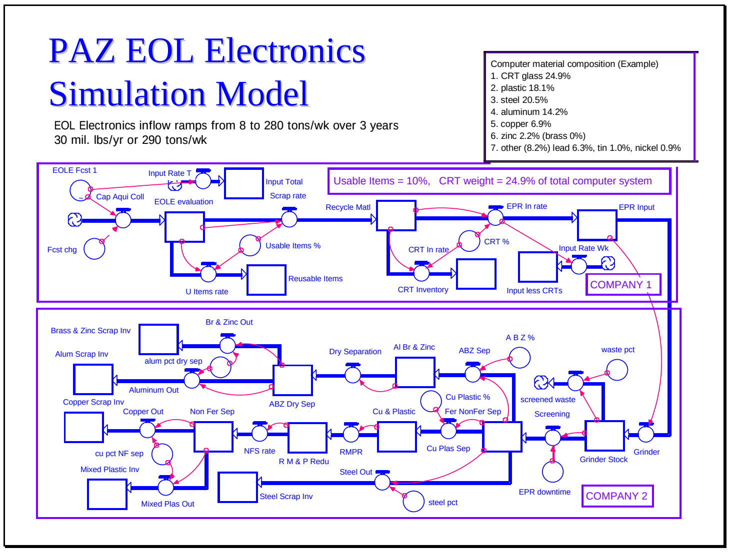
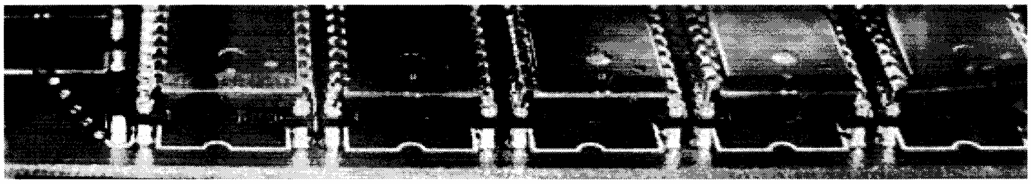
Appendix G: Task 2.1

Slide 1





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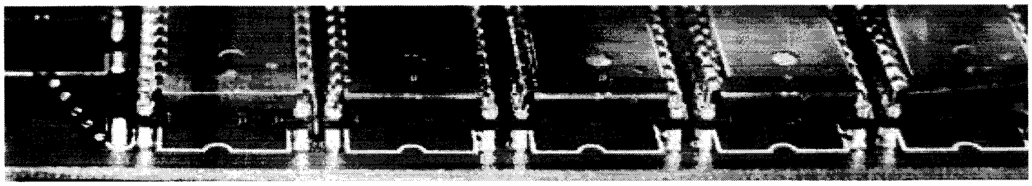


EXECUTIVE SUMMARY

Building upon knowledge gained through simulation of a regional end-of-life electronics (EOLE) recycling industry, this business plan proposes implementation of an electronics recycling model by the Polymer Alliance Zone of West Virginia (PAZ). This effort centers on the creation of a model Regional Recycling Center to provide on-site and outreach capabilities supporting electronics recycling needs within PAZ and the surrounding region. Significant drivers for the program's success include targeted subsidies and the cooperation of industry, government, and municipalities. Program activities of particular note are the creation of an Industry Coalition, establishment of the online marketplace and infrastructure, and additional research and development (R&D).

Given future funding to support a comprehensive recycling system, PAZ is uniquely positioned to lead this program.

This program began as an R&D project focusing on the separation of plastics in 1998, as an alliance between West Virginia University and PAZ under the name "Mid-Atlantic Recycling Center for End-of-life Electronics" (MARCEE). MARCEE's mission has evolved and is now to create a self-sustaining, EOLE recycling industry within the PAZ. Presented in this document is a MARCEE Regional Model and below is the set of high-level interrelated tactical objectives to make this model a reality.

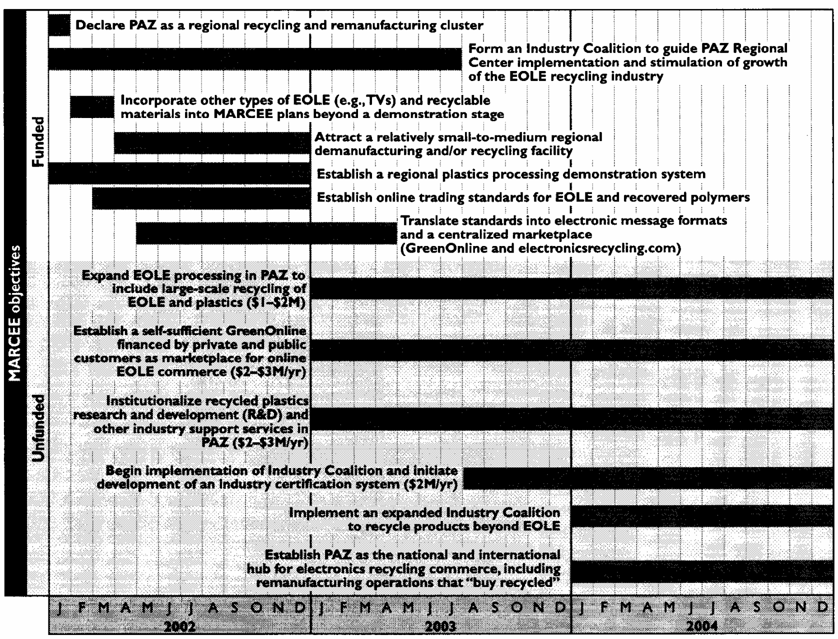
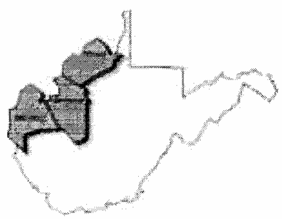


Figure 1. MARCEE Objectives and Timeline

INTRODUCTION

The PAZ was formed in 1996 as a pilot project of the state of West Virginia, through an executive order of Governor Gaston Caperton. PAZ covers an area of West Virginia along the Ohio River that includes Jackson, Wood, and Mason counties. PAZ has the highest concentration of production of high-technology, specialty, and engineering polymers in the world. There are 65 industrialized and public sector members of the PAZ whose members include polymer and related industries. Through the collective efforts of the stakeholders in PAZ, its goal is to expand the breadth and depth of economic activity relating to the polymer industry to provide increased quality job opportunities for West Virginians.



The Polymer Alliance Zone

PAZ initiated MARCEE in 1998. The founders of MARCEE acknowledge the existence of an active electronics recycling industry—particularly for EOLE refurbishment/resale, metals, and glass recovery—but recognize the need for a sustained, comprehensive, and coordinated effort to effect the collection and recycling of EOLE and to offset costs of recycling activities that are not otherwise economically viable.

On November 19, 2001, members of the PAZ MARCEE Steering Committee met in Charleston, West Virginia, to articulate a high-level strategy for MARCEE. The items endorsed at this meeting have evolved into the following overall MARCEE strategy:

1. Develop a Wood County site for EOLE processing
2. Formulate and implement an Industry Coalition during the next 2 years
3. Incorporate electronics recycling industry standards into MARCEE programs for efficient functioning of the industry (including online Extensible Markup Language [XML] standards)
4. Build a business model operations plan
5. Generate supporting activities (e.g., GreenOnline, the West Virginia University [WVU] Research Center)
6. Develop strategies to offset costs for the recycling industry, including the private and public sectors
7. Evaluate and integrate best available technology (including R&D) into MARCEE plans and programs.

A key element to implementing this strategy is the identification of applications and markets for recycled materials, particularly in high-value remanufacturing operations. PAZ seeks to attract not only electronics recycling operations but manufacturers who will use recovered and raw materials produced in PAZ and the surrounding area.

For the purposes of this plan, "end-of-life electronics" or EOLE is limited to end-of-life computers. Although other types of electronics are potentially viable as feedstock for the recycling system described in this plan, the material composition, supply quantities, and financial implications of including other types of electronics are yet to be analyzed. The term "electronics recycling" means the system for collecting, refurbishing, disassembling, and processing parts and components of used computers for resale.

For planning purposes, the MARCEE target region is the mid-Atlantic region of the United States, including the area 500–750 miles from Parkersburg, West Virginia. Although there are also several large metropolitan areas in the Midwest within a short driving distance of PAZ, the critical mass of population and computer supply source in this region is along the Atlantic Coast.

The Industry Coalition described in this plan is a select group of original equipment manufacturers (OEM), resin producers, and electronics recyclers working together to develop and support an economically viable and environmentally attractive end-of-life recycling program in PAZ and in other regions around the country. Key industry organizations and initiatives relevant to development of the Industry Coalition are described in Appendix A.

STATE OF THE INDUSTRY

Disposition of current EOLE supplies includes storage, donation to schools and nonprofits, landfilling, and—to a lesser extent—recycling. Without a stimulus or regulatory change, disposition patterns are not expected to change significantly during the coming decade. However, regulatory initiatives abroad and in some states have created pressure to recycle and/or avoid landfilling.

There are numerous electronic recycling firms in existence. These facilities employ a variety of techniques and technologies, with some facilities more dependent on refurbishment/resale of reusable products, while others focus primarily on revenues from material recovery. Many recyclers are small demanufacturing facilities using a more labor-intensive inspection and disassembly process. Other recyclers operate more automated crushing and grinding operations early in the recycling process and focus on revenues from EOLE generators and the sale of recovered metals. Niche operators also provide processing and recovery services for EOLE-derived metals and glass. One EOLE plastic recovery service is established in California (MBA Polymers) and, according to numerous industry participants, recovers a small fraction of the available mixed plastics stream in the United States.

Recovered materials from EOLE are also exported for processing abroad. Until late last year, several industry sources identified China as the destination for much of the plastic separated from EOLE. This buyer of plastic, however, has apparently scaled back or stopped procurement of EOLE plastics in the U.S.

Several states have established restrictions on disposal of EOLE and there is an overall expectation for additional state actions. Because of these and regulatory actions in the European Union and other international markets, companies are evaluating future regulatory risk and their methods for manufacturing electronics. In order to head-off economically adverse regulatory action and to stimulate growth in electronics recycling, leaders of several OEMs and trade associations have begun to analyze variations of an Industry Coalition to meet this challenge. Currently there is no entity, public or private, better positioned than PAZ to successfully organize such a coalition and avoid anti-trust actions of the federal government. Assessing and optimizing this role is a central PAZ tenet needed to sustain this vision.

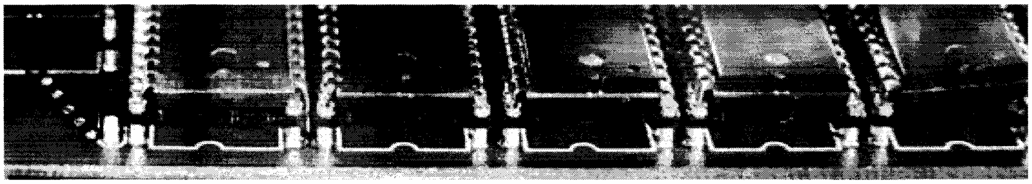
PLAN AND MODEL DEVELOPMENT

Data used in this plan were collected from numerous industry and government sources, previously published studies, site visits, conference materials, and information provided by industry principals and staff. Quantitative analysis presented in this plan relies substantially on a simulation model developed by PAZ that contains representations of both operational and financial components of this recycling system.

The PAZ simulation was specifically designed and developed to evaluate the feasibility of different business model alternatives for the MARCEE project. As MARCEE matures, additional simulation development is planned to analyze recycling of televisions and other electronic equipment, and to understand more fully the financial and operational implications of a comprehensive EOLE recycling system on a national scale.

Major topics for analysis included the feasibility of different types and sizes of electronics recycling operations in PAZ. The PAZ simulation tool was also used to analyze the financial pros and cons associated with focusing EOLE processing on different types of applications.

As a result of this analysis, the proposed regional model includes specific recommendations for action during the next 18 months. The foundation of the regional model is the creation of an Industry Coalition to stimulate recycling market development and coordinate development of MARCEE Regional Recycling Center in PAZ.



INDUSTRY/SYSTEM OVERVIEW

The EOLE recycling industry is relatively new and emerging. The industry typically has a large quantity of supply potentially available, but only a fraction is accessible due to marginal economics. Current system economics limit recycling activity due to high costs (e.g., EOLE collection) and low demand for:

- Recycling services as paid for by generators or collectors of EOLE
- Recovered materials from EOLE, particularly plastics.

The challenge has not been the lack of activity. The need has been present for decades, and various businesses have arisen—and fallen—around the country during this time. Government agencies have sponsored initiatives with interested parties, and many conferences and symposia have been held.

Several OEMs and retailers in the industry have announced industry initiatives to recycle their own products. This is a step in the right direction toward a comprehensive OEM-initiated recycling system, but current OEM initiatives have been developed independently and do not include all OEMs and the manufacturers of less expensive and/or peripheral equipment.

What seems to be missing is a coordinated plan that the majority of the industry participants can agree with and work together to create. Everyone has knowledge in his or her area, but systemwide coordination is required. Everyone seems to feel that "there has to be a better way," but, so far, it has not emerged. This is a common problem in new and evolving industries.

Of common concern to all present recycling companies is the need for buyers of recycled materials. Commoditizing recycled materials is an enticing concept but is often difficult to commercialize without strong R&D and marketing efforts. Potential users like materials that are consistent in quality and quantity, and adhere to common industry standards—characteristics that recycled materials often lack.

The Challenge of Plastics

These characteristics are especially true with plastic materials. It is a commonly held industry truism that it is very difficult to achieve complete separation between the high strength thermoplastics currently in use. Can acceptable separation be achieved? If so, how? If not in the short term, then how can the combination of acrylonitrile butadiene styrene (ABS), high impact polystyrene (HIPS), polycarbonate (PC), and other polymers be commoditized to make marketable products?

As discussed below, this plan offers an approach for tackling these and other economic and environmental challenges that have inhibited development of a comprehensive electronics recycling industry for all materials used in the manufacture of electronics.

Past Attempts

Several years ago a firm in Texas used scrap polymers from various PC manufacturers to make a backing board for table and counter tops. The backing board of mixed plastics was the strength member (thickness 3/16–1/2") to which a decorative veneer was bonded. PC manufacturers and recyclers were delighted with this application for their scrap polymers, but unfortunately this business stopped accepting mixed plastics. Another large customer has yet to emerge.

Potential Opportunities for Commoditizing Mixed Plastics

Other applications discussed among electronics recycling industry principals include an application where a thick sheet of mixed plastics is extruded and then die cut into interlocking tiles used to cover outdoor patios and walkways. Another similar application uses extruded thick sheets to make protective linings and covers for use in boat marinas.

Among other applications based on this concept could possibly be plastic lumber or posts, spacer blocks for guard rails, counter top filler, various automotive uses (steering column components, interior speedometer housing components), and

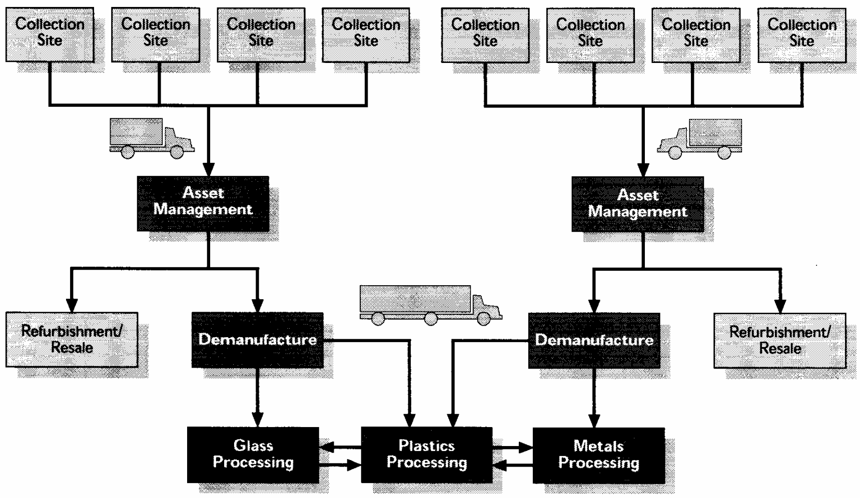


Figure 2. The EOLE Recycling System

thick section outdoor furniture. These and other uses need to be identified, tested, and marketed as recommended below.

ELECTRONICS RECYCLING

PRODUCT LINES

The product lines described in this section constitute the operational components of the regional model that underlie this plan. A graphical representation of this system is presented in Figure 2.

The output products of recycled electronics are:

1. Refurbished and reusable components or complete systems
2. Recovered glass from the cathode ray tube (CRT)
3. Recovered metals: aluminum, copper, steel, zinc, brass, and precious metals
4. Recovered plastic: HIPS, ABS, PC, and others
5. Waste from all these materials, some of it hazardous.

Generators and collectors (e.g., municipalities) of EOLE generally pay electronics recyclers to take away and process EOLE in an environmentally responsible manner to avoid future environmental liabilities.

Refurbishment/Resale of Electronic Components, or Complete Systems; Demanufacturing

At present this is an established industry. Every major city has used computer stores, and several mail order companies are active and successful (such as Sun Remarketing Inc. for Macintosh products). Finding sales outlets for "good" systems and components is not a problem. A less desirable but common alternative to reuse at many of these operations is demanufacturing. Either through automated grinding/ shredding or a manual separation process, EOLE is dismantled for further processing and material recovery.

Monitor Glass

Recycling CRT monitors and the glass therefrom is more complicated but also well defined. The monitor manufacturers are known, as are the environmental hazards. Large quantities of monitor glass are now recycled into glass for use in new televisions. Recycling operations for glass involve both manual and automated processing and use equipment such as glass saws, crushers, air filtration, and a furnace.

Metals

There always has been and always will be a market for recycled metals. The only question is price/cost. Several companies are now in this industry for EOLE metals, and most appear to be profitable. Metals operations generally utilize shredders, separators, and a furnace.

Plastics

This has been, and continues to be, the most problematic area of EOLE. The two big problems are:

1. Can assorted polymer scrap be separated into high purity materials to compete with virgin resins (ABS, HIPS, etc.)? There has been a lot of work done in this area but the majority of potential supply has not been recycled due to its mixed composition.

2. Can applications be found for scrap polymers (mixed) at material prices that can financially justify recycling? It is clear that some type of subsidy is required—at least for the short term—to identify and sell scrap polymers for new applications.

THE PAZ SIMULATION TOOL

In order to craft a viable regional model and Business Plan, PAZ developed a simulation model to explore numerous industry scenarios and to test various regional model configurations. The simulation was developed with a baseline set of relationships among the stocks and flows that typically make up the electronics recycling industry.

The PAZ simulation is a system dynamics model using software called iThink, Version 7.0. Electronic copies of the simulation are included on CD-ROM with all original copies of this plan.

Assumed Available EOLE Volume

As a starting point, and based on suggestions from various industry sources, the simulation assumes a weekly regional input volume of 1,300 tons of EOLE. This is a starting point for simulation purposes and is a reasonable estimate based on the best data available to PAZ and the simulation team. This supply volume is expected to be within an order of magnitude and generally consistent with estimates by published studies, OEM representatives, earlier studies by PAZ, and other published documents. The unit of time used in the simulation is per week for up to three years.

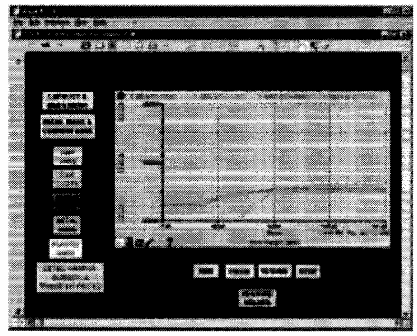


Figure 3. The PAZ Simulation Tool User Interface

The simulation is a mathematical representation of the recycle facilities, so every element requires a number, formula, or graphical value. In developing the simulation, the technical team received substantial information from a variety of sources, but in some cases considered assumptions were used. The overall set of simulation relationships and input data were reviewed with several experts in the industry as a "reality check" and modifications made accordingly. Appendix B contains a list of the most important values used in the simulation and their source(s). These values can be easily changed and the resultant impact of new values on industry breakeven evaluated.

The simulation assumes several different operating units: demanufacturing and refurbishment (D&R), glass processing, metal processing, and plastic processing. The following is a brief explanation of each.

Demanufacturing and Refurbishment (D&R)

The initial EOLE recycling step is an amalgamation of three activities: 1) the initial evaluation, followed by 2) demanufacturing, and/or 3) refurbishment/resale. EOLE is gathered, most disassembled, individual items evaluated (monitors, central processing units [CPU], hard drive, CD drive, and SCSI drive), the "good" items set aside for minor repair and resale, and the balance sent on for material processing and recovery. Some demanufacturers use an automated grinding process as an alternative to manual disassembly, forwarding virtually all the ground material for additional processing, recovery, or disposal.

Glass

Although as many as half of all EOLE monitors are resold by demanufacturers as reported by industry sources and site visit reports, monitors deemed as scrap are sent to a glass facility for pre-processing into leaded or unleaded glass, followed by material recovery for sale to a glass manufacturer.

Metal

The balance of the scrap material generated by this system, including the residual metal from the glass facility, is generally shredded into small pieces that are separated by a variety of methods into metal and plastic. The metals are separated by a variety of means and sold to metal smelters. The plastic materials are available for delivery to a plastic processor.

Plastics

In some facilities the plastics material is separated at the D&R step in order to achieve increased purity. Others shred everything and separate the various polymers at the particle level. The problem here is material consistency or purity. Theoretically, at high purity levels the recovered resin can be sold for high prices, but the reverse is also true. For the most part, recovering higher purity resins from EOLE does not appear to be economically feasible.

Investment, Capital Equipment, and Capacity

Gathering accurate price and capacity numbers for the wide variety of equipment used in recycling was one of the more difficult tasks in building the simulation. Some hard numbers were obtained, but most should be called "reasonable estimates." The simulation tool was developed to allow operators of these facilities to input actual numbers as a decision support tool for investment decisions.

Simulated Break Even

In some recycling facilities there appears to be insufficient economic incentive for the company to be financially viable through the sale of recycled materials alone. **In these cases revenues from some external source(s) are required**. To achieve the approximate financial breakeven condition for all four facilities presented in the baseline simulation tool, the following revenues were assumed:

1. $8, or about 16 cents/lb., for each computer system collected at time of turn-in for disposal or at point of sale. $1 is assigned to the glass facility for disposal of the monitor, and $7 is assigned to the D&R facility for processing the balance of the computer system. Again, a source of this $8 per computer payment is not specified in the simulation.

2. This subsidy is carried through to subsidize downstream processing steps at rates from $0.07–$0.14 per pound.

Note that these numbers are valued only for purposes of the simulation and should not be extrapolated independently of all other variables and assumptions built into the simulation model. Also, as mentioned above, this method of subsidy allocation is used by the simulation only to achieve breakeven. In "real life" other allocation methods may be used, although this type of internal transfer subsidy has been used with CRT glass in the industry for several years.

Real-life subsidy systems do exist in many states and around the world, including front-end fees for car batteries, motor oil, and tires. Appendix C contains examples of EOLE and other material recycling systems from around the world. Appendix D is a more detailed description of the system developed in Switzerland, called "SWICO"—Swiss Economic Association of Information, Communication, and Organization.

Goal of the Simulation

The goal of the SAIC/MARCEE Team in building the simulation was to present the recycling activity as accurately as possible to support development of a recommended regional model by comparing different development scenarios and comparing resulting gross margins for all four activities (D&R, glass, metal, and plastic). The following issues should be kept in mind by anyone reviewing this simulation:

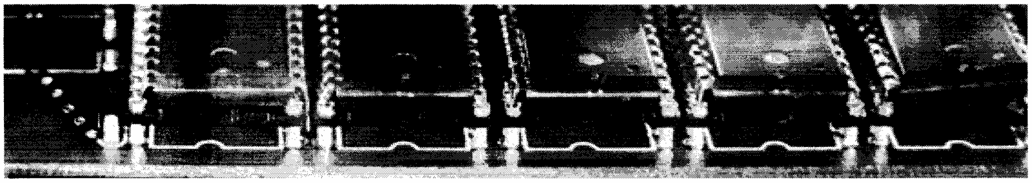
1. New and more accurate information can and should be substituted for the data used in the simulation. All original copies of this business plan will include CD versions of the simulation so users can change simulation input and run different scenarios. The simulation, however, is a generalized representation of the industry in the region as a whole and will not correspond to any individual company or localized market.

2. The scope of the simulation—other operating activities within the recycling industry—can be expanded or conversely reduced to provide insight to other projects beyond development of the regional model, but many alternate uses will require changes in the simulation structure (and not just new input values).

Operating Reports from the Simulation

The simulation software provides two methods of presenting reports: tables of data and graphs. Because this is a mathematical model, any variable or combination thereof can be presented in report form. The graphic form of the table and graph icons clearly show their purpose. On the simulation a text block states the purpose of the more important tables and graphs.

Operating reports can be presented for any time frame that is a multiple of the "unit of time," which in this case is 1 week. This means that reports can be for 1 week, 4 weeks, 13 weeks (quarter of a year), 52 weeks (annually), or for the total run of the forecast, in this case 3 years (156 weeks).



THE MARCEE REGIONAL MODEL

The proposed regional model described in this document provides a model for short, medium, and longer term development of electronics recycling, remanufacturing, and support industries in PAZ. This regional model was developed to attract and facilitate expansion of private sector end-of-life computer recycling and processing facilities, remanufacturers, and related industry services.

The regional model was developed using data and insight provided by industry participants from numerous companies, non-profits, and governments interested in increasing the scale of electronics recycling activities in the United States. Data sources included: OEMs; recyclers; processors; conference proceedings; previously published studies; site visits; web sites, including Electronic Industries Alliance (EIA), National Electronics Product Standardship Initiative (NEPSI), International Association of Electronics Recyclers (IAER), American Plastics Council (APC), Institute of Electrical and Electronics Engineers (IEEE), Carnegie Mellon, and the Environmental Protection Agency (EPA); and the comprehensive content site at www.electronicsrecycling.com. The regional model also benefited from operational and financial analysis performed by the PAZ simulation tool described in an earlier section.

The MARCEE business plan team explored numerous ways to achieve break-even scenarios via use of the PAZ simulation tool. Based on extensive analysis, it became clear that in order for PAZ to achieve a significant increase in economic benefits associated with the recycling of EOLE the following events must occur:

- There needs to be a coordinated industry approach to increase the volume and consistency of recycled EOLE materials.
- Certain recycling activities (e.g., plastics processing) require additional R&D to develop new methods to process EOLE.
- Markets for recovered materials must be developed, supply must be consistent, and efficient transportation available.

Development of the regional model involved analyzing trade-offs among supply requirements, geographic locations, and the current market. Although PAZ does not plan to operate any recycling facilities, development of a viable model requires an understanding of the operational, financial, and competitive landscape facing the industry.

Limitations in Regional Model Development

The conclusions reached in this plan were achieved following analysis of all available information and use of available tools, including the simulation tool. The caveats below are noteworthy, but are not expected to change the conclusions and plan recommendations.

- *Data.* Portions of the break-even analysis in the simulation relied more heavily on consensus among industry experts and anecdotal information. The goal of the simulation tool was to reflect the electronics recycling industry as closely as possible (i.e., within an order of magnitude) to support development of the regional model. Although inputs and analyses of the simulation tool have been reviewed by several industry experts and are deemed reasonable, the industry is very complex. In some cases, more accurate data could only be obtained through additional data collection and advanced statistical sampling—an activity that would certainly increase the accuracy of the simulation tool but would not be expected to change the recommended regional model significantly.

- *EOLE Supply.* The regional model calls for a smaller demanufacturing facility to be located in PAZ that can identify and process between 5 and 10 million pounds per year, or roughly 75 tons per week. Although the baseline simulation assumes the existence of a much larger regional quantity (1,300 tons per week of EOLE), existing demanufacturing facilities appear equipped to process efficiently most available EOLE supply. The annual availability of 5–10 million pounds for a PAZ demanufacturer appears reasonable by industry experts, but is untested.

COMMON ASSUMPTIONS ACROSS REGIONAL MODEL ANALYSIS

The major assumptions below underlie the recommendations in the Regional Model.

Supply Requirements
All variations of the Regional Model described below assume supply thresholds are met or exceeded in order to start business operations. These assumptions were derived from companies operating different types of EOLE recycling processes that have reported or shared with PAZ supply requirements for locating new operations, and generally range from 5 million pounds per year for EOLE management operations early in the recycling process (i.e., demanufacturing/refurbishment) operations to up to 50 million pounds per year for new glass processing facilities. Note that previously published supply requirements for plastics processing (e.g., 30–50 million pounds per year) are discounted and an alternative approach for managing these materials is recommended, as no processing of EOLE plastics has been produced at this scale anywhere in the U.S.

Proximity to Customers
Although close proximity to customers was described as desirable by industry participants contacted, other factors such as available supply and economic incentives to locate in a specific area were cited as more important in future facility location decisions.

Existing EOLE Operations to Continue
EOLE recycling operations established elsewhere in the region are assumed to continue. When compared with existing competition in the region (see Figure 4) and after analyzing freight costs for different facility location scenarios, these estimates were critical benchmarks in determining the near-term viability of different types of EOLE processors in PAZ.

Transportation Costs More Critical Early in Recycling Process
As shown by the PAZ simulation tool, EOLE processing activities that occur immediately after collection are the most sensitive to transportation costs,

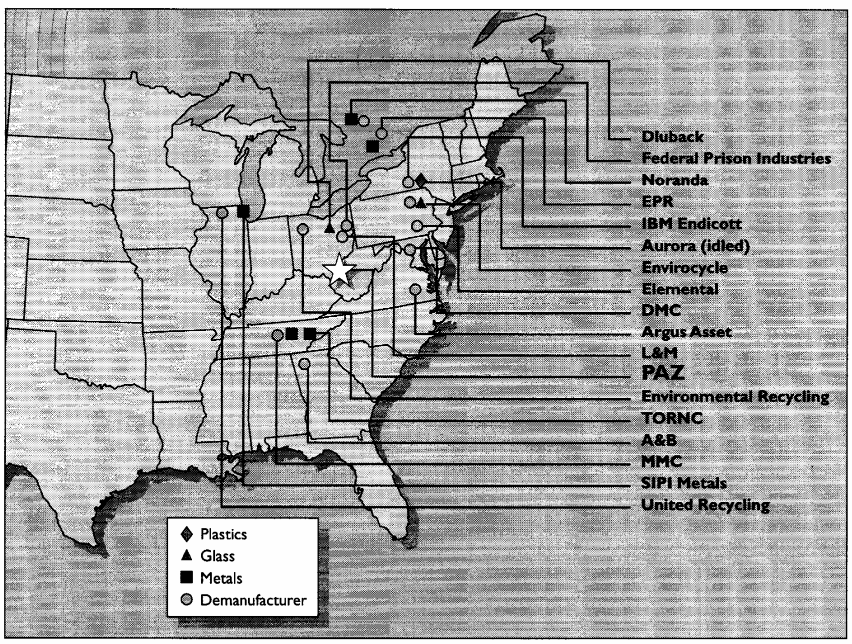
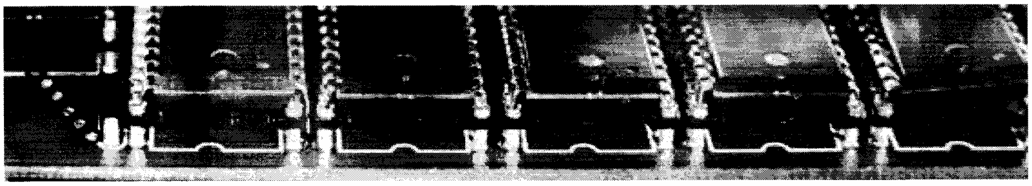


Figure 4. Sample of Existing EOLE Recycling Centers

and therefore to location. Basically, this is due to the lack of densification of EOLE at collection, which—except for EOL monitors—results in considerably higher increases in freight costs. Once materials have been demanufactured, generally they can be packed and loaded in full loads and at higher weights—thus lowering transportation costs.

New EOLE Industry Development Will Occur When and Where It Is Profitable

Although the existing structure and distribution of EOLE recycling facilities are useful in providing insight into the existing EOLE market, investment decisions will be made based on foreseeable economics and markets.



THE OPTIMAL REGIONAL MODEL: THE PROCESSING CLUSTER SCENARIO

The optimal regional EOLE recycling scenario is characterized by a widely distributed but coordinated EOLE collection and initial management tiers (e.g., demanufacturing and refurbishment) that supply back-end material processing and recovery operations that are clustered and located in close proximity to manufacturing customers (see Figure 5). Adequate physical infrastructure (roads) and virtual infrastructure (online tools and information) are assumed available to efficiently move goods and information through the different steps in the EOLE recycling process. To develop industry efficiencies, an industry environmental ethic, and the economic stimulus to make large-scale EOLE recycling viable, a coalition of key industry participants will be formed to assume responsibility for creating and managing the EOLE recycling system. Finally, the optimal model system is expandable and can efficiently incorporate recycling of products beyond EOLE that are saleable in the same or similar markets and have similar processing requirements.

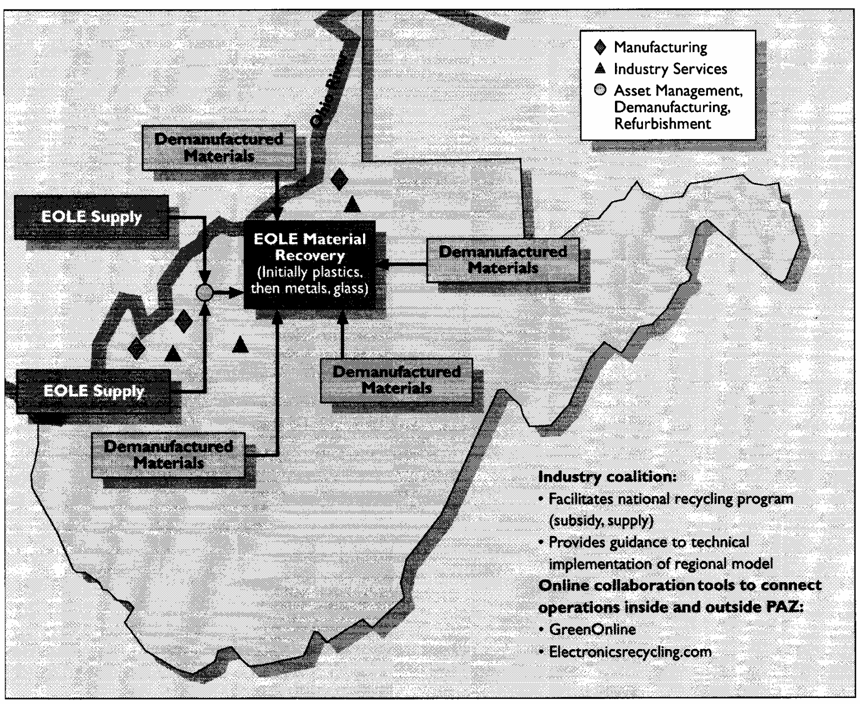
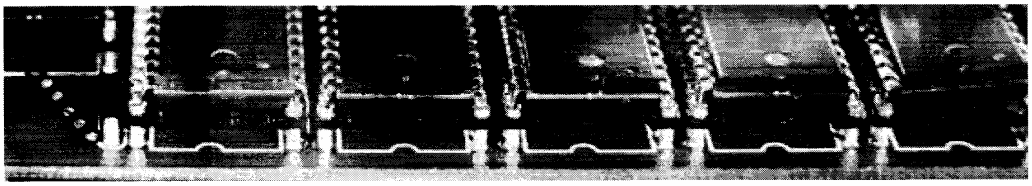


Figure 5. The Optimal Regional Model for PAZ



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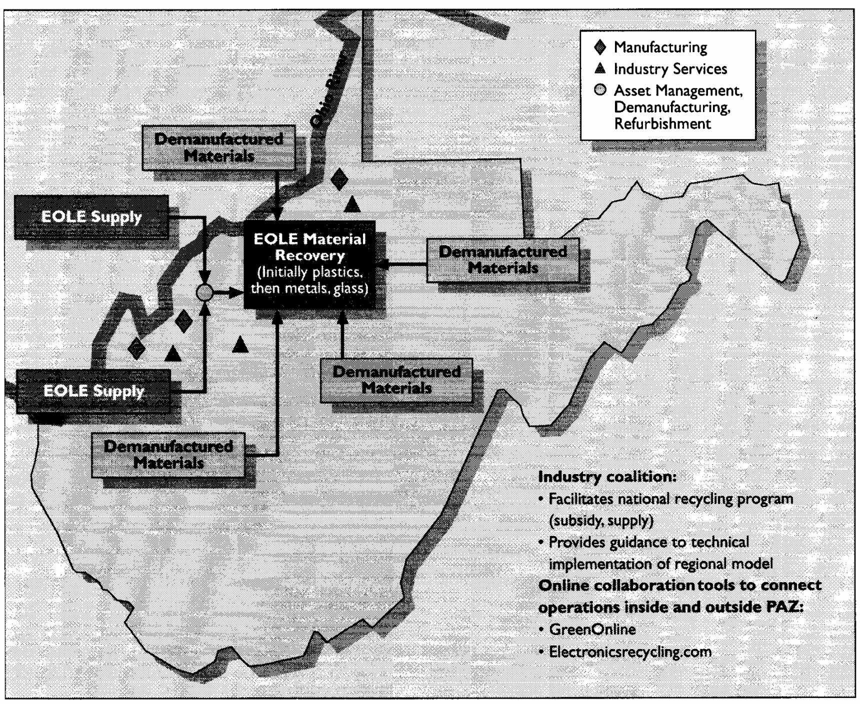


Figure 5. The Optimal Regional Model for PAZ

Regional Model Implementation in PAZ
Specific to PAZ, the optimal Regional Model calls for establishment of a cluster of EOLE recycling facilities, including small to mid-size demanufacturing and/or refurbishment operations and material processing and recovery facilities for plastics, glass, and metals. Outputs from EOLE recycling would supply remanufacturing operations in the PAZ region. PAZ should also lead development of the Industry Coalition required for market growth and required economic enhancements, and contribute support for development of required industry infrastructure where it is insufficient or does not exist.

Figure 5 presents a high-level overview of the Regional Model. Recommended action items to implement this model in PAZ are included in the next section.

Cluster Options
As MARCEE works to develop sites to serve as the hub of the Regional Recycling Cluster, major questions are the location, character, and extent of the site necessary to support the near-, medium-, and long-term objectives of the regional model.

As a first cut, the economics of colocation of EOLE processing facilities were analyzed with the assistance of the PAZ simulation tool. Regional location questions were analyzed using the geographic locations of existing facilities presented in Figure 4.

The technical team analyzed the geographic location of existing EOLE facilities and, for "what-if" purposes, simulated different distribution patterns for these types of facilities. Using the simulation tool, freight costs associated with different hypothetical facilities distribution scenarios were evaluated: a maximum concentration of facilities (mostly in PAZ), a medium concentration, and a minimum concentration/maximum distribution scenario. For the medium and minimum concentration scenarios, this analysis involved plotting major recycling operations already in operation within the general PAZ region.

Risks
This optimal scenario presents the least business risk of all alternatives explored, but significant risks are still noteworthy. First, large-scale recycling of EOLE will require significant economic enhancement to break even. Even on a regional basis, in which approximately 10 million computers are recycled annually (assuming an ultimate national EOLE recycling total of 25–35 million/year), and assuming $8/computer to break even, economic enhancements in the tens of millions of dollars will be required. It is not clear that an Industry Coalition can be organized or required financing secured. Also, limiting focus to end-of-life computers only would raise the risk of non-participation by key OEMs.

The most noteworthy risk may be time for implementation. First, implementation of any legislative change by Congress or individual states is often a long and uncertain process. Second, it may take years, not months, for the main industry players to agree to a viable solution to EOLE.

Challenges of Implementation
Immediate implementation challenges include:

- Identification of 5–10 million pounds of EOLE for initial management in PAZ. Although this volume is significantly smaller than volumes assumed required (and subsequently discounted) in previous studies, a formal investigation of the quantity of available supply in the immediate PAZ region (including southeast Ohio) should be initiated by PAZ or a company interested in establishing this service. Markets for demanufactured outputs will also need to be identified prior to initiation of operations.

- Identification of immediate applications for EOLE plastics. During the next year, with a coordinate R&D and marketing efforts it should be possible to identify one or two viable, if lower value applications for EOLE plastics. Identification of one or more applications in the immediate term will create the initial supply network for EOLE plastics and help make plastics processing viable for one or more companies operating in PAZ. Concurrently with this short-term approach, R&D on high-value uses should continue in close cooperation with the Industry Coalition discussed elsewhere in this plan.

Glass, Metals, and Plastics Processor in the Cluster
The technical team observed from the simulation that once EOLE is separated and densified (except for whole monitors), the sensitivity of distance to gross margins is relatively small. Thus these facilities are less sensitive to geographic location, and therefore are prime targets for eventual recruitment into the MARCEE Cluster.

Based on this analysis, which accounted for consideration of existing recycling operations and expansion plans among industry participants, the recommended regional model includes short-term milestones of attracting a smaller demanufacturing facility (5–10 million pounds/year) and establishment of a national plastics processing facility.

Site-Specific Cluster Questions

Because the impact of freight costs within a local area is less significant than in a regional context, less tangible issues such as management and collaborative learning are more critical as a determiner of whether MARCEE should establish a single site for all recycling activities in PAZ or multiple sites. Where the economics outlined above are not prohibitive, it is clearly beneficial for EOLE processors to be tied together at one location, or in close proximity, to provide a total recycling solution to achieve greater efficiencies and avoid excessive transportation expense.

Furthermore, MARCEE should focus on using this Regional Recycling Center site not only for processors of EOLE but also for remanufacturers using recovered materials. These remanufacturers can be recruited by the proximity of a large supply of relatively inexpensive recovered materials. The remanufacturing component is an important component of the regional model to attract higher value uses and activities into PAZ.

Colocation of facilities at a single Regional Recycling Center site is preferable for the near-term and should be a large enough land area to house at least two facilities of approximately 50,000 sq. ft. The site should offer easy access to Interstate 77 or US 50 and, of lesser importance, to rail. Ideally, the site will already have one or more existing buildings usable for EOLE processing and should be available for occupancy in 2002.

Below are the recommendations on what types of facilities should be incorporated into this PAZ facility in the near-term. However, for the longer term, MARCEE should plan for multiple sites around PAZ.

Over the long term, the Regional Recycling Center should incorporate an extensive outreach component to link together industry participants through a "Global Recycling Village" concept that will facilitate commerce, not only in the PAZ region, but throughout the country and around the world. The Global Recycling Village is consistent with the MARCEE goals for GreenOnline and is an important component of developing MARCEE into a global hub for electronics recycling and remanufacturing.

ALTERNATIVE REGIONAL MODEL

SCENARIO #1:
Centralization of All New EOLE Recyclers/ Processors, Including Demanufacturing

This scenario is identical to the Optimal Regional Model depicted in Figure 5 except that all EOLE recycling activities following collection are centralized in an EOLE cluster. Although this scenario presents some interesting opportunities for economies of scale, freight costs associated with moving undensified EOLE more than 150–200 miles from EOLE collection points appear to overtake any benefit achieved from lower facility and equipment costs. The profitably comparison of this alternative (i.e., the "Maximum Industry Consolidation Scenario") and data assumptions are presented in Figure 6.

Risk

Clearly, there is substantially more business risk for conducting all new demanufacturing in a centralized facility scenario than in a widely distributed scenario. This is confirmed by the current geographic distribution of demanufacturing facilities generally consistent with population densities.

Interestingly, these scenarios show that a single plastics processing facility (to be located in PAZ) suffers margin erosion as the demanufacturing portion of industry becomes more widely distributed.

Challenges of Implementation

Existing firms such as Envirocycle, MMC, Metech, DMC, Dluback and several others are located throughout the mid-Atlantic region and suggest that consolidating most regional EOLE demanufacturing facilities in PAZ would be impractical for the near-term. For the longer term, shipping costs appear to support widely distributed demanufacturers around the region.

As an alternative to physical colocation, "virtual collaboration" among industry participants along the electronics recycling supply chain will create additional implementation challenges. GreenOnline can

	Maximum Industry Consolidation Scenario	Medium Industry Consolidation Scenario	Minimum Industry Consolidation Scenario
Demanufacture/Refurbish	PAZ	Chi/Phi/NY/Nashville/PAZ	20 distributed locations, including PAZ
Glass	Halstead, PA	Halstead, PA/Cleveland	5 in PA, 1 in OH
Metals	PAZ	Chicago, Nashville	5 distributed locations
Plastics	PAZ	PAZ	PAZ
Deman to Glass	500 miles	250 miles	250 miles
Glass to Metal	500 miles	250 miles	200 miles
Deman to Metal	50 miles	300 miles	100 miles
Metal to Plastic	50 miles	300 miles	250 miles
Deman to Resale	400 miles	150 miles	50 miles
Glass to Corning	400 miles	150 miles	50 miles
Metals to Smelter	400 miles	150 miles	50 miles
Plastic to Molder/Manufacturer	50 miles	50 miles	50 miles
Collection to Demanufacturer	450 miles	200 miles	50 miles
Cap Equip D&R	$2M	$3M	$4M
Cap Equip Glass	$800K	$1.2M	$1.5M
Cap Equip Metal	$1M	$1.6M	$2M
Cap Equip Plastic	$1.5M	$2.3M	$3M
PROFITABILITY COMPARISON (weekly $ gross margins in week 156)			
D&R	-31,647	10,886	45,811
Glass	617	8,079	9,880
Metals	18,240	26,925	25,599
Plastic	10,836	7,061	3,759
Total	**-1,954**	**52,951**	**85,049**

Figure 6. Regional Facility Location Analysis

serve a useful role in bringing together geographically dispersed industry participants into a virtual supply chain using online industry standards to do business with each other.

Production Costs

While investment costs are expected to be lower in the maximum concentration scenario, shipping costs are generally higher.

Demanufacturing/Refurbishment Distribution

Freight costs associated with demanufacturing and refurbishment point toward a widely distributed network of facilities to conduct this initial recycling activity. This is consistent with predictions by some industry participants that demanufacturing will generally be located within a 2- or 3-hour drive of collection locations.

Although it does not appear to be realistic to centralize most U.S. demanufacturing operations in PAZ, PAZ should seek to build partnerships with these facilities as part of a larger supply network for processing recovered materials.

ALTERNATIVE REGIONAL MODEL

SCENARIO #2:

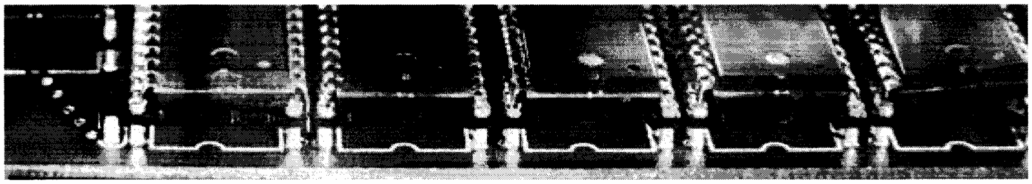
Immediate Implementation of EOLE Plastics High-Value Uses

Scenario #2 is also identical to the Optimal Scenario, except for the EOLE plastics processing operations. During development of this plan, the technical team discussed the state of EOLE plastics processing with numerous industry participants and experts about the near- and long-term prospects for high-value applications for EOLE-derived plastics. There is near unanimity in the EOLE industry that an existing production-scale process for processing EOLE plastics into high-value applications does not exist in the United States.

However, with enough subsidy (from some unidentified source) to cover additional pre-processing costs incurred at the collection and demanufacturing stages, it is theoretically possible to separate EOLE resins to achieve high-value uses. Implementation of this scale of pre-processing is difficult at best and is probably only realistic within the context of a larger

EOLE recycling system managed by an Industry Coalition, as described elsewhere in this plan. As the Industry Coalition will not be in place before the end of next year, it does not appear that near-term processing of EOLE plastics for high-value applications is feasible.

How much subsidy is required? Although not the focus of this regional model and planning effort, the required subsidy could easily surpass $100 million annually (assuming recycling of three billion pounds of plastics used annually in all electronics from *Plastics News*, May 5, 1998, at an additional cost of 5¢/pound=$150 million). This estimate would be accurate only if separation is technically feasible at an additional 5¢/pound, and that applications and demand for recovered plastics exist on the back-end of the system. As these conditions are not in place or supported by previous recycling attempts, this alternative scenario is not recommended.



ANALYSIS AND RECOMMENDATIONS

The analysis below describes the potential profitability, risk issues (including supply), challenges of implementation, production costs, and demand for different scenarios of interest to MARCEE. The conclusions from these analyses are the bases for the recommended near- and mid-term action items.

ACTION ITEM #1:

Identify and Declare PAZ a Regional Recycling and Remanufacturing Cluster

The critical first step in the establishment of a Regional Recycling Cluster is the identification of a site or sites within PAZ on which the Center will be built. Once identified, PAZ should coordinate a highly visible campaign to announce the establishment of a regional recycling center. Ideally, this would occur concurrently with an announcement of attraction or expansion of a regional EOLE processing facility, attraction or expansion of a plastics processing facility, or some other major MARCEE milestone.

Next Steps on Action Item #1:

- Develop site(s) for location of EOLE recyclers
- Develop MARCEE cluster rollout strategy
- Implement cluster rollout.

ACTION ITEM #2:

Form an Industry Coalition to Guide PAZ Regional Center Implementation and Stimulate Market Development

As described elsewhere in this plan, there is a large number of PCs that have already reached end-of-life (EOL) and are currently in storage awaiting final disposition, and an increasing number of PCs being taken out of service each year. This growing waste stream, with the lack of an efficient return logistics and recycling infrastructures to support recycling, indicates that this will be a difficult problem to solve.

Although the final recommendations from various national and regional dialogues described in Appendix A are forthcoming, it is clear that the development of regional recycling centers will play an important role in the final solution for EOLE. Therefore, it is reasonable that a regional recycling implementation plan should be developed while these dialogues are in progress and before any national program can be successfully implemented. Ideally, a technical implementation plan would be developed by an Industry Coalition with coordination provided by a non-profit organization such as PAZ. In this coordination role, PAZ would build upon the MARCEE regional model described in this plan to identify and recruit core coalition members to develop a regional recycling center technical implementation plan that would serve as the footprint for a national recycling program.

Development of a Regional Recycling Center Technical Implementation Plan

To develop such a plan and pilot its operations, a concerted effort will be needed to identify and recruit key stakeholders (e.g., OEMs, resin suppliers, recyclers) and service providers with the "best-of-class" recycling technologies and processes. Such an industry coalition would include selected core members based upon their individual experiences, capabilities, unique perspectives, and consistency with the regional model (see Appendix D). These core members would then work together to develop the technical framework for a regional recycling implementation plan that would ensure the best reuse and recycling efficiencies. Also, their input would be vital in further refinement of a sound business plan for PAZ. Once this plan was developed and proven through a regional pilot implementation, it would serve as a model for additional implementations in other regions toward achieving a successful national program.

RECRUIT CORE MEMBERS

OEMs

Initially, PAZ will focus on recruiting selected OEMs to join this development effort. This is a key first step as these manufacturers will most likely be required to play a significant role in any implementation of a national recycling program. Further, they are probably more interested in the deployment of a collective system solution rather than developing individual systems due to reduced manufacturer costs, prevention of duplicated efforts, and increased efficiencies. Also, these manufacturers can provide strategic planning for any refurbishment or reutilization activities by the regional center and possibly help build the needed supply by directing their return volumes to the center for processing.

Recycling Service Providers
The second category of core members needed for a successful development of an implementation plan is the service providers of the top tier recycling technologies and processes. There are existing technologies and processes that provide unique performances and benefits. Typically, these small stand-alone businesses have not been tied together at one location or in close proximity to provide a total recycling solution, achieve greater efficiencies, and avoid excessive transportation expense. These potential industry coalition core members should be recruited based upon a determination by PAZ that their technology and processes will complement the overall efficiencies of a regional recycling center operation consistent with the regional model, willingness to participate, and the abilities of these service providers to transfer or establish satellite processes in a single or multi-complex recycling site. Top tier recycling technologies and processes will be identified and recruited for the following elements that will be included in a regional recycling center implementation plan and pilot. These will include:

- In-house receiving, tracking, transporting, and storage systems
- Information systems for identifying reusable machines and parts
- Central control station and observation system for viewing critical points in the operation and actual processing of materials
- Information systems for identifying hazardous contents and location in EOLE
- Methodology for easy removal of hazardous parts prior to shredding
- Efficient demanufacturing operations and parts removal
- Certification of parts and assemblies for reuse
- Shredding of remaining EOLE, carcasses, and parts
- Separation of major materials (e.g., metal, plastic, glass, paper)
- Purification processes to create multiple material streams with increased value, purity, and usability from major material streams
  a. Metal stream (e.g., non-ferrous, ferrous, aluminum, precious metals)
  b. Plastic stream (e.g., PC/ABS, PC, ABS, PVC, PS, FR resins, mixed)
  c. Glass stream (e.g., suitable for use by glass manufacturer)
- Compounding and extruding of recovered plastic resins and mixed resins.

Material Suppliers
A third group of core members should consist of key material suppliers (e.g., plastic resins, glass, metals) who can assist in developing the appropriate material standards, specifications, markets, and business cases for recovered materials. These material suppliers not only understand the materials they created, their values and potential uses, but they also would be interested in an opportunity to demonstrate their commitment to recycling these materials. If EOLE manufacturers are to have extended product responsibility, it stands to reason that the manufacturers who provided them with the components and materials to produce these products should also play a significant role in developing the right solutions and opportunities for their reuse.

Industry Trade Associations
A fourth group of core members will include PAZ-selected industry organizations (e.g., EIA, IAER, APC, ASM) that can provide strategic planning assistance, perform specific research projects, and define optimum end uses and final disposition for their respective materials. These members can also provide industry with available sales and use data to support the development of marketing plans.

Next Steps for Industry Coalition Development

- Develop strategic approach for Industry Coalition development
- Define near-, mid-, and long-term objectives for Industry Coalition
- Review proposed Industry Coalition plan with PAZ Steering Committee
- Begin meeting with leading OEMs and others one-on-one to get industry coalition members to begin development of industry consensus
- Determine resource allocation needed to support near-term objectives
- Identify potential core membership candidates for the four categories
- Recruit and select core members by and during the EPR2 conference
- Conduct initial Industry Coalition meeting during IEEE conference
- Develop work plan, define responsibilities, and establish time lines

- Develop implementation plan to support selected processes and recovered materials
- Obtain acceptance for regional recycling center technical implementation plan
- Develop schedule for establishment of pilot facility.

ACTION ITEM #3:
Incorporate Other Types of EOLE (e.g., TVs) and Recyclable Materials into MARCEE Plans

Concurrently with development of the Industry Coalition, MARCEE should begin exploration and analysis of incorporation of other types of EOLE and recyclable materials into the regional model. Supporting activities could include refinement of the PAZ simulation tool to evaluate operational and financial "what-if" scenarios associated with recycling different product types.

ACTION ITEM #4:
Develop and/or Attract a Relatively Small-to-Medium, Regional Demanufacturing and Recycling Facility

Based on the industry simulation, geographic distribution and current market analysis described above, PAZ is an attractive location for establishment of a small-scale demanufacturing facility (e.g., 5–10 million lbs/year as confirmed by industry participants). PAZ should focus recruitment efforts on companies that offer reasonable potential to scale this initial demanufacturing operation into a larger or more vertically integrated EOLE processing facility. Ideally, a PAZ demanufacturing facility should be operated by a company already active in processing EOLE glass, metals, or plastics. With the future growth in the EOLE recycling industry described below, recruitment of a demanufacturer that integrates with or is part of a larger firm actively processing other EOLE will increase the chances for location of glass and/or metal processors, as planned in the regional model build-out.

To help determine the optimal type of demanufacturing process, the analysis described in Figure 7 below was conducted, with the help of the PAZ industry simulation tool, to shed light on the "pros and cons" associated with a MARCEE manual demanufacturing process versus an automated shredding process.

This analysis used the regional baseline simulation tool scenario described above, with two major exceptions: the size of the demanufacturing operations (20K sq. ft. facility) and projected supply (78 tons/week, or approximately 8 million pounds/year).

The simulation suggests that a more manual demanufacturing operation offers—at least initially—a better business case than an automated grinding process.

Note that this and other simulation scenarios in this plan are done for comparison purposes (all other variables not shown below are held constant). Actual gross margin projections should be made by enterprises using their proprietary data of actual costs and projected revenues.

Risk

Without a larger volume of available supply, an investor in the Automated Grinding process would appear to be taking on significantly more business risk than a manual demanufacturer.

Availability of 78 tons/week of EOLE is also a risk for a smaller demanufacturing facility, although, given the targeted supply requirements and lack of large competitors in the immediate PAZ region, this risk is significantly reduced.

The Smaller MARCEE Demanufacturing Facility Simulation		
	Manual demanufacturing	Automated grinding
Cap Investment	200K	3M
% refurbish/resale	14%	0%
% scrap monitors	50%	80%
Hires	35	5
PROFITABILITY COMPARISON		
Weekly Gross Margin (in week 156)	$776	($8,524)

Order of magnitude estimates from SAIC are used for comparison purposes only

Figure 7. Manual vs. Automated Shredding

Challenges of Implementation
Identification of supply source(s) and customers for output will be the primary challenges for either option.

For the longer term, an automated grinding operation will scale faster and easier to larger supply volumes than a manual facility.

Production Costs
Production costs are higher for the manual option due to increased labor requirements, but capital requirements are lower by 15 times under this scenario.

Demand
Demand for process outputs is as follows:

- *Plastics.* Demand for recovered plastics is being generated through other activities in this plan. In the future, and depending on plastics recycling processes employed, the manual demanufacturing option may yield plastic outputs with more demand given the higher degree of plastic separation potential by preprocessing and separating whole parts. However, if PAZ chooses to pursue the Mixed Plastics Commoditization Plan, as presented in this document, separation of resins would not be required.
- *Glass.* No difference, given that monitors are separated and shipped before both processors. "Demand" for monitors exists at a price of $1–$3 per monitor.
- *Metals.* Demand for metals could vary by the different physical metal forms. A manual demanufacturer would generally separate out whole parts or fasteners while the automated grinding operation will perform initial metals separation activities as part of its grinding process.

Next Steps on Action Item #4:

- Follow up with demanufacturers known to have expansion plans
- Identify specific sources of EOLE supply in Ohio Valley
- Develop motives package for recruitment of firm into PAZ.

ACTION ITEM #5:
Establish a Regional Plastics Processing Demonstration System in PAZ

A PAZ EOLE plastics processing operation could either be recruited in the region or grown from one or more of the existing companies in PAZ with similar recycling operations. Ideally, a company interested in developing a large EOLE processing operation in PAZ will be incorporated into MARCEE R&D efforts to help implement both this action item and the action item below calling for identification of new applications/markets for recovered plastics.

The recommended approach in this plan is one of commoditizing mixed plastic as a set of products. With this approach, no separation of resins is required either upstream from the plastics processor or in the processor itself. Capital equipment requirements are significantly less under this approach and include the following types of equipment: shedders, separators (flake, hydrocyclone, eddy current), polymer pelletizer, forklifts, air filtration, test equipment, and conveyors.

One of the most important elements in initiating near-term EOLE plastics recovery is the identification of new applications. It is critical, however, that R&D efforts for new applications be closely coordinated with marketing and sales efforts.

By initially focusing on identification of lower grade plastics applications following the approach described in this plan, establishment of EOLE production-scale plastics processing in PAZ is realistic within the next 18 months. Once operations in such a facility are underway, there appears to be a sufficient if inconsistent supply of mixed plastics to process volumes in the tens of millions of pounds per year. Based on conversations with industry participants from several companies operating in the eastern United States and Canada, an environmentally acceptable non-disposal option for EOLE-derived plastics does not exist.

The initial focus on near-term application should complement the ongoing efforts of WVU to find long-term, high-value uses for these plastics through advanced separation techniques. WVU's efforts to institutionalize research efforts for advanced processing technologies and applications are critical to the long-term success of MARCEE.

Other key elements to an efficiently functioning plastics processing system are the identification and use of niche processing facilities specializing in recycling of specific resin types and/or blends. Given the variability of mixed plastic composition and the range of processing requirements anticipated to commoditize these mixed plastics, no single primary plastics recycler is expected to perform all the work associated with this effort. Rather, the initial plastics processing facility will coordinate processing of recovered mixed plastics into commodity products—whether the processing occurs primarily (or solely) at its facility, or at another location.

Create a Consortium to Identify Immediate, Viable Applications/Markets for Recovered Plastics

The EOLE recycling industry is generating tens of millions of pounds per year of mixed plastics. Five engineering thermoplastics make up most of this volume. They are: ABS, HIPS, PC, PC+ABS, Fire Retardant (FR) ABS, FR HIPS, PVC, and polyphenylene oxide (PPO). According to industry sources, most of these mixed polymers are either exported or burned (at essentially "zero" value to the recycler), or dumped in landfills (at a cost to the recycler of 2¢–4¢/pound). Since on average these polymers are priced at about $1.00 per pound, this appears to be a missed economic opportunity.

However, for near-term action, the technical team evaluated "what-ifs" when lower grade applications for mixed plastics were identified. Variables for transfer pricing (or costs) specific to recovered plastic are among the most sensitive in the PAZ simulation tool. After reviewing a range of prices from –5¢/lb. to $1/lb., it appears that if only a small positive value for recovered plastic is achieved (e.g., 5–20¢/lb.) that break even for a plastics processing operation is achievable. Lower grade plastics applications would require less up-front investment in capital equipment, little presorting among specific resins, and is consistent with automated grinding/shredding operations as practiced by MMC, EPR, and others. Furthermore, development of new, lower grade applications for mixed plastics is achievable with existing technologies and is more of a marketing/sales challenge than technical.

For the short-term, PAZ should focus on establishing plastic processing operations to find reasonable, nondisposal applications for mixed plastics.

Note that a short-term emphasis on lower grade applications is not a replacement for longer term efforts to identify higher value applications using separation techniques or technologies that currently are not available.

The Mixed Plastics Commoditization Concept

MARCEE should put together a consortium (private company, university, and/or research group) to identify application targets and blend, extrude, and characterize the physical properties of these mixed plastic materials.

The premise of this work is that high strength and high melt temperature granulated polymers contained within a lower strength and lower melt temperature polymer acting as a matrix will result in a combined material of equal or higher strength than the matrix polymer alone. The market price of these recycled polymers will then be a major fraction of that of the virgin matrix polymer.

Based on available information, estimates of average percentages of the five subject polymers in the mixed plastic material from recycled computers are as follows:

HIPS	30%
ABS	27
PC	25
PC+ABS	18
FR ABS (used in older EOLE)	<1
FR HIPS (used in older EOLE)	<1
PVC (used in older EOLE)	<1
PPO (used in other electronic equipment)	<1
Total	**100%**

As part of the R&D effort, different lots of mixed plastics from EOLE should be blended, extruded, and characterized, with this percentage mix as an initial target concentration. Other combinations around these values should be selected and characterized as desired. These mixed plastics might be blended with post-industrial plastics or virgin resins to create product specifications to facilitate sales of these new mixed plastic commodities in the marketplace. The (1) post-industrial resin polymer and (2) "pure" resin/mixed plastic ratio also will be important parameters in the characterization study.

The mixed plastic material list of values that should be included in the "Characterization Data Table" can be determined from available industry sources, such as APC, "Modern Plastics World Encyclopedia," or other industry information sources and then modified by visits to the plastic processing companies that may be customers for these mixed plastic materials to see what characteristics will be most important to them. All the values listed by *Modern Plastics* will probably not have to be characterized, but most will.

In addition to characterization data, the polymer facility should provide extruded mixed plastic material cut into industry standard test sample sizes and containers of mixed plastics of the various blends characterized. This will complete the initial characterization study.

Once characterized, these new mixed plastic "commodities" can be created through blending of EOLE plastics with post-industrial scrap or other plastics to achieve the product specifications established in the characterization portion of this effort. The personnel selling this material will have characterization data sheets, extruded test samples and small bags of mixed polymers, the same support as salesmen from any major polymer manufacturer. They will be selling "standard" materials.

The price per pound for the final blend and the resultant price per pound for the included recycled polymers will depend upon competitive market conditions. However, if the steps outlined in the blending function are within reasonable accuracy, the price per pound for recycled polymers should be significantly lower than virgin polymers.

Among the currently envisioned applications for mixed plastics materials are the following:

1. Outdoor patio blocks, which can be made interlocking
2. Marina products: bumpers, dock liners, etc.
3. Lawn furniture
4. Highway rail backing blocks
5. Decorative fencing; posts, rails, interconnect devices
6. Toys

This list is meant only as an incentive for further thought and marketing efforts. Each application mentioned above meets two important constraints:

- The product cross-section must be "thick" (estimated 2–3 times max. particle size). This is required by the unmelted granules in the matrix. Probable minimum thickness: 3/16–1/4 in.
- The color must be "dark": green, brown, red, blue, gray, or black. Because the mixed plastics will be of various colors, a common dark color will be necessary for uniformity.

By combining marketing efforts into MARCEE R&D activities, PAZ could help facilitate short-term markets for mixed plastics from EOLE to complement efforts to recruit and build up plastic processing operations in the Regional Recycling Center. PAZ's contribution could include funding to offset both R&D and marketing costs associated with this effort. Furthermore, associating R&D closely with marketing efforts will increase the likelihood of marketable products from R&D efforts.

Next Steps of Action Item #5:

- Integrate near-term applications development work with WVU's efforts to develop long-term, high-value uses through the WVU Center for Polymer Research
- Identify and recruit niche processors in the region to participate in the initial characterization study
- Initiate the characterization study to create a new suite of plastic products made from EOLE plastics
- Work with recyclers to blend samples of EOLE plastics with other resins to achieve new product specifications
- Take samples "on the road" to find new customers and applications.

ACTION ITEM #6:

Incorporate and Establish Online Trading Standards for EOLE and Recovered Polymers for Use by GreenOnline, Electronicsrecycling.com, and Other Trading Systems

One significant element in the proper functioning of a comprehensive EOLE recycling and remanufacturing effort envisioned in this effort is the establishment of industry standards and online tools. Regardless of the collection or processing techniques employed, the lack of information from one stage in the recycling system to another creates numerous processing and engineering challenges, and limits demand for recovered materials in the remanufacturing and manufacturing industries.

Easy and fast communication of information is required for viable downstream recovery, processing, and remanufacturing, especially for plastics. Depending on the specific application for the recovered material, critical information requirements include:

- Whole product composition at point of collection, such as resin composition of casing, quantity of precious metals, etc. In many cases, product brand and vintage may serve as surrogates for specific composition data.
- Whole parts composition at demanufacturing.
- Shredded parts composition after shredding.
- Finished primary material composition prior to molding or remanufacturing.

The lack of information on material composition and associated uncertainty drives up costs (i.e., requires additional processing) and drives down potential revenues by creating reliability questions among buyers.

It also is critical that material information consistent with common industry standards be communicated. In the online world, industry standards are communicated through use of XML. XML is a new way of transferring and storing data using some of the built-in characteristics of the Internet. XML is a very simple and effective way to exchange data across numerous platforms and allows businesses to exchange information with numerous suppliers and vendors without the problem of worrying about data from one system being able to interface with data from another system.

GreenOnline will use XML as an Enterprise Application Integration tool, thereby allowing multiple systems to communicate with each other. Several pieces of the core GreenOnline trading engine software are being adapted to allow for data integration with outside systems using XML technology. However, with any complex business-to-business (B2B) exchange or marketplace, a number of issues must be addressed, such as work flow error handling, data mapping tools, communication protocols, and partner management. That is why GreenOnline has positioned its XML efforts into three main focus areas.

1. XML standards—focusing efforts to help businesses establish a common language, vocabulary, and methods for data exchange among multiple business partners

2. XML usage and adoption—efforts include helping businesses identify where XML can play a role within their organizations and developing methods for adoption of XML

3. XML tools and technology—efforts focus on what technologies and tools are available to help businesses realize the full potential of XML.

For each of these three focus areas, PAZ is conducting extensive outreach, requirements analysis, and design development in the electronics recycling and other targeted GreenOnline markets (brownfields and renewable energy).

An industry certification program tied to an industry information system (just described) also will be explored, along with other scenarios that include coordinating the materials characterization system with a logistics management system to optimize movement of materials from facility to facility.

Concurrently with development of the requirements analysis, and to prepare GreenOnline for use by the Industry Coalition as the adopted industry standard for this market, GreenOnline should provide support to the EPA Region III/EIA ecycling project as the information hub for this data collection pilot. GreenOnline support efforts for ecycling include:
- Online host for the ecycling data collection forms that each collector, transporter, and recycler will be required to fill out to participate in the pilot program
- Use of the GreenOnline commerce engine to administer the EIA grant as a bidding system for qualified electronics recyclers interested in hauling and processing end-of-life electronics collected at ecycling collection centers.

Create a "Global Electronic Village" to Digitize Exchanges and Logistical Support Services
As an extension of the MARCEE online standards development and GreenOnline marketplace development activities, MARCEE should explore creation of an extended "Global Polymer Village" to integrate complementary business operations and support services around the world with the Regional Recycling Center and National Trading Exchange. There are significant advantages for MARCEE in developing complementary partnerships with companies and facilities located elsewhere:
- Increased visibility in the marketplace
- Stronger supply chain relationships
- Increased opportunities for PAZ businesses to develop joint ventures and partnerships.

Development of a sophisticated industry network with support services is another important way for MARCEE to develop high-value service businesses in PAZ.

MEDIUM TERM REGIONAL

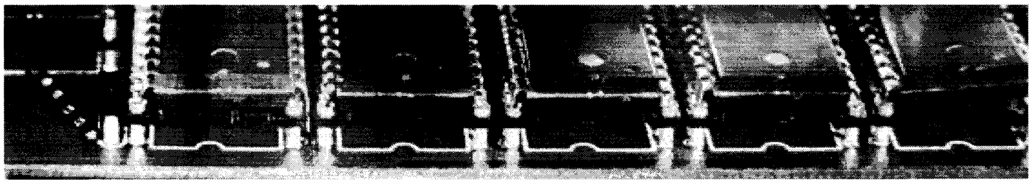
MODEL OBJECTIVES

The following objectives are to be achieved during the next 1 to 3 years. These objectives also will need to be explored in detail prior to initiating action to ensure objective relevance and realism. Medium-term objectives include:
- Expansion of the EOLE processing industry in PAZ to include large scale recycling of all EOLE and derived materials

- Establishment of a self-sufficient GreenOnline as a central marketplace for online EOLE commerce and recovered materials
- Institutionalization of recycled plastics R&D and other industry support services in PAZ.

- Development of an industry certification system for products, facilitities, and/or companies to ensure that all producers, recyclers, and remanufactures in a comprehensive EOLE recycling system adhere to the highest standards of environmental and quality performance.

The long-term objective for MARCEE is the establishment of PAZ as the national and international hubs for electronics recycling commerce, including remanufacturing operations that "buy recycled."



APPENDIX A

RELEVANT INDUSTRY ACTIVITIES AND ENTITIES

There are several related initiatives currently underway focusing on electronics recycling. Each of these initiatives presents opportunities and potential obstacles for MARCEE as discussed below.

NEPSI

NEPSI is an effort by 45 representatives from electronics manufacturers, government agencies, and environmental groups to develop a joint plan in the United States for managed used electronics. The focus is on product stewardship and has sparked intense discussions among participants about how to share the costs and responsibility for the reuse and recycling of electronics by those who produce, sell and use these products.

PAZ's continuing involvement in NEPSI is recommended as a precursor to PAZ efforts to organize the Industry Coalition and to demonstrate PAZ's leadership related to successful EOLE activities.

Stakeholder Dialogue

In May 1999, the Gordon Institute at Tufts University initiated a series of Stakeholder Dialogues on Recycling Engineering Thermoplastics from Used Electronic Equipment. The Stakeholder Dialogues bring together the plastics supply chain to discuss barriers and opportunities in recycling electronic engineering thermoplastics (EETP), and to develop collaborative industry strategies to advance recycling of plastic resins from used electronic equipment.

The Stakeholder Dialogue process has identified major challenges to the successful and sustained recycling of engineering thermoplastics, including cost-effective collection and processing of resins and the development of adequate markets, particularly for mixed resins. Several task forces have been established to develop strategies for overcoming these challenges using the collective expertise of this unique, multi-stakeholder process.

The dialogue process has actively engaged companies throughout the supply chain, including major resin suppliers and original equipment manufacturers, along with plastics processors, molders, electronics recyclers and federal, state and regional government officials, and other industry experts. Over 60 organizations have participated in the dialogue process since its inception.

The dialogue has been useful to MARCEE in several areas, including development of a plastics characterization matrix for use by GreenOnline. The dialogue will continue to be a useful forum for identification of new applications for plastics derived from EOL electronics.

Region III Pilot: e-Cycling

EIA recently solicited proposals from regional governments, states, and non-governmental entities to partner with EIA in a program to recycle end-of-life electronic products from households. The program is intended to gather data from various collection models, analyze the data, and assess the data to identify environmentally beneficial, cost-efficient, voluntary systems for the management of residential end-of-life electronics.

In response to EIA's solicitation, EIA received over twenty proposals from federal, state, local governments, and interest groups across the country. EIA selected three proposals for funding. One of the selected recipients is EPA Region III. The intent of this grant program, which is called "e-Cycling in Region III", is to provide funding to help implement electronics recycling programs and develop data to model the economics of various electronics recycling models.

PAZ has been asked by EIA and Region III to administer the program. Although data collection is the primary goal for this effort by EIA and EPA, administration of e-Cycling or PAZ/MARCEE could provide the opportunity to explore a leading role for PAZ that could be scaled nationally via an Industry Coalition. PAZ e-Cycling administration also could provide the opportunity to promote GreenOnline as the default online commerce engine for the electronics recycling industry.

EIA

EIA is a national trade organization that includes the full spectrum of U.S. manufacturers, representing more than 80% of the $550-billion electronics industry. The Alliance is a partnership of electronic and high-tech associations and companies whose mission is promoting the market development and competitiveness of the U.S. high-tech industry through domestic and international policy efforts. EIA, headquartered in Arlington, Virginia, is comprised of more than 2,300 member companies whose products and services range from the smallest electronic components to the most complex systems used by defense, space, and industry, including the full range of consumer electronic products. The industry provides more than two million jobs for American workers.

EIA is involved in virtually all electronics recycling initiatives described in this business plan. As a trade association, however, it is more commonly associated with advocacy of industry positions externally, less on development of intra-industry support systems.

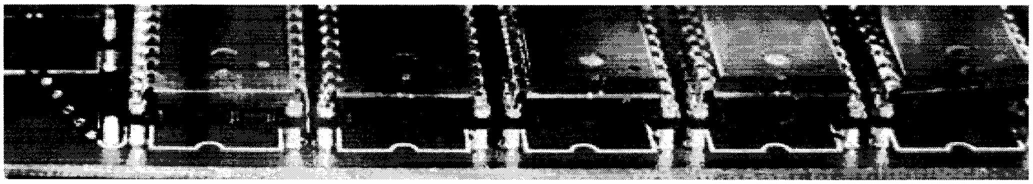
APC

APC is a major trade association for the U.S. plastics industry working to ensure that plastics are recognized as a preferred material by actively demonstrating they are a responsible choice in a more environmentally conscious world. APC demonstrates the benefits of plastic products and the contributions of the plastics industry to the society it serves. APC demonstrates that plastics are an efficient use of natural resources and that plastics and the industry are part of the solution to the public's environmental performance expectations. APC members are among the nation's largest manufacturers of plastics. APC also includes seven business units and an affiliated trade association, each comprised of APC members and customers whose purpose is to address technical and public policy issues specific to their products.

During the 1990s, APC led an effort to establish some type of Industry Coalition of OEMs in anticipation of government product take-back requirements. APC efforts of interest to PAZ now focus on R&D for new plastics separation technologies and applications from the electronics and other industries (e.g., automotive). APC also will be a key player in providing support for development of the Industry Coalition.

IAER

IAER is a trade association organized in 1998 to represent firms that recycle electronics. IAER has taken the lead on development of an electronics recycler certification program. PAZ's development of an effective Industry Coalition will certainly need to involve IAER in planning and implementation.



APPENDIX B

SIMULATION TOOL ASSUMPTIONS

The following list of data includes many estimates that were "normalized" following review of sometimes widely varying data values. Data were collected from numerous industry and government sources, including previously published studies, site visits, conference materials, and interviews of numerous industry principals.

Capital Equipment:		Price	Capacity
1.	Shredders source: Amer Pulv.	$150,000	2700 lbs/hr
2.	Balers others sources	65,000	3500 lbs/hr
3.	Conveyors other sources	5,000 unit	–
4.	Separators, magnetic	15,000	2700 lbs/hr
	" eddy current	75,000	2700 lbs/hr
	" flake	–	–
	" hydrocyclones	–	–
	other separators		
5.	Glass saw, Envirocycle other sources	5000	–
6.	Forklift trucks	20,000	–
7.	Ring mill	72,000	–
8.	Glass crusher	10,000	–
9.	Monitor test equipment	10,000	–
10.	Electronic test instrumentation to test and characterize CPU, hard drive, CD drive and SCCI	50,000	–
11.	Polymer Pelletizer	50,000	
12.	Air Filtration Equip.	100,000	
"For Sale" Prices for Material Output from Recycling Facilities			
13.	Metal aluminum	$0.12/lb	
14.	Copper	0.06	
15.	Steel	0.02	
16.	Zinc (and brass)	0.08	
17.	Other		
18.	Plastic HIPS	$0.04	
19.	ABS	0.04	
20.	PC	0.04	
21.	PC ABS	0.04	
22.	HIPS FR	0.04	

"For Sale" Prices for Material Output from Recycling Facilities (continued)		
23.	ABS FR	0.04
24.	Other	
25.		
26.	Glass, recycled	$0.04/lb
Refurbishment Prices		
27.	Monitor	$8 each
28.	CPU	7
29.	Hard drive	5
30.	CD drive	5
31.	SCCI	5
32.	Other	
33.	Plant new, for recycling	$45/sq ft
34.	Other real estate	
35.		
Material Breakdown of a Recycled Computer (100%)		
36.	Monitor glass, total	23.5%
37.	Monitor glass, salable	21.0%
38.	Monitor glass, waste	2.5%
Refurbish		
39.	Monitor	10%
40.	CPU	1.5%
41.	Hard drive	0.33%
42.	CD drive	0.33%
43.	SCCI	0.33%
Total refurbish		**12.5%**
Metal for Sale		
44.	Aluminum	6%
45.	Steel	24%
46.	Zinc and brass	2%
47.	Copper	9%
48.	Other metal	0%
Total metal		**41%**

Plastic for Sale	
49. HIPS	5.3%
50. ABS	5.1%
51. PC	4.7%
52. PC ABS	2.9%
53. HIPS FR	0%
54. ABS FR	0%
Total plastics	**18%**
Waste Products for Landfill	
55. EOLE (metal, etc.)	1.5%
56. Plastic waste	3.4%
57. Hazardous waste	0.1%
Total waste	**5%**
Total percentage	**100%**
58. Incoming Material Forecast	8 tons/wk to 1,300 tons/wk from week 1 to 156
59. Burden rate	30% of salary
60. Interest rate	8%
61. General recycle subsidy	$8/computer system

SIMULATION OPERATIONS

Sources for the simulation model and this Business Plan include technical papers, plant visits, and conversations with knowledgeable people in the industry. The following outline of operations is provided to allow a review of the operational assumptions that underlie the simulation and this plan.

1. EOLE materials are gathered through a variety of means and locations: retail stores, garbage collection, OEM activities, municipal turn-in drives, etc. Significant labor and shipping costs are involved.

2. The demanufacturing and refurbishment (D&R) function should occur as close to the collection points as possible to reduce shipping costs.

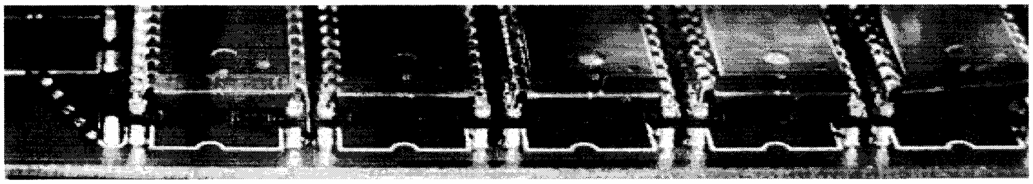
3. The D&R function includes:
   a. Collect materials and ship to a local D&R facility.
   b. Evaluate and separate potentially reusable materials from obviously scrap material.
   c. In some cases, disassemble reusable materials to recover components for resale.
   d. Send reusable materials for resale.
   e. Compact scrap material and send to either a glass or metal recycling facility.

4. The glass function includes:
   a. Evaluate incoming material and separate reusable from scrap monitors.
   b. Send reusable monitors for resale.
   c. Separate scrap monitors from metal and plastic components.
   d. Separate (saw) the unleaded (panel) glass from the leaded (funnel) glass in the monitor.
   e. Crush glass (unleaded and leaded separately) and sell to primary glass company.
   f. Send metal and plastic components to a metal recycling facility.

5. The metal function includes:
   a. In some cases, separate metal from plastic components by hand or other techniques.
   b. In other cases, shred all incoming material and do separation after shredding.
   c. Separate materials through a variety of techniques: magnetic, flake, eddy current, hydrocyclone, and others.
   d. Separate ferrous from nonferrous metals magnetically.
   e. Send other metals to a furnace for melting and separation.
   f. Sell separated metals to appropriate smelters.
   g. Send plastics (separated and mixed) to a plastics recycling facility.
   h. Send waste products to landfill or hazardous material facility.

6. The plastics function includes:
   a. If incoming material has been separated by polymer type, maintain separation.
   b. Shred materials.
   c. Separate materials through a variety of techniques: magnetic, flake, eddy current, hydrocyclone and other.
   d. Sell separated polymers to appropriate customers.
   e. Sell mixed polymers to appropriate customers.
   f. Send waste products to landfill or hazardous materials facility.

This is the list of operations that to some degree we have incorporated into the simulation. For a specific facility in the recycling industry there are probably missing, unnecessary, or improperly described operations. However, the simulation is intended as a general representation to assist in planning, analysis, and decision support, and is not specific to any function or locale.



APPENDIX C

EOLE RECYCLING SYSTEMS FROM AROUND THE WORLD

The following descriptions of different recycling systems were derived from presentations and working papers of participants in numerous EOLE meetings, symposia, and initiatives over the past 12 months. The list is not intended to be comprehensive, but provides a snapshot of the major attributes of recycling systems as potential models for a U.S. EOLE recycling system.

Switzerland
SWICO program has an Advanced Recovery Fee (ARF) covering recycling costs with office technology, consumer electronics, software, graphical industry waste and phones. SWICO is described in detail in Appendix D.

Norway
EOLE financed by a visible ARF for a broad range of electronics, except for batteries and refrigerators with chlorofluorocarbons (CFC). Fee covers orphan products (where the OEM no longer exists) and historic products (where OEMs still operate). Recycling is defined by legislation, and the government enforces against free riders.

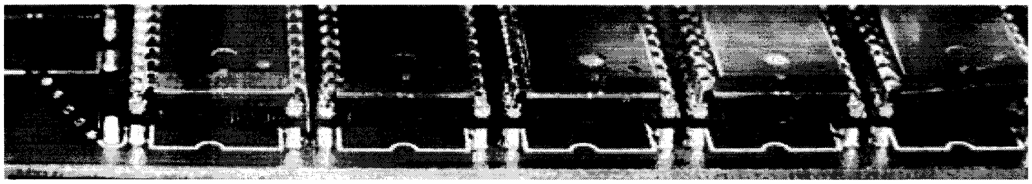
Holland
There are two distinct Dutch systems: an ARF for TVs, appliances, and stereos and a licensing fee for PCs, printers, fax machines, copiers, and telephones. In the licensing system, the OEMs pay to an organizations set up to administer this program a sum based on their shares of discarded products collected for processing. Both these programs are implemented with national legislation.

Sweden
Sweden also operates under a licensing fee system that covers recycling costs for most electronics—excepting refrigerators and freezers. Local governments collect the EOLE, but their costs are covered by producers and retailers. The system also is implemented with national legislation.

Japan
This program is known as the "Specified Home Appliance Recycling Law", and covers TVs, air conditioners, and washing machines. Consumers are charged recycling fees at EOL, except for recycling programs established by OEMs to recycle their own products.

Taiwan
In Taiwan, the government passed legislation in 1998 to establish a licensing fee to cover recycling costs. Fees are paid directly to the government, which manages the system and contracts with recycling firms. Recycled products include computers, air conditioners, and household appliances. Fees cover recycling of orphan and historic products.

Australia
This program recycles cell phones through an ARF. OEMs pay the fees, retailers collect the EOL phones, and a third-party organization manages the recycling. Orphans and historic products are covered. There is no legislation implementing this program that was formed by a memorandum of understanding (MOU) among OEMs and the third-party organization.



APPENDIX D

SWICO RECYCLING GUARANTEE PROGRAM: A CRITIQUE

This critique is based upon information obtained during visits to SWICO headquarters and follow-up telephone discussions with SWICO officials. The information is intended to be factual and is based on notes taken and recollections from those interactions. The information provided herein is intended for Financing Subgroup discussions only, not to be published or transmitted, as additional information will be obtained as appropriate.

Background

The Financing Subgroup agreed to concentrate on three models: the Advanced Recycling, Product Licensing, and End-of-Life Fees. All three models were placed in a matrix-type chart (attached) to be completed for various identified programs for each of the models. The SWICO Recycling Guarantee Program is representative of an ARF model. Buddy Graham and J. Ray Kirby agreed to review and examine in fairly good detail the pertinent aspects of the SWICO program. Emphasis was to be given to how a program addresses the "metrics" listed in the matrix chart, in particular the financial aspects of the program. Other subgroups are investigating collection and recycling issues and regulatory issues.

The following notes should be relevant to formulating what was requested:

1. General description of the SWICO objectives and key elements
2. Listing of perceived "positives" and negatives" of SWICO
3. Completed matrix chart for the SWICO program.

I. GENERAL SWICO PROGRAM DESCRIPTION

SWICO, a nonprofit company organized by industry, has over 400 member companies that focus on the collection and recycling of waste from office technology, consumer electronics, software and the graphical industry, development of standard recycler contracts, supporting orbit fairs, and educational activities. In 1993, the SWICO membership decided that it was not efficient for each company or manufacturer to set up separate collection operations and manage recyclers in satisfying the most important environmental issue of product take-back (PTB) in Switzerland.

Recycling Guarantee Program

A SWICO information technology (IT) subgroup, consisting now of more than 130 member companies*, was organized to address this issue and formed the "Recycling Guarantee" program. The purpose of this program was not to make money, but to ensure that economic and environmentally sound collection and processing were provided. This initiative grew from a collective effort by a small group of founding companies and today is exemplary in its low administrative cost for handling the day-to-day business operations. All major decisions, such as customer prices, certification of recyclers, and new contracts are made by the 130-plus members. A change in the charter of the Recycling Guarantee program requires acceptance from the entire 400-member SWICO organization.

*Signatory list published and includes, e.g., Acer, Canon, Compaq, Dell, Ericsson, HP, Hitachi, IBM, Kodak, Lexmark, 3M, Motorola, Nokia, Panasonic, Phillips, Sharp, Siemens, Sony, Unisys, Xerox.

Program Guarantees

There are four guarantee elements to the Recycling Guarantee program: (1) the ecological responsibility, (2) national acceptance of the concept, return system for manufacturers, importers, and dealers, (3) the control of recycling and disposal, and (4) secured financing through a prepayment for disposal at the time of purchase by the customer. This prepayment fee is prorated based upon the original sale price of the equipment. Using this approach, the prepayment disposal fee would be approximately $7 USD for an average PC system consisting of a CPU and a monitor. The fees collected from current equipment sales are used to pay for historical waste. Over 8 years, SWICO has been able to reduce customer prepayment fees twice, due to competition created among the SWICO-certified recyclers and increased recycling efficiencies.

Collections/Responsibilities
All dealers are required to accept customer returns, and EOL equipment can be collected by the local municipality or original manufacturers. With this approach, the manufacturers, importer, or dealers, accept the ownership of the technical issues and processing through the SWICO nonprofit organization while the customer pays the PTB expenses through the collection of ARFs at the time of purchase.

Program Cost
The SWICO organization works to lower customer fees and ensures economic and environmentally friendly processing for the manufacturers. SWICO identifies, recommends, and licenses transporters and recyclers, establishes and manages contracts, performs periodic audits of recycling operations, and investigates and controls the final disposition of recycler output streams. Typically, SWICO maintains over fourteen certified recyclers to process all returned waste streams, focuses on reducing cost, and encourages recyclers to develop and implement new recycling technologies.

Reuse of Parts
Only producers and dealers are allowed to remove and reuse parts from EOL machines. Recyclers are not permitted to reuse parts unless granted permission by the manufacturer. This practice helps to control the flow of parts and false warranties, reduces recycler cost (no labor cost to demanufacture), and allows recyclers to focus on improving recycling technologies and efficiencies. This approach, combined with the dedicated volumes as a SWICO-certified recycler, allows recyclers the opportunity to invest in the best recycling technologies and stay competitive.

Typical Recycler Practices
Typically, SWICO-certified recyclers remove hazardous materials such as freon (refrigerators) and batteries (computers) prior to total shredding and materials recovery. They use several materials-separating techniques (e.g.,magnetics, eddy current, screens, weight differences) to process the shredded fluff and finally produce clean streams, such as aluminum, copper, and ferrous metals and separate mixed streams of glass and plastics. Their production lines are typically automated using only a few workers to remove the hazardous materials and maintain the mechanical equipment. As of early 2000, recyclers did not have a recycling solution for plastics, but were actively pursuing alternatives to incineration. Recycling alternatives for glass from monitors and TVs were close to implementation.

Summary
The SWICO Recycling Guarantee program is based upon the belief that an owner, producer, or others would want to pay for collection and processing expenses at the EOLE. With the ARF approach to financing, fees are published and consistent for all products and customers. They are visible to the customer, are easy for the dealer to implement, and financing of PTB is secured. Also, the SWICO program controls the recycling and disposal operations to ensure the EOL IT equipment is processed and disposed of in an environmentally friendly manner. The SWICO representatives believe it is important that the IT industry define the solution before any legislation is mandated. This makes it more efficient and favorable for both the consumer and the manufacturer. After the SWICO Recycling Guarantee program was established and operating, the Swiss government adopted it and mandated that consumers return EOL equipment through this system. The SWICO program also was required to recycle both physical equipment and packaging materials.

II. "POSITIVES AND NEGATIVES" OF SWICO PROGRAM

The following "positives" and "negatives" of the SWICO Recycling Guarantee Program perceived by Buddy Graham and J. Ray Kirby are presented for consideration and follow-on discussions. Additional investigations are needed to fully understand the benefits and weaknesses of this type of program and how this program (or specific elements of this program) could be implemented in the United States.

Perceived Positives

1. Secured financing for the PTB and recycling of EOL IT equipment
2. Simplicity of ARF assessment and charge
3. Competitive biding of recycler and transport contracts to lower cost
4. High participation rate (e.g.,producers, customers)
5. Combined volumes builds basis for efficiencies and investments in best recycling processes and technologies
6. Eliminates duplicated efforts and cost of individual producers' programs
7. Ensures economic and environmentally sound management
8. Reassesses fees periodically based on actual EOL cost
9. Financial responsibility for product recycling on first owner when product has value
10. Controlled recycling; only dealers and manufacturers can remove and reuse parts eliminating risk of false warranty claims.

Perceived Negatives

1. ARF not based on specific EOL cost, e.g., expensive equipment subsidizes the recycling of inexpensive equipment.
2. Plastics from EOL machines are currently used as "waste to energy."
3. No apparent DFE component for manufacturers other than the removal of parts.
4. Collected fees are accrued by manufacturers in a special account.
5. Surplus funds in some accounts could be perceived as a negative.
6. Will sufficient fees (for all companies) always be adequate?

Other Comments

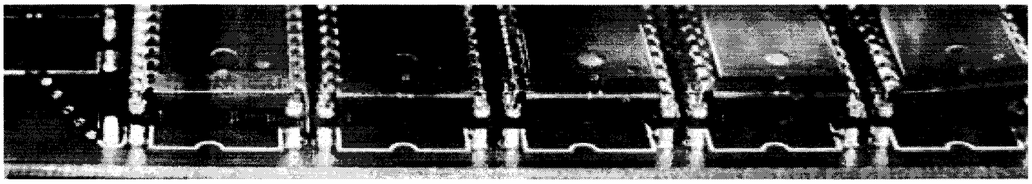
1. DFE could be a separate proactive supplemental program such as the EPA's Energy Star.
2. Any U.S. implementation of this model may require a different product scope (e.g., SWICO includes consumer, commercial, and government customers, and products range from handheld products to servers and mainframes) and alternate fee schedule.
3. Need to learn more about relative EOL costs of various product types.
4. Program guarantees—four elements
   a. Ecological responsibility—system in place to ensure proper disposition of EOL equipment.
   b. National program—industry, owners, and recyclers participate.
   c. Management of certified vendors—SWICO selects, contracts, and audits vendors.
   d. Secured financing—prepayment for disposal at the time of purchase by the customer.
5. Some U.S. manufacturers are likely to say that they are already servicing and should service commercial customers and their volumes, and that they should not be included in any implementation of this model.

III. ARF MATRIX CHART FOR SWICO PROGRAM CHARACTERISTICS

Characteristics	Description		
Who Pays?	Customer		
Where They Pay?	Point of purchase		
What Fee Covers?	Collection, transportation, recycling, contracts, and administration		
Legislation Needed?	Implemented without legislation, but government later adopted/mandated program		
Who Manages $?	Collected by dealers, accrued in special manufacturer accounts, and used to pay SWICO invoices for recycling expenses		
How is Fee Set?	Prorated based upon product sale price and product category (e.g.,office and graphic industry equipment and IT)		
Who Sets Fee?	SWICO IT subgroup		
Fee Visible, Invisible?	Visible fee to customer and published		
Orphan, Historic?	Orphan and historical product recycling paid by ARFs collected from new product sales		
Enforcement? Free Riders?	Consumers required by law to return EOL equipment through SWICO program Product with sale prices below 250 Swiss Francs have no ARF.		
Incentives for Return?	Customer already paid and return required by law		
Seal or label for participating products?	Available		
Uniform Fee (national)?	National program and fee schedule		
Incentives for DFE?	Improve manufacturer's ease of recovering and reusing parts		
Costs or fee levels?	Note: February 2001 fee schedule (SWICO brochure)		
	List Price *	Office Equip*	IT Equip*
	0–250	0	0
	251–1,000	5	5
	1,001–3,000	20	7
	3,001–6,000	50	10
	6,001–15,000	100	20
	15,001–30,000	200	50
	30,001–60,000	350	100
	60,001–150,000	500	250
	150,001–600,000	1,000	500
	More than 600,001	1,500	1,000

* In Swiss Francs

Note: 1.00 SF (CHF) = .6053 U.S.Dollars (USD)



APPENDIX E

PRELIMINARY LIST OF STAKEHOLDERS FOR INDUSTRY COALITION DEVELOPMENT

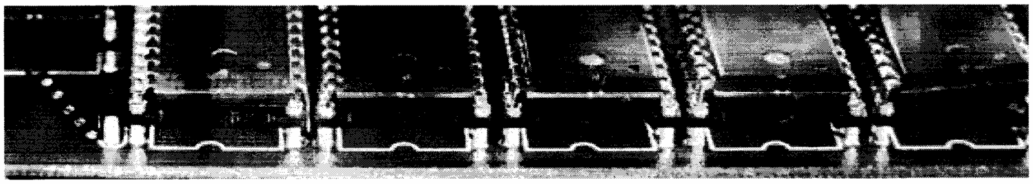
The following companies and organizations identified by SAIC are candidates for core membership in the development of an Industry Coalition. PAZ wishes to express special thanks to companies and organizations on this list that shared data and insights with PAZ in bringing the regional model and Business Plan together.

I. PC Manufacturers
- Dell
- IBM Corporation
- Hewlett Packard
- Sony
- Panasonic

II. Recycling Service Providers
- Micrometallics—control station and shredding
- Butler McDonald—materials separation
- METECH—metal separation
- Dlubac—glass recycling
- Envirocycle—glass recycling
- MBA Polymers—plastic separation and recovery
- SDR—compounding and extrusion of plastic resins
- RC Plastics—compounding and extrusion of recycled plastics

III. Material Suppliers
- GE Plastics—PPO, PC, and PC/ABS
- Bayer—PC/ABS
- Dupont—PC
- Polymer One—PVC
- Dow—PS
- Techneglass, Inc.—glass
- Corning—glass
- NKK—recycled metals

IV. Industry Trade Associations
- EIA—OEMs
- APC and APME—resin suppliers
- ASM—metals
- Glass Association of North America—glass
- IAER—recyclers



GLOSSARY

DEFINITIONS OF SELECTED TERMS USED IN THIS PLAN ARE PROVIDED BELOW.

Demanufacturing and Refurbishment (D&R)

The initial EOLE processing step in EOLE recycling. D&R is an amalgamation of three activities: the initial evaluation, followed by demanufacturing and/or refurbishment/resale. EOLE is gathered, most disassembled, individual items evaluated (monitors, central processing units (CPU), hard drives, CD drives, and SCCI drives), the "good" items set aside for minor repair and resale, and the balance sent on for material processing and recovery. Some demanufacturers use an automated grinding process as an alternative to manual disassembly, forwarding virtually all the ground up material for additional processing, recovery, or disposal.

EOLE (End-of-Life Electronics)

For the purposes of this plan, EOLE is limited to computers.

Free Riders

Product producers that do not participate financially in an advance recovery program for used electronics and whose products are managed by that recovery program.

Front-End Fee

A fee that is imposed at the point of purchase (e.g., advanced recovery fee) or when a product is placed on the market (e.g., product licensing fee). It may be imposed on consumers or on producers.

Historic Waste

Term refers to electronic products that were sold prior to the establishment of an advance recovery fee.

Industry Coalition

A select group of Original Equipment Manufacturers (OEM), resin producers, and electronics recyclers who will be working together to develop and support an economically viable and environmentally attractive end-of-life recycling program in PAZ and in other regions around the country.

MARCEE

Mid-Atlantic Recycling Center for End-of-life Electronics

MARCEE Regional Model (the Regional Model)

A road map for near-, medium-, and long-term development of electronics recycling, remanufacturing, and support industries in the PAZ region. This regional model was developed to attract and facilitate expansion of private sector end-of-life computers recycling and processing facilities, remanufacturers, and related industry services.

Orphan Waste

Electronic products that can no longer be linked to an existing manufacturer (i.e., the company that manufactured the product is no longer in existence).

PAZ

The Polymer Alliance Zone of West Virginia.

PAZ Simulation Tool

The simulation model developed by PAZ as a dynamic analytical tool to support development of a recommended regional model by comparing different development scenarios and comparing resulting gross margins for all major EOLE recycling activities.

The Regional Model

See MARCEE Regional Model.

Third Party Organization

A private organization that is developed either through statutory mandate or voluntarily by interested parties such as manufacturers, retailers, or independent groups to implement and manage funds. Such programs are normally funded by the participants who may recoup their costs.

Appendix H: Task 2.2

Table 83 – Properties of Plastics obtained by shredding End-of-life Computes

Sample	Density	Source and Description	Polymer	% Ash
1	1.0582	PCS - Grey (CPU)	SAN (20% A)	0.8825
2	1.0583	PCS - Creamish (CPU)		0.8726
3	1.0857	PCS - Black (CPU)		0.8913
4	1.0577	Dell QuietKey Keys (Keyboard)		0.7355
5	1.0561	Gateway Anykey Keyboard (Keyboard)		0.9329
6	1.1299	CCS 386 - Grey (CPU)		2.2387
7	1.0456	GIC 486 - Yellow (CPU)		0.1809
8	1.0515	PC Importers - Yellow (CPU)		0.0836
9	1.0755	PC Importers - Front Panel (CPU)		3.5237
10	1.0795	HP DJ 870C - Blue (Printer)		2.2298
11	1.1095	HP DJ 680C - Blue (Printer)		5.0127
12	1.0588	Apple Design - Keys (Keyboard)		0.8219
13	1.0653	Micron Keytronic - Keys (Keyboard)		2.4339
14	1.0543	Microsoft Monoblock - Keys (Keyboard)		1.7503
15	1.0608	Mitsumi - Keys (Keyboard)		1.6011
16	1.0499	PC Concepts - Keys (Keyboard)		0.9451
17	1.0345	Dell QuietKey Keyboard (Keyboard)	Polystyrene	0.4900
18	1.0345	Gateway Anykey Keyboard (Keyboard)		0.6792
19	1.0344	CCS 386 - Green (CPU)		0.5679
20	1.0405	GIC 486 - Muddy White (CPU)		0.4133
21	1.1173	HP DJ 870C - Grey (Printer)		1.8076
22	1.0425	HP DJ 680C - Creamish (Printer)		2.0870
23	1.0579	Apple Design - Keyboard (Keyboard)		3.3165
24	1.0418	Fujitsu Ltd - Keyboard (Keyboard)		0.9566
25	1.0336	Fujitsu Ltd - Black (Keyboard)		0.5768
26	1.0461	Micron Keytronic - Keyboard (Keyboard)		1.4550
27	1.0386	Micron Keytronic - Keybase (Keyboard)		0.0446
28	1.0438	Microsoft Monoblock - Keyboard (Keyboard)		0.8075
29	1.0517	Mitsumi - Keyboard (Keyboard)		1.6736
30	1.3607	IBM (2235) Keyboard (Keyboard)	Vinyl – acetate/ chloride/alcohol	4.3090
31	1.5312	Gateway 2K - Black (CPU)	PBT	23.7269
32	1.3231	IBM (2235) Keys (Keyboard)		1.0960

33	1.3025	Fujitsu Ltd. - Keys (Keyboard)		2.0583
34	1.3292	Gateway 2K - Greenish White (CPU)	PPO	31.2259
35	1.1624	Gateway 2K - CD - Floppy (CPU)	Styrene - Butadiene (85% Styrene)	2.1030
36	1.1734	Gateway 2K - White (CPU)	↓	1.9740
37	1.1843	PCS - Floppy (CPU)	↓	2.2460
38	1.0384	PC Concepts - Keyboard (Keyboard)	↓	0.9356
39	1.3925	HP DJ 870C - Dark Grey (Printer)	Polycarbonate	25.5822
40	1.3156	HP DJ 870C - Black (Printer)	↓	14.4103
41	1.3839	HP DJ 680C - Rough Grey (Printer)	↓	25.2895
42	1.2458	HP DJ 680C - Black (Printer)	↓	5.4185
43	1.2607	HP DJ 680C - Smooth Grey (Printer)	↓	4.0992
44	1.4209	Apple Design - Key Supports (Keyboard)	Polyacetal	-
45	1.4142	Fujitsu Ltd - Key Supports (Keyboard)		-

Separation of Dissimilar Plastics from End-Of-Life Electronics

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A.1 Introduction

A major obstacle in the recycling of valuable engineering thermoplastics found in end-of-life (EOL) electronic equipment is the separation of the dissimilar plastics. Several approaches to accomplish these separations exist, and they all have their own drawbacks: manual pre-sorting is extremely labor-intensive, automated pre-sorting has is not completely reliable and becomes problematic if plastics are not completely separated, and post-shredding techniques also have technical complications. However, post-shredding techniques involve minimal dismantling and pre-sorting before materials are fed through a granulator and therefore reduce labor costs, which is the primary operating cost for recycling/refurbishing centers. The subsequent task of separating granulated plastics is particularly difficult due to the lack of variation between their physical properties, most importantly their densities. The various polymers, some of which are blended together, have very similar density ranges. These ranges overlap, making density based separations ineffective for creating pure component streams. Alternative methods of purification, such as froth flotation and electrostatic separation, take advantage of differences in surface chemistry. These techniques have been found to be highly efficient in separating specific polymers. However, they are very sensitive to surface contamination, and they almost always require a simple binary or at most a tertiary combination of polymers. Considering current technologies, the best available technological process would be to use density separation techniques to isolate streams that consist of primarily two or three polymers, and then use either froth floatation or triboelectric separation to produce pure products.

A.2 Discussion

A.2.1 Density Separations

Although separation by means of differences in densities is rarely able to produce pure products, the principle can be used to concentrate streams or reduce the total number of polymer components to be dealt with. This step is critical if a clean split from either of the surface chemistry techniques is to be achieved. The science behind the separation requires a carrier fluid (generally a salt solution) with a density between the two streams that are to be split, and either a gravitational or centrifugal force to disperse and separate the plastics through the medium according to their respective buoyancies.

A.2.1.1 Float-Sink Tanks

Float-sink tanks are merely tanks that hold the granulated plastics in a particular medium for a residence-time long enough to allow buoyant forces to fully disperse the granules. The slurry entering the tank should be well mixed, and baffles or mixers may be necessary upon initial entry into the tank to discourage agglomeration of the individual granules. The basic process of gravity separation is illustrated in Figure 1 below.

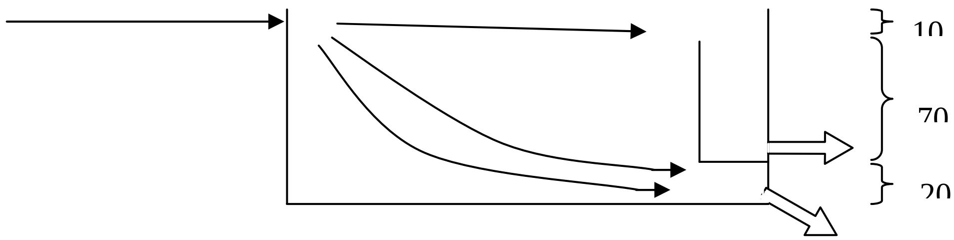


Figure 1: Schematic diagram of a Float-Sink Tank

Towards the end of the tank stands a vertical baffle that pushes any midline granules to either the overflow or the underflow.

A spreadsheet model was developed to size these tanks based on plastic properties and flow rates. The percentages shown in Figure 1 represent the relative lengths used in the spreadsheet to size the tanks. Given a flow rate of plastics and the length of the baffle, various tank dimensions are calculated according to the respective slurry concentration. The average horizontal velocity is found by dividing the cross-sectional area of fluid flow (assumed square) into the volumetric flow rate. The length of the tank can then be determined by equating the time required for the settling of the granules to the horizontal length traveled. The following correlations for the terminal velocity of non-spherical particles were used [O. Levenspiel, *Engineering Flow and Heat Exchange*, p. 157],

$$d_p^* = d_{sph}\left[\frac{g\rho_g\left(\left|\rho_s - \rho_g\right|\right)}{\mu^2}\right]^{1/3} \tag{1}$$

$$u_t = \left[\frac{18}{\left(d_p^*\right)^2} + \frac{2.335 - 1.745\phi}{\left(d_p^*\right)^{1/2}}\right]^{-1} * \left[\frac{\rho_g^2}{g\mu\left(\left|\rho_s - \rho_g\right|\right)}\right]^{1/3} \tag{2}$$

Where d_p^* is a dimensionless particle size defined in Eqn. (1), d_{sph} is the effective diameter of the particles, g is gravitational force, ρ_s is the density of solid particles, ρ_g is the density of the fluid, μ is the viscosity of the fluid, and ϕ is the sphericity factor.

The fact that the stream comprises a slurry, as opposed to individual particles, creates the possibility of hindered settling. As the slurry becomes more concentrated, the interaction between particles has the effect of increasing both the apparent suspension viscosity and density, thus slowing the terminal velocity of the settling particles. The following relation for spherical particles [R.H. Perry and D.W. Green, *Perry's Chemical Engineers'*

Handbook, Software Version, section 6-52] was used to estimate the influence of this phenomenon:

$$u_{ts} = u_t (1 - c)^n \qquad (3)$$

Where u_{st} is the terminal velocity in the suspension, u_t is the terminal velocity of a single particle (found by solving Eqns. (1) and (2)), c is the volume fraction of the solid in suspension, and n is a function of the Reynolds number.

This basic approach requires little expertise to operate, but there are some disadvantages. The tanks often require a significant footprint and generally have low throughputs. Material wetting problems may also affect their performance. An alternative density separation technology is discussed next.

A.2.1.2 Hydrocyclones

Hydrocyclones use fluid flow to create a rotating motion that develops into a vortex. Inside the vessel there are two opposing forces that act upon the particles suspended in the fluid; one is a centrifugal force in a outward radial direction, and the other is in a inward radial direction due to the drag force of the inward moving fluid.

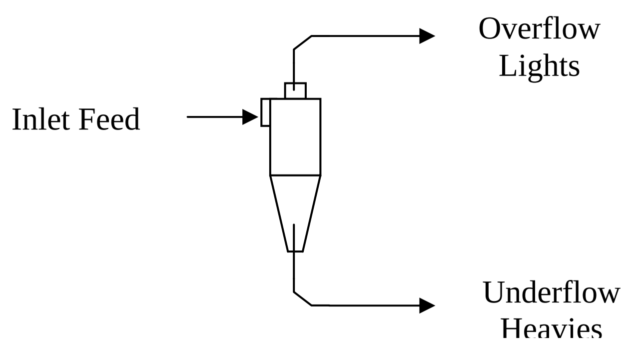


Figure 2: Schematic diagram of a Hydrocyclone

As seen in Figure 2, the well-mixed slurry is fed tangentially into the top of the cyclone. The heavier particles are forced outward and swirl down the inner walls of the vessel and out with the underflow. The lighter particles are displaced by the fluid, swept into the center vortex, and carried up and out in the overflow.

The advantages of using hydrocyclones over float-sink tanks are clear; they require a much smaller footprint, they have much higher throughputs, they are relatively inexpensive, and they suffer from fewer wetting problems. Hydrocyclones are also advantageous when multiple stages must be set up in series to accomplish a sharp separation.

AXSIA MOZLEY is a company that manufacturers hydrocyclones for the purpose of separating plastics. This company was contacted regarding general information on applications of hydrocyclones. Their larger models, both the 125 mm diameter and predominantly the 250 mm diameter, have been used to separate granulated plastics with a size up to 10 to 15 mm. The price of their 250 mm diameter hydrocyclone is between $2500 and $3500. This particular model can handle flow rates between 20 and 90 m^3. Generally, operating pressure is usually approximately one bar and solids concentration is roughly 5% plastics by weight or less.

A.2.2 Surface Chemistry based Separation Techniques

A.2.2.1 Froth Flotation

Tanks with specially formulated solutions of controlled density, pH, and surface tension can be used to adjust the hydrohpobicity or hydrophilicity of plastic particles. An air stream is passed through the vessel and one of the materials becomes engulfed in the bubbly froth and floats to the surface while the other sinks to the bottom. This technology was originally developed in the minerals processing industries and has recently been adapted to some of the separations involved in plastics recycling. Argonne National Laboratories (US Patent No. 5,653,867) have effectively applied this technique to float granulated HIPS from ABS. With a controlled solution pH, surface tension, and density, their process can separate ABS from HIPS at a purity of 98% with a recovery of over 88%. The technique has also been shown to be effective in separating PET and PVC.

A.2.2.2 Electrostatic Separation

Triboelectric methods have also been used to separate dissimilar plastics. These separators create surface charges on the materials by friction; this results in surface charge differences between different materials. The sign of the charge imparted to a given particle is based on the surface properties of the particles, and hence is function of the composition of the solids. The charged particles can then be passed through an electric field where they are separated. The process is operated dry, but is affected significantly by surface contaminants. An article by Xiao et al. (American Plastics Council Report, 1999) claims efficient separations of various plastics using triboelectric techniques, most notably 98% pure ABS from HIPS with yields over 80%. Such separators are provided by companies such as Carpco and their V-Stat separator and by Hamos, whose EKS separator has recently been put into use by Butler-MacDonald for purposes of dry plastic-plastic separations.

A.2.3 Liquid Holdup and Solids Washing

Another important consideration relates to the carrier fluids used in either float-sink tanks or in hydrocyclones. By draining the slurry over shaker screens, as it leaves the vessel, the solution can be easily recycled. This is important since loss of these different density liquids can be a significant operating expense. The fluid that remains on the plastic granules is referred to here as the liquid holdup. The amount retained is dependant upon the balance of surface tension forces holding the fluid and gravitational forces displacing the fluid. This fluid is lost and would have to be replaced. An estimation of the amount of fluid lost (h_s) can be made from correlations derived for various types of packing used in packed beds [R.H. Perry and D.W. Green, *Perry's Chemical Engineers' Handbook*, Software Version, section 14-47].

$$h_s = 2.79 \frac{C_1 \mu^{C2} \sigma^{C3}}{\rho_l^{0.37}} \quad (4)$$

Where u_l = liquid viscosity, mPa, σ = surface tension, mN/m, ρ_l = liquid density, kg/m^3, and C_1, C_2, and C_3 are specific to packing type

Methods developed by Dombrowski and Brownell relate static holdup with a dimensionless capillary number and give more data for various types of packing [Industrial and Engineering Chemistry, volume 46, page 1207, 1954].

A.3 Experimental

Three out-of-date computers have been gathered and dismantled (cpu's only). From the dismantled components, all of the predominately plastic pieces were cut into sections approximately 2.5 in by 2.5 in, and all of the metal parts were discarded. These plastic sections were separated according to computer and then further separated into those that came from circuit boards and wiring and those pieces from the chassis and front panel. A Dell dimension XPS P90c yielded roughly 7.75 pounds of plastics, much more than the other two. The reason for this is because the chassis was made mostly of plastic where the others were metal. The Gateway 2000 4dX-33 yielded about 3.75 pounds of plastics. It had about the same amount of plastics coming from circuit boards and wiring as the Dell did; the big difference between the two is in the amount of plastic used in the casing. The last computer dismantled was an older generic 486. More of its pieces were metal when compared to the other two, but the archaic circuit boards were noticeably larger and produced 4.25 pounds of plastic, about the same as the Gateway 2000. Photographs of the three computers (taken before being dismantled) can be seen in Figure 3.

The precut plastic sections were shipped to Gilson Company, Inc. to be processed in their LC-136 cutting mill with the LCA-458 tungsten carbide cutting set and the LCA-489 10 mm sieve insert. Further analysis of the sample can then be conducted once the sample has been processed and returned. The Gilson Co., using a small cutting mill without a tungsten carbide blade, carried out some preliminary work. Photographs of some of the shredded plastic materials collected on different screens are shown in Figure 4.

A.4 Conclusions and Future Work

The research into separation techniques for commingled plastics shows that current practice consists of a shredding step, followed by some form of density separation to obtain crude density cuts. Relatively pure plastics streams may then be obtained from some of these density cuts via froth floatation or triboelectric separation. Work will continue to be done to characterize and quantify the amount of plastics in different generations of EOL computers. When samples are obtained from Gilson Co., chemical analysis and some density-based separation will be attempted. The long term goal of this part of the work is focused on obtaining a data bank of information to use as a reliable basis for designing and optimizing a EOL electronics recycling plant.

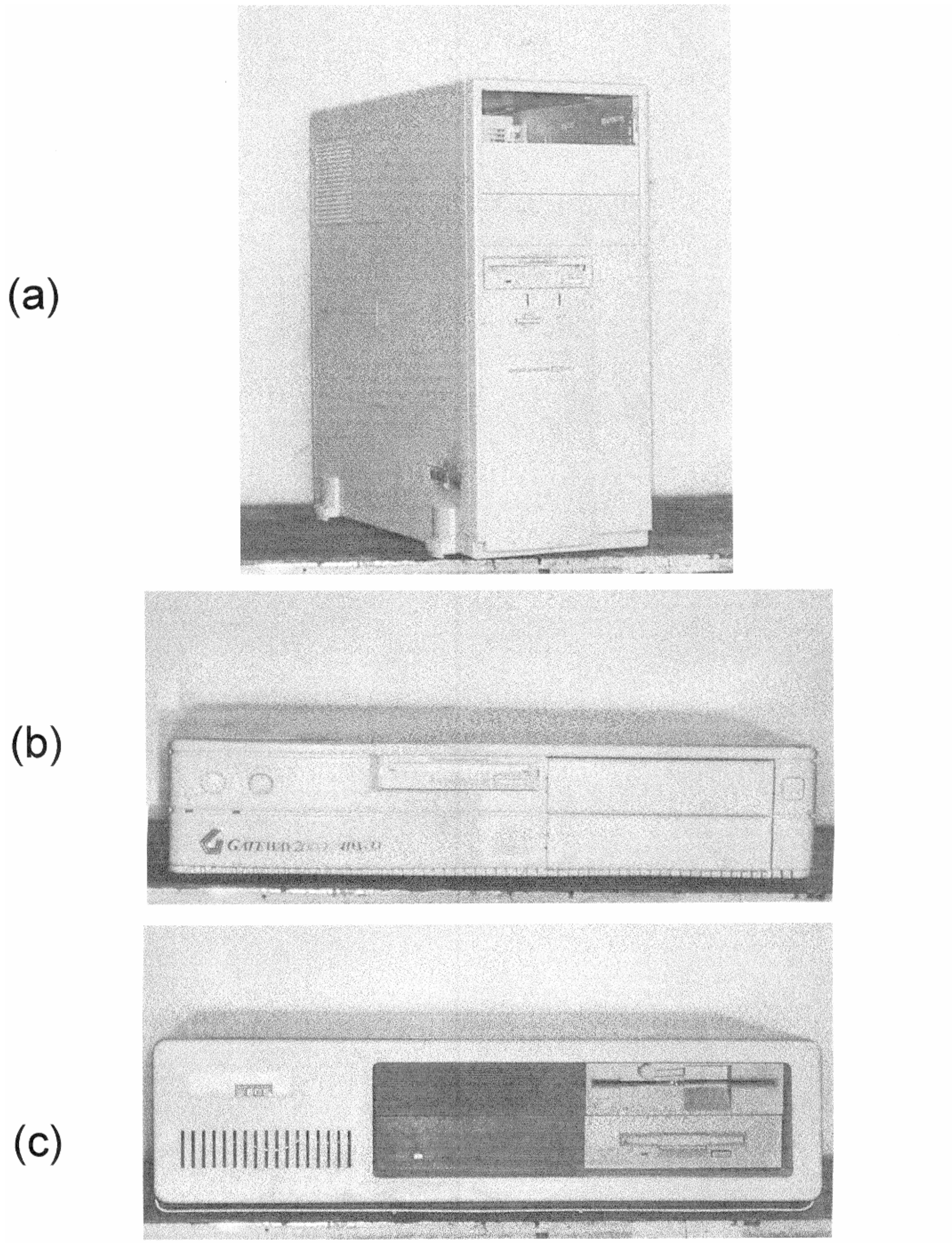


Figure 3: Computers before being sent to shedder: (a) Dell XPS 90c, (b) Gateway 2000 4dX-33 (c)Generic 486

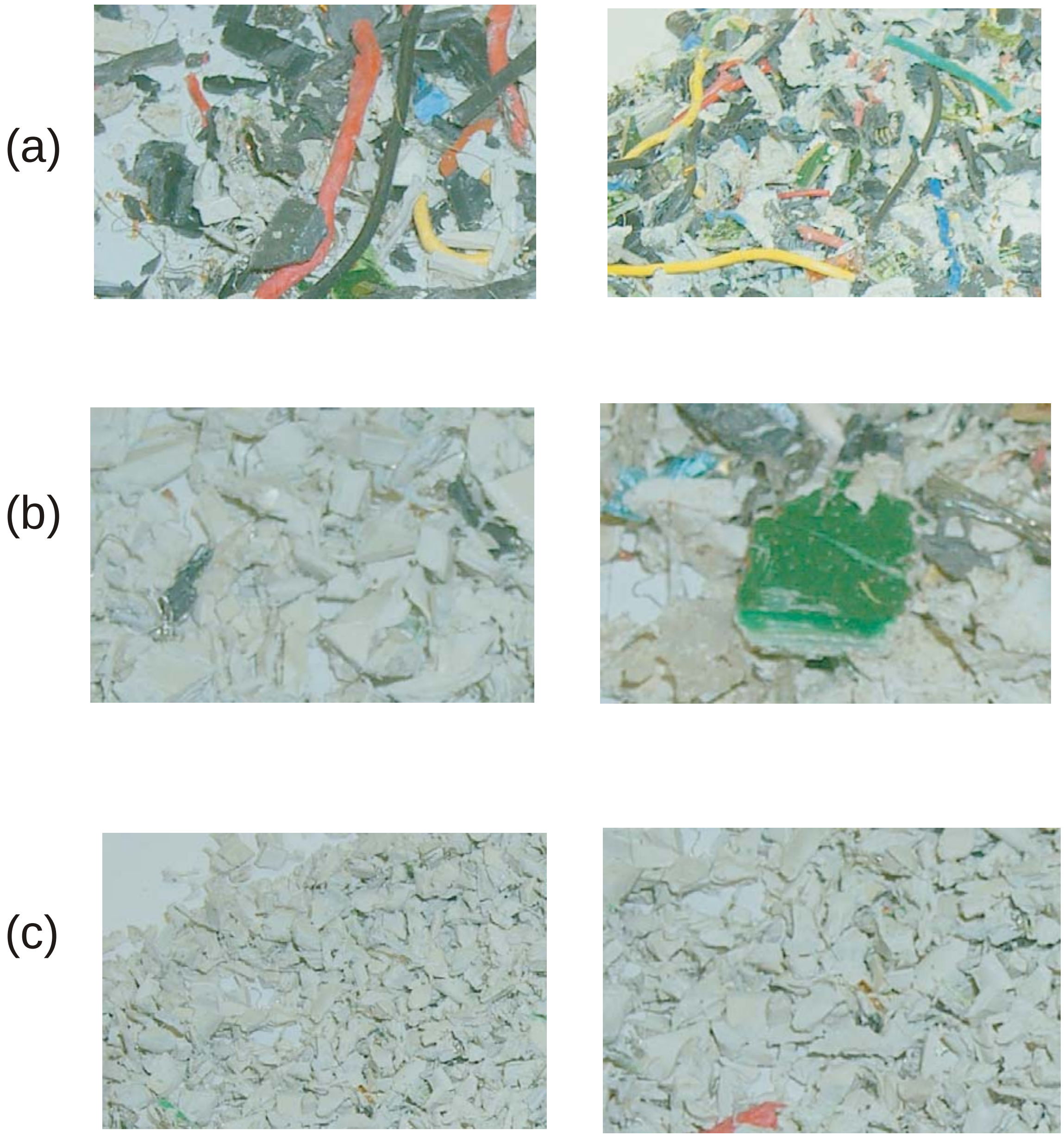


Figure 4: Samples of Shredded Computers Supplied by Gilson Company: (a) Material Captured on 15 mm screen, (b) 10 mm Screen, (c) 4 mm Screen

Appendix I: Task 2.3

Application of Online Rheometer to the Blending of Recycled PC and Virgin ABS

Objectives

We wish to install an online rheometer on the currently existing Brabender twin screw extruder to assist the compounding of recycling polymers with other components. The experiments which have already been conducted on the Dynisco facilities are designed in such a way that the experimental result will demonstrate whether the ViscoSensor online rheometer is able to detect and monitor, instantaneously, the change in flow properties after altering the feeding composition.

The idea

Our research has concluded that it is possible to re-use recycled polymers in their original high value applications by formulating a composition by blending with the chemically identical virgin resins if the recycled polymers have a high purity level and are added below a certain amount; and the recycled content may be further increased to a higher amount by formulating a composition by blending with the chemically different virgin resins to produce alloys such as PC/ABS compound. But solutions are still needed to eliminate batch-to-batch variations of the recycled polymers.

Take polycarbonate as an example. Polycarbonate is commercially blended with ABS. Virgin PC is mixed and compounded with virgin ABS at a specific ratio. Now we want to use high purity, recycled PC to replace virgin PC for this application to yield a material which has the same flow and mechanical properties as those of the material made from virgin PC and virgin ABS. However, this situation cannot be easily achieved because recycled polymer always varies from batch to batch in their molecular weight and thus processing behavior. Therefore, the difference in properties caused by addition of the recycled polymer has to be detected first and then adjusted as needed.

Once the difference in properties (such as viscosity) caused by addition of the recycled polymer is known, the adjustment can be accomplished by using molecular weight modifiers as illustrated in Figure 1(a). Here one low MFI (low Melt Flow Index, meaning higher molecular weight) virgin PC and high MFI (meaning lower molecular weight) virgin PC are employed to mask the batch-to-batch variations of the recycled PC. If the addition of recycled polymer gives a higher viscosity than that of virgin PC, a lower molecular weight grade PC will be added as a thinning modifier; in contrast, if the addition of recycled polymer gives a lower viscosity than that of virgin PC, a higher molecular weight grade PC will be added as a thickening modifier. The model represented in Figure 1 can be used for any recycled polymer to produce either chemically identical blends or chemically different blends. It would be desired that the effect of adding the molecular weight modifier be also monitored instantly for further action.

An online capillary rheometer may serve the above purposes as shown in Figure 1(b). Dr DeLaney recently presented the work on the development of ViscoSensor online rheometer at the SPE meeting at GE Plastics, Parkersburg, WV. We realized that the ViscoSensor would be an excellent candidate for the described work. After discussion with Dr DeLaney, we proposed and carried out the following experiments for a trial demonstration.

Experimental plan

A blend of PC and ABS at a ratio of 50: 50 was chosen as the target compound. First, virgin PC (50%) and virgin ABS (50%) are used to establish a reference of measurement. Second, recycled PC (50%) and virgin ABS (50%) are extruded and measured at the same conditions. Since we know recycled PC has a higher molecular weight than virgin PC, the viscosity of recycled PC/virgin ABS is expected to be higher than that of virgin PC /virgin ABS. Third, we add 5-25% high MFI virgin PC into recycled PC (45-25%) together with virgin ABS (50%) and run measurements again. Adjust the amount of high MFI PC in terms of the result of measurement to yield a viscosity which is equal to the magnitude of virgin PC /virgin ABS.

Materials to be tested

Ideally we need a multiple-stream feeding system on the extruder hosting the ViscoSensor unit so that any amount of the molecular weight modifier can be added instantly as judged from the measured online result. Since the existing extruder at the Dynisco is not equipped with this kind of feeding system, several compositions must be pre-selected. In addition, since the process involves a compounding of two polymers, a twin screw extruder is desired for a better mixing. But the experiment is limited to be conducted, at the Dynisco, on a single screw extruder with a diameter of 3/4 inch. Therefore, the materials tested have been pre-prepared at WVU using the twin screw extruder. The compositions of the materials prepared are listed in Table 1. All 7 samples were prepared at 35rpm and with a extruder temperature profile from the feeding rear zone to the die nozzle as 230C, 245C, 250C, and 245C.

Details of experiment

All samples were dried overnight at 90C. The single screw extruder temperature profile was set from the rear zone to the die nozzle as 235C, 250C, 250C, and 251C. The extruder was feedback controlled by a given extrusion pressure (400psi), giving a screw speed of 8-9 rpm. Sample 1 was first extruded and measured as a reference, then Sample 2, and followed by Sample 3-6. Sample 7 was not extruded due to the insufficient amount. All samples were extruded at the same conditions.

The flow properties of those compounds were measured using the Viscosensor mounted on the single screw pilot extruder. The measurements were taken at five melt-pump speeds, i.e., 5rpm, 10rpm, 20rpm, 40rpm, and 60rpm, giving shear rate in the range of 20 to 280 1/s. The extrudate strands at 20 rpm for each sample have been collected for 10 minutes and grinded for further mechanical and rheological characterization. For sample 1 and sample 2, offline capillary rheometry was also carried out at 250C and the viscosity vs. shear rate was obtained for comparison.

Results

Typical raw experimental data are plotted in Figure 2-5 from the measurements on sample 3#. These figures demonstrate several important features of the Viscosensor, including stable melt pump speed, high accuracy temperature control, fast response to speed change, and reproducible viscosity measurements. Processed viscosity data are shown in Figure 6 and Table 2. Figure 7 indicates that the Viscosensor is capable of quickly detecting the composition change as reflected by the viscosity change.

Figure 8 shows the comparison in viscosity vs. shear rate data obtained on the Viscosensor for 6 samples. The result reveals that the recycled PC/ virgin ABS blend has a lower viscosity than the virgin PC/ virgin ABS. This is verified with the data obtained from the lab offline capillary rheometer (also plotted in Figure 8). As the added high MFI PC content increases, the viscosity decreases as expected.

The mechanical, MFI and rheological characterization of these samples, listed in Table 1, before and after online measurements are being conducted. The initial result shows that the samples, which have experienced a second run of extrusion process due to the online measurements, appear to exhibit poor mechanical properties and become brittle. More results will be presented in the next Quarterly Report.

To sum up, the ViscoSensor is a well-purpose-designed instrument and is able to detect and monitor, instantaneously, the change in flow properties after altering the feeding composition. The encouraging trial result has ensured that the Viscosensor should be exploited for recycling polymer compounding. It is our belief that the employment of online rheometer is essential to the development of successful compounding processes that will yield consistent quality resin blends acceptable for commercial use.

Table 1. The materials prepared for online rheometer measurements.

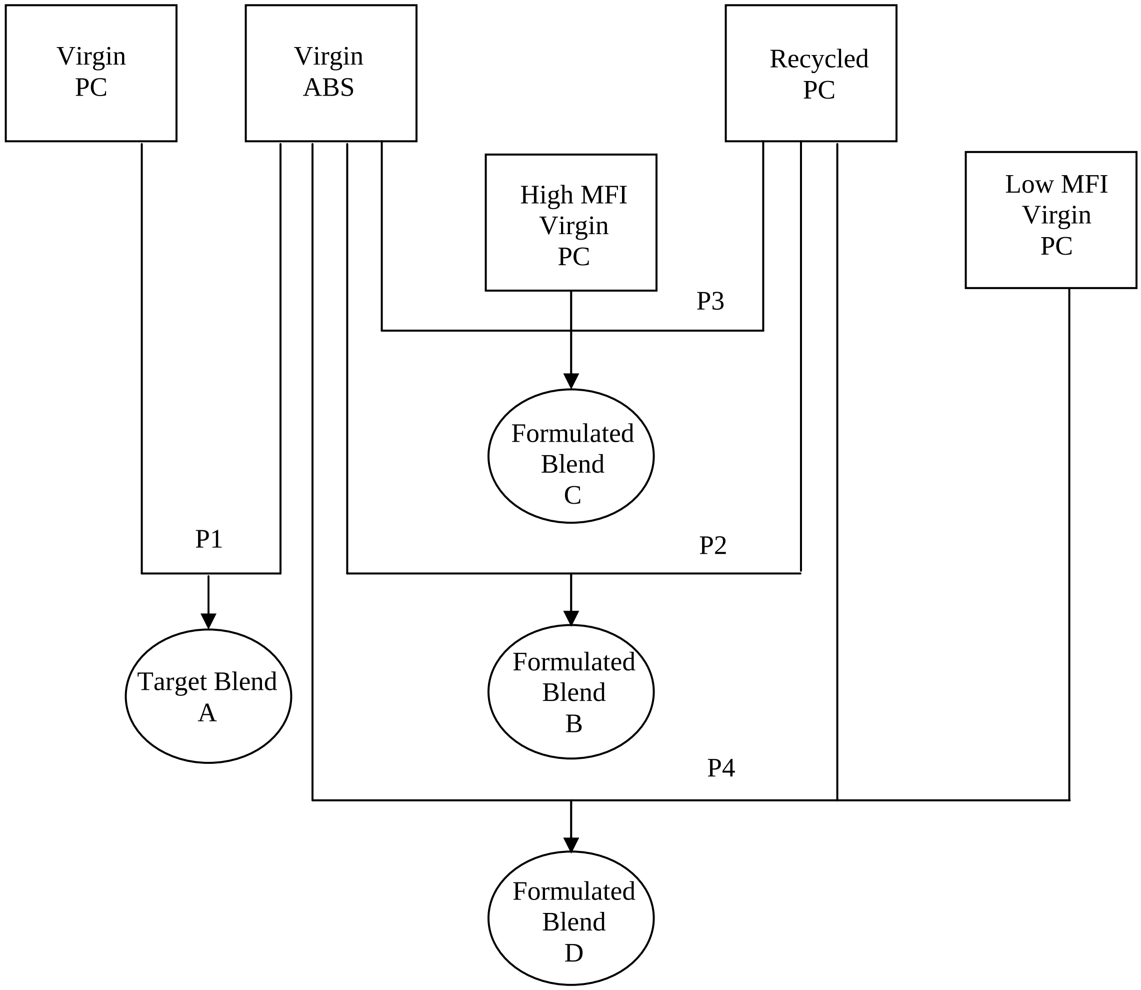
Sample No.	Virgin PC	High MFI PC	Recycled PC	Virgin ABS	Quantity, gram
1	50%	-	-	50%	3000
2	-	0%	50%	50%	3000
3	-	5%	45%	50%	1500
4	-	10%	40%	50%	1500
5	-	15%	35%	50%	1500
6	-	20%	30%	50%	1500
7	-	25%	25%	50%	1500
Total, gram	1500	1125	4125	6750	13500

Table 2. Viscosity vs. shear rate data for sample #3.

Pump speed (Shear rate)	**5 RPM** (19.96 sec^{-1})	**10 RPM** (39.93 sec^{-1})	**20 RPM** (79.85 sec^{-1})	**40 RPM** (159.7 sec^{-1})	**60 RPM** (239.6 sec^{-1})
Mean viscosity (Pa-s)	602.5	524.0	440.7	357.0	311.4
Standard *deviation*	11.3	2.48	1.22	0.323	0.667
Coeff. of *variance*	1.88	0.474	0.276	0.091	0.214

Figure 1a. Application of Online Rheometer to the Blending of Recycled PC and Virgin ABS.

(a) Diagram illustrating recycled polymer compounding technique. Here recycled PC is used to replace virgin PC to produce PC/ABS blend. Two molecular weight modifiers (low MFI virgin PC and high MFI virgin PC) are employed to mask the batch-to-batch variations of the recycled PC.



Criteria:

i). If blend B**'s MFI <** A**'s MFI, process P2 is adjusted into P3 to yield** C**'s MFI ≈** A**'s;**

ii). If blend B**'s MFI >** A**'s MFI, process P2 is adjusted into P4 to yield** D**'s MFI ≈** A**'s;**

iii). If blend B**'s MFI ≈** A**'s MFI, process P2 no change.**

Note: MFI stands for 'melt flow index'. High MFI reflects low molecular weight; low MFI reflects high molecular weight.

Figure 1b. Application of Online Rheometer to the Blending of Recycled PC and Virgin ABS.

(b) Diagram illustrating the application of an online rheometer in recycling polymer compounding.

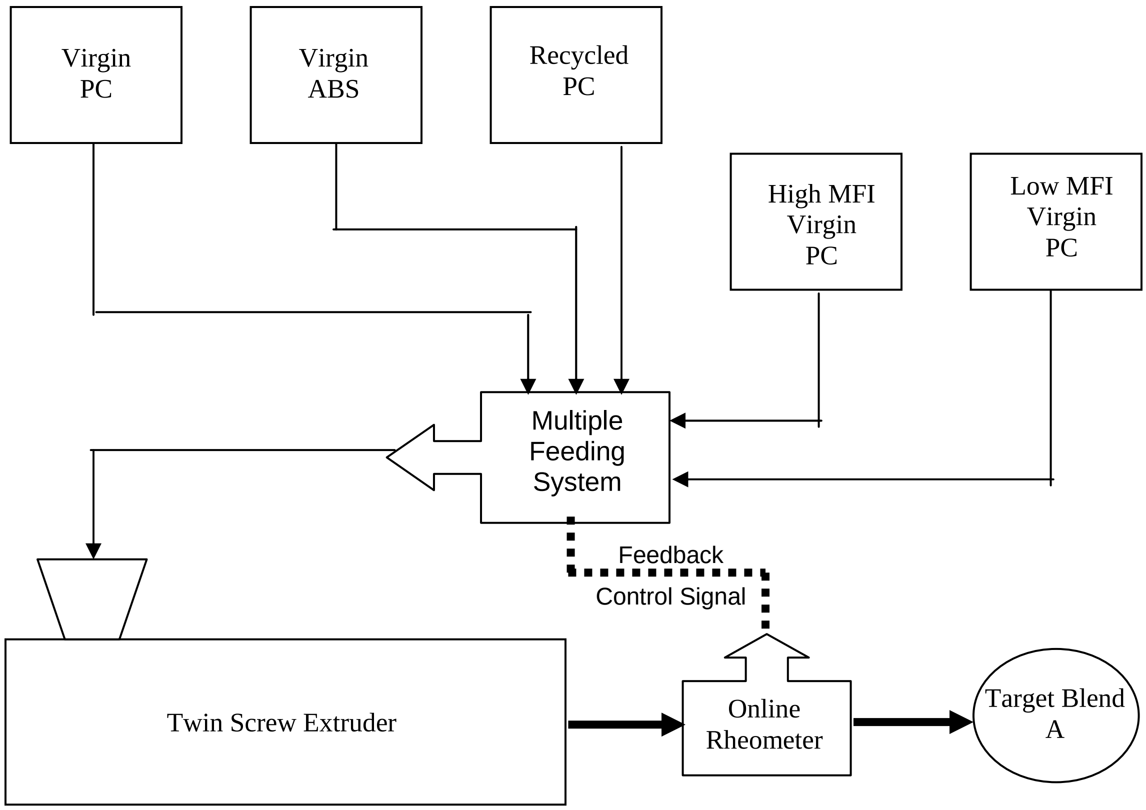


Figure 2. Melt pump speed vs. time for sample #3
(5% high MFI-PC/45% R-PC/50% V-ABS)

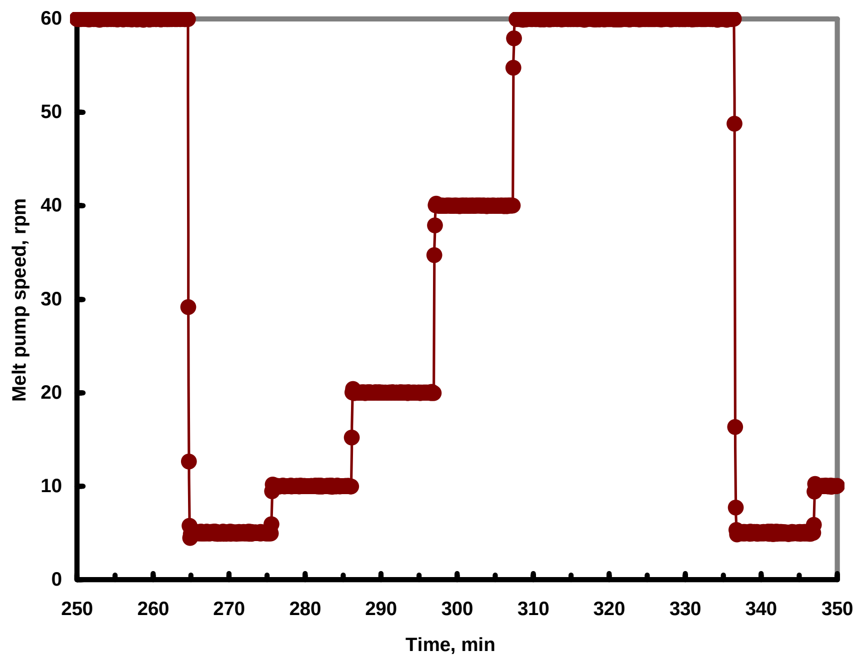


Figure 3. Temperature profile vs. time at different rpm for sample #3
(5% high MFI-PC/45% R-PC/50% V-ABS)

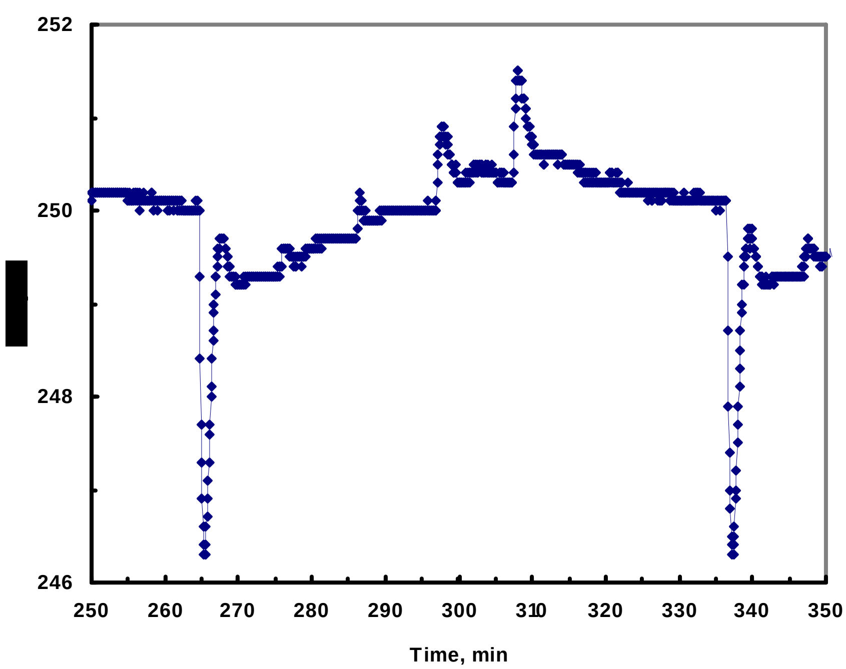


Figure 4. Pressure drop vs. time at different rpm for sample #3
(5% high MFI-PC/45% R-PC/50% V-ABS)

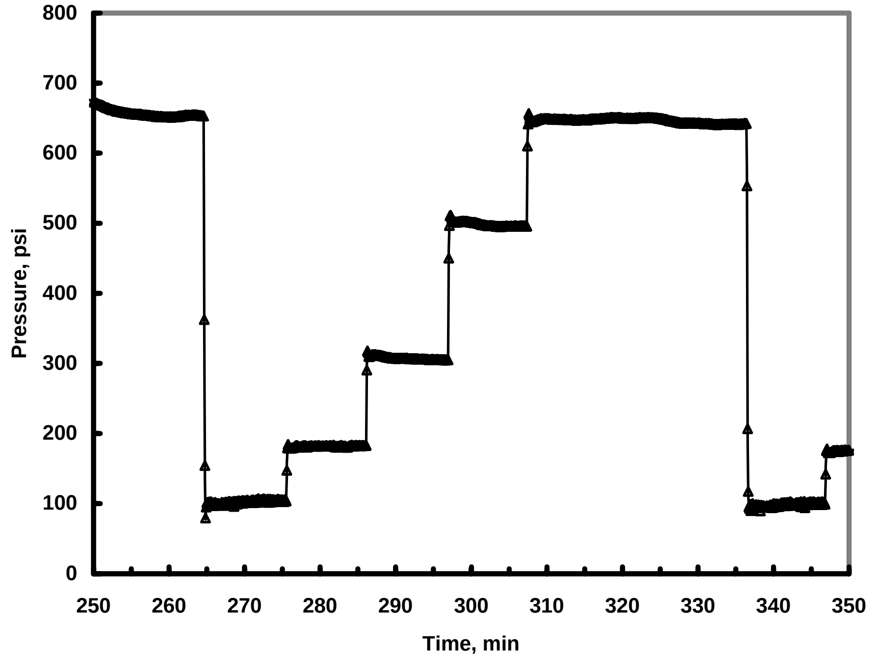


Figure 5. Viscosity vs. time at different rpm for sample #3
(5% high MFI-PC/45% R-PC/50% V-ABS)-s)

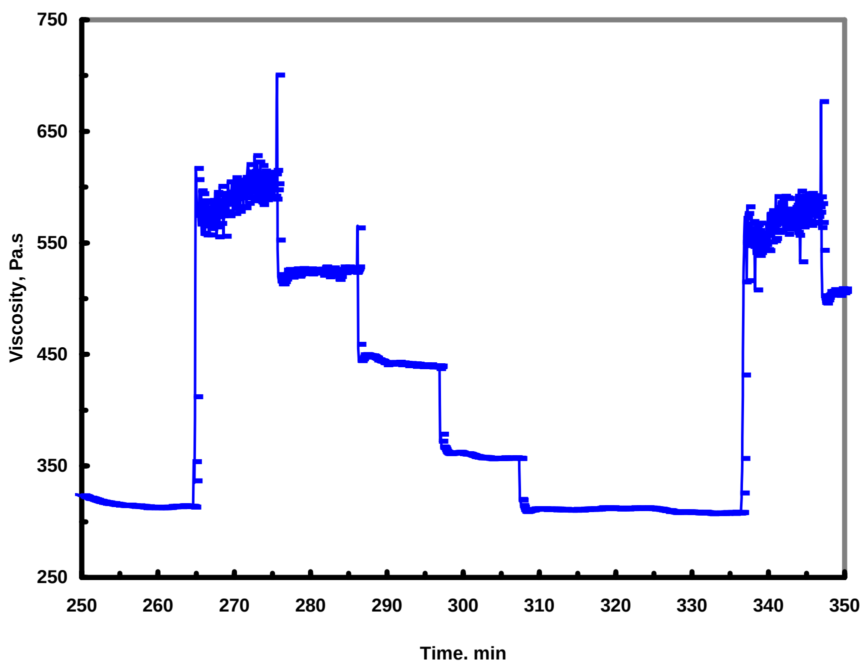


Figure 6. Processed viscosity vs. time data at different rpm for sample #3.

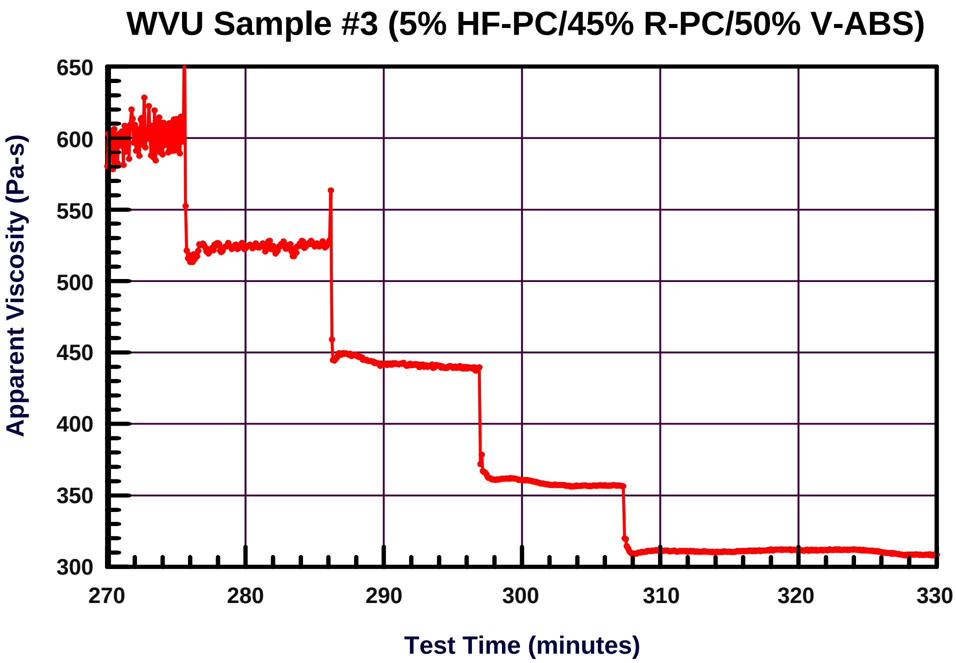


Figure 7. Typical Viscosensor response to the sample change.

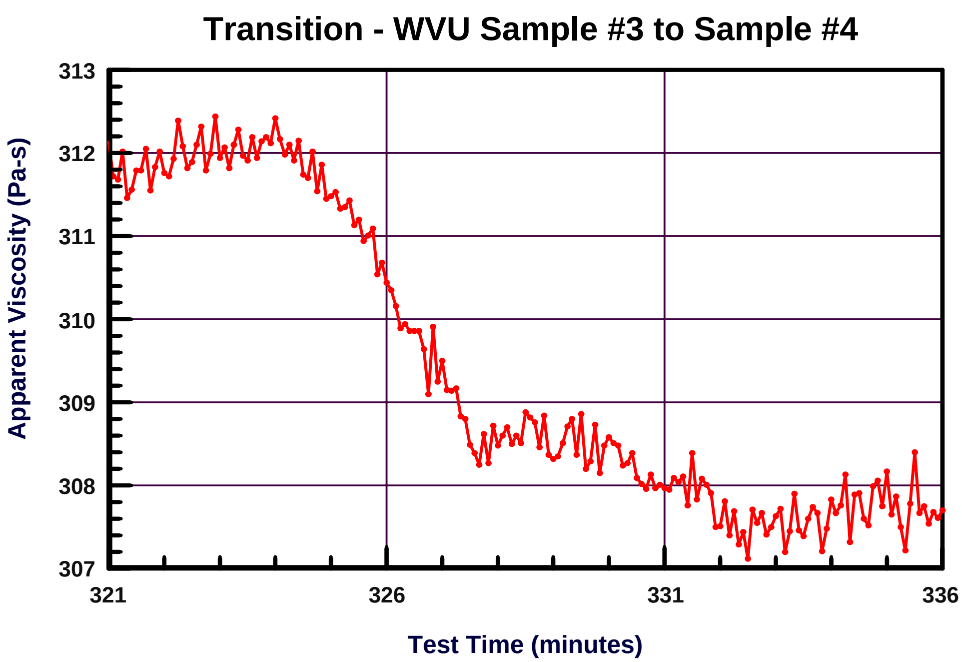


Figure 8. Comparison of ViscoSensor data to the lab offline capillary rheometer data

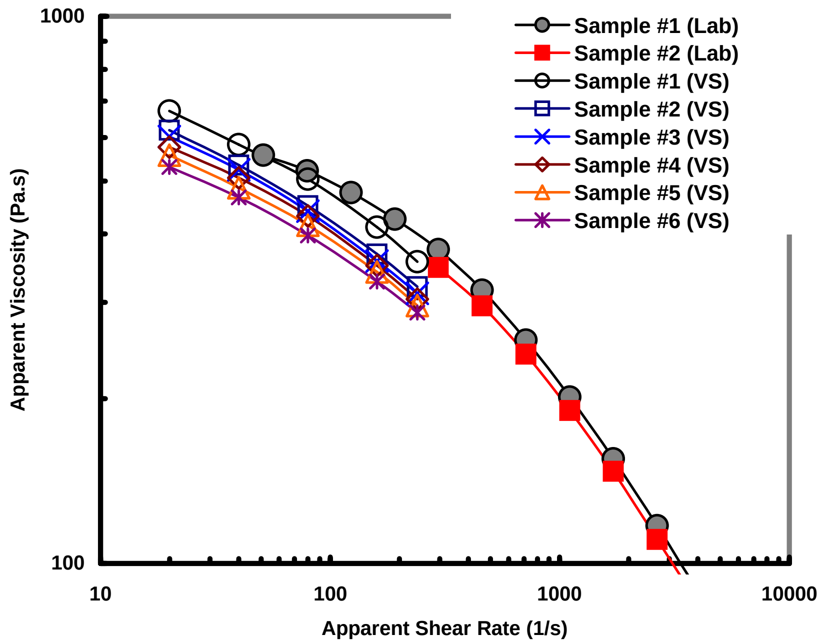


Table 1. Composition of PC Samples Containing Glass Fibers

	%Glass fiber	Source of Polycarbonate
1.	0	Recycled
2.	5	Recycled
3.	10	Recycled
4.	15	Recycled
5.	20	Recycled
6.	0	Virgin
7.	5	Virgin
8.	10	Virgin
9.	15	Virgin
10.	20	Virgin
11.	0	50% Recycled + 50% Virgin
12.	5	50% Recycled + 50% Virgin
13.	10	50% Recycled + 50% Virgin
14.	15	50% Recycled + 50% Virgin
15.	20	50% Recycled + 50% Virgin

Figure 9. Tensile strength of PC containing glass fibers vs. % glass fibers

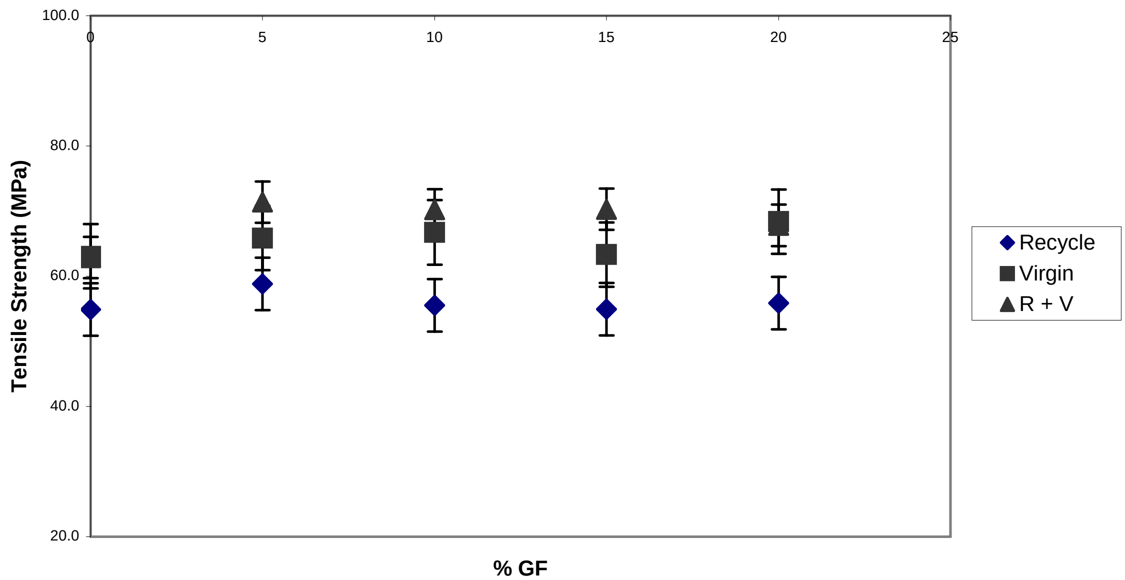


Figure 10. Tensile modulus of PC containing glass fibers vs. % glass fibers

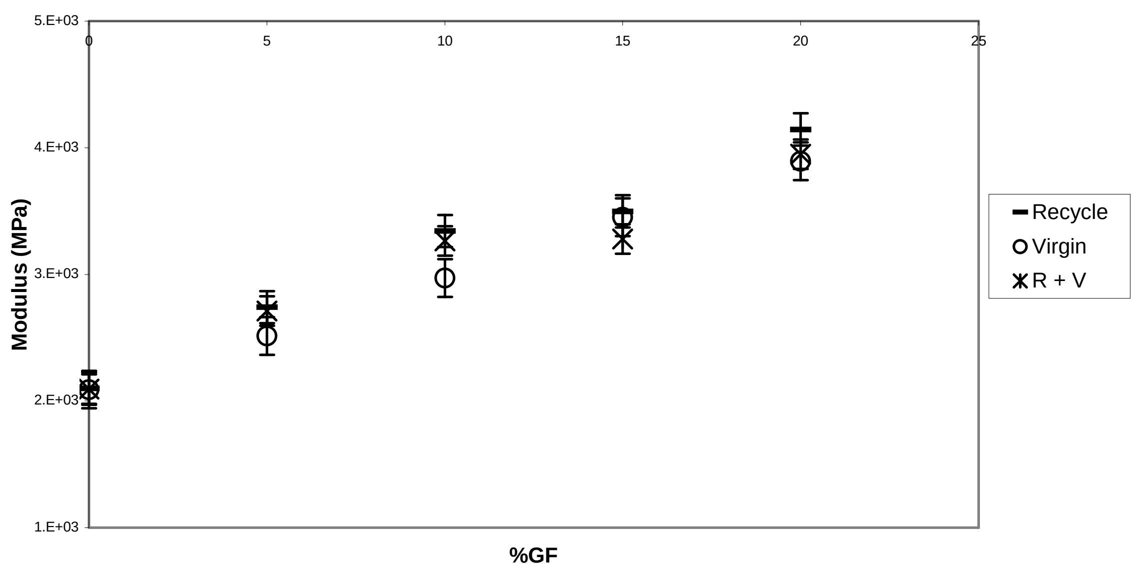


Figure 11. Impact strength of PC containing glass fiber vs. % glass fiber

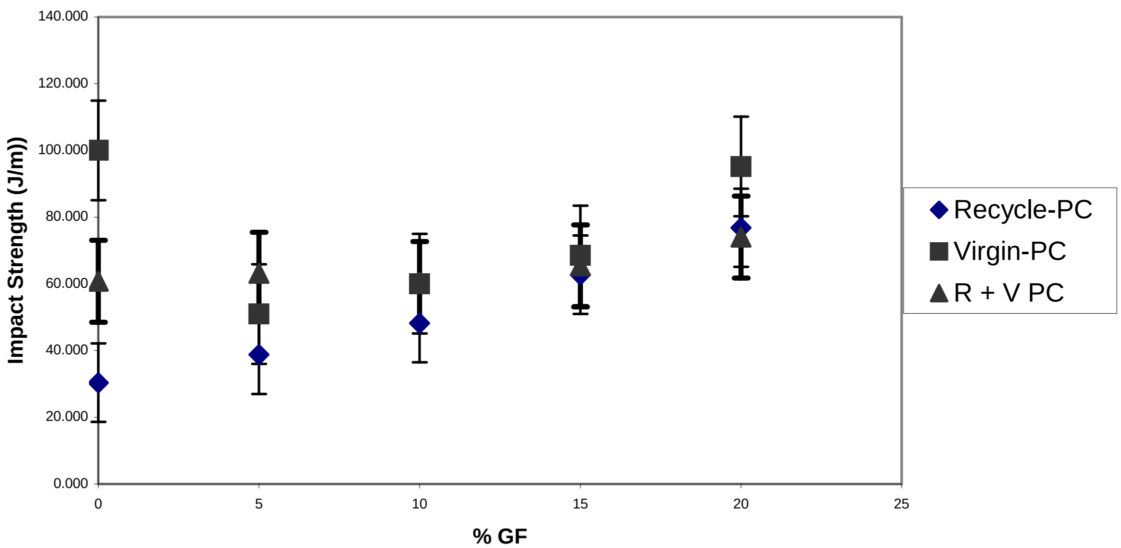


Table 4. Comparison of measured and reported values of impact strength

Resin	Measured (J/m)	Reported (GE Plastics) (J/m)
V-PC (LEXAN 101)	952.2	907.7
V-ABS (CYCOLAC GPM 5500)	280.9	293.1

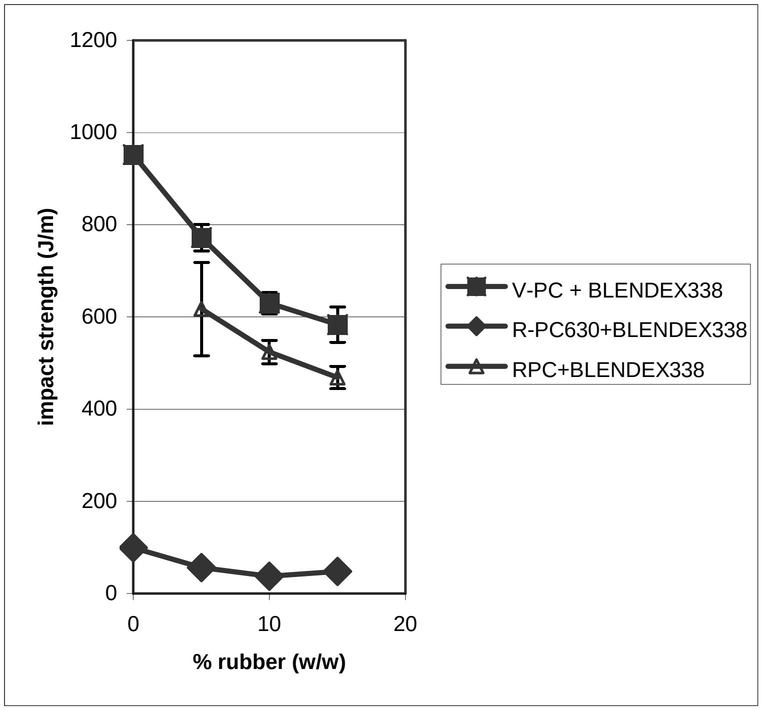


Figure 12. Impact strength versus rubber content for blends of polycarbonate with BLENDEX 338.

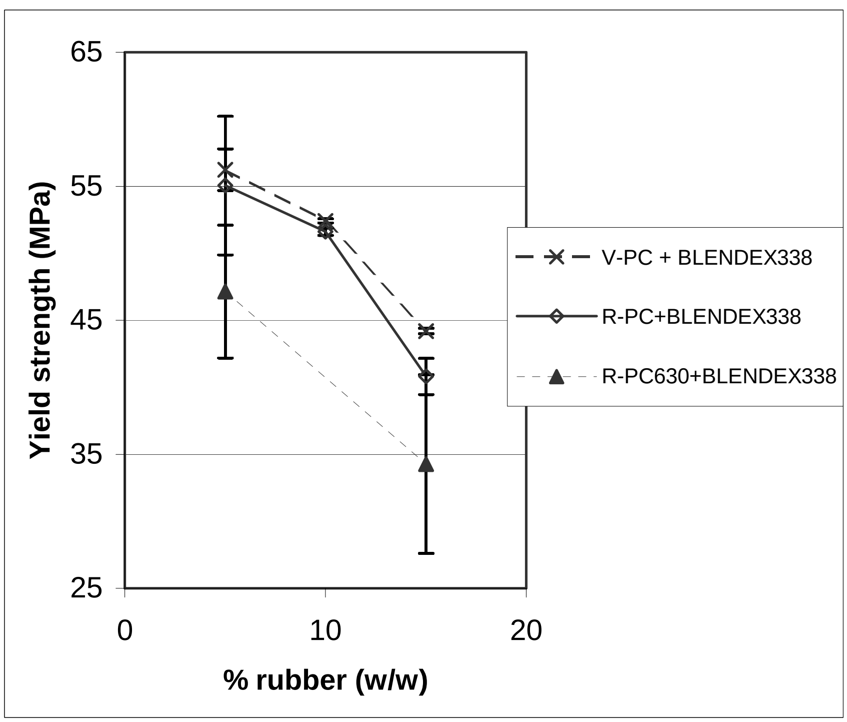


Figure 13. Yield strength of various blends with respect to rubber content.

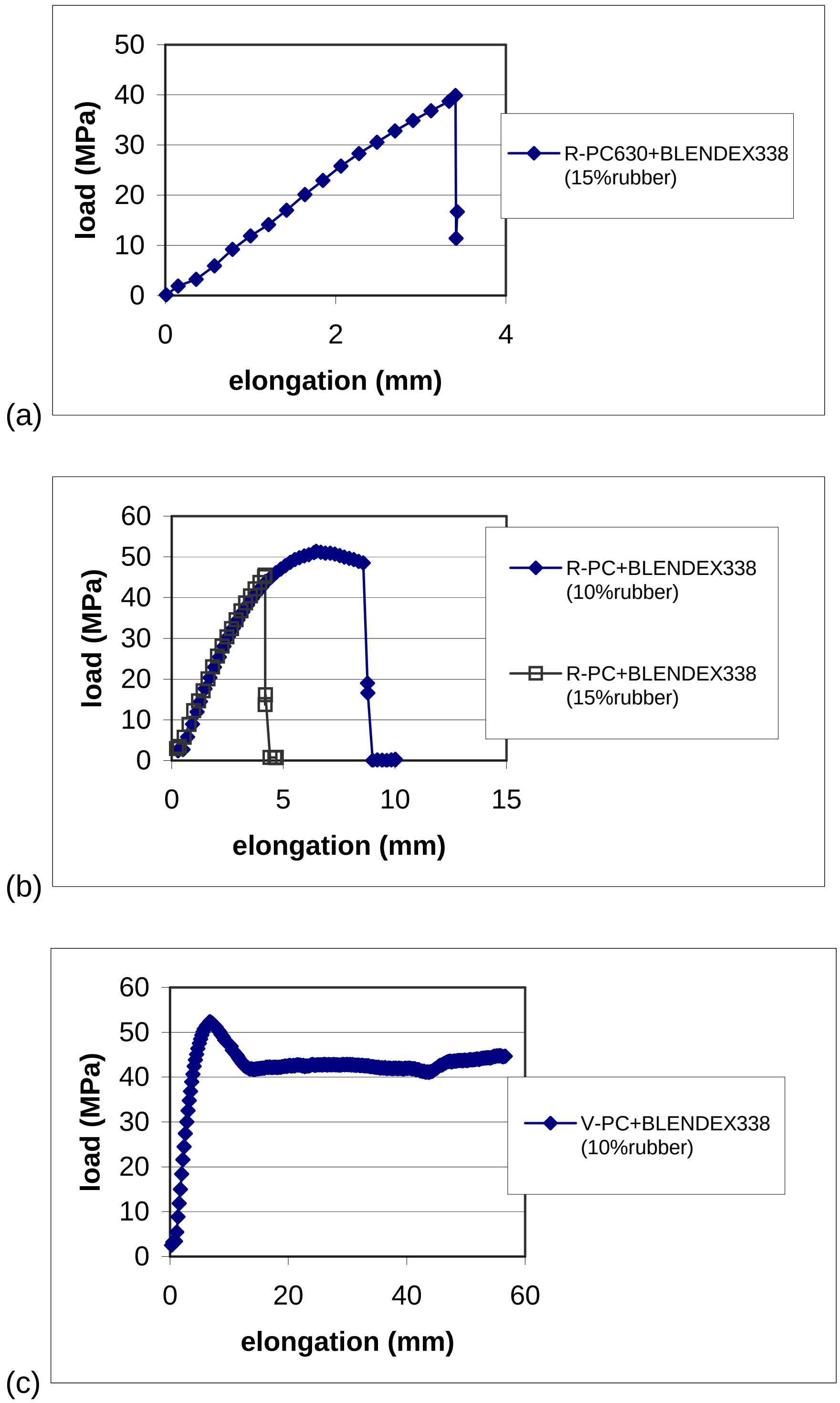


Figure 14. Tensile behavior of various blends of PC with BLENDEX 338, (a) R-PC 630 with 15% rubber shows brittle behavior (b) R-PC with 10% rubber shows ductile behavior whereas with 15% rubber shows brittle behavior (c) V-PC with 10% rubber shows necking but no breakage takes place, similar behavior with 5 and 15% rubber content was observed.

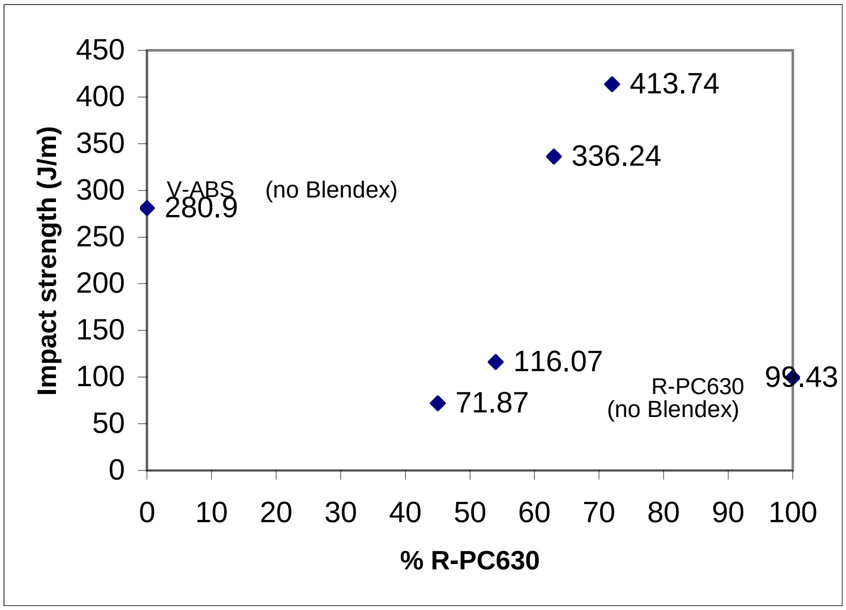


Figure 15. Impact strength versus R-PC630 content for blends of R-PC630, virgin ABS and BLENDEX338. BLENDEX338 concentration is constant at 10% for all the blends, only concentrations of R-PC630 and v-ABS are varied.

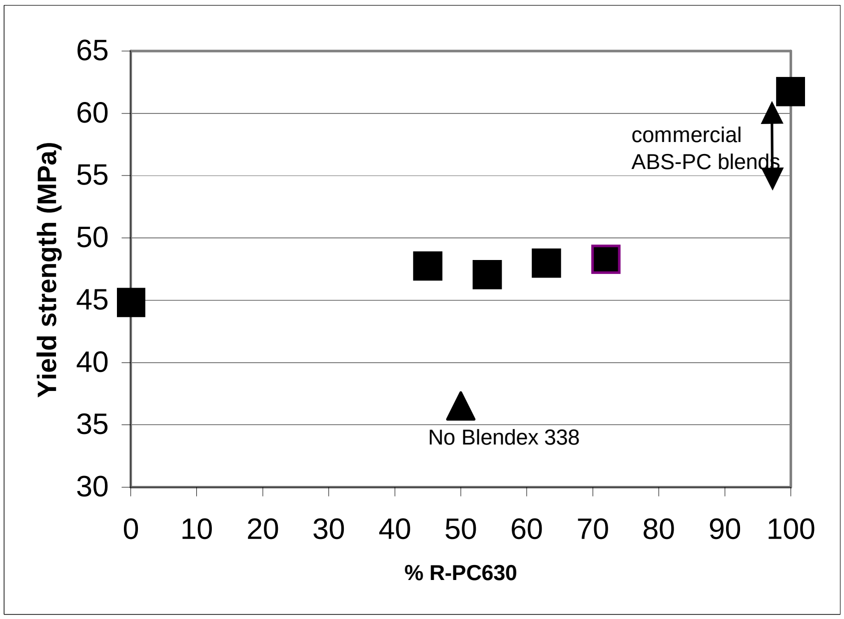


Figure 16. Yield Strength as a function of R-PC630 content. All the blends contain 10% (w/w) BLENDEX 338, only concentrations of R-PC630 and v-ABS are varied. Arrow shows the range of yield strength for commercial PC/ABS blends.

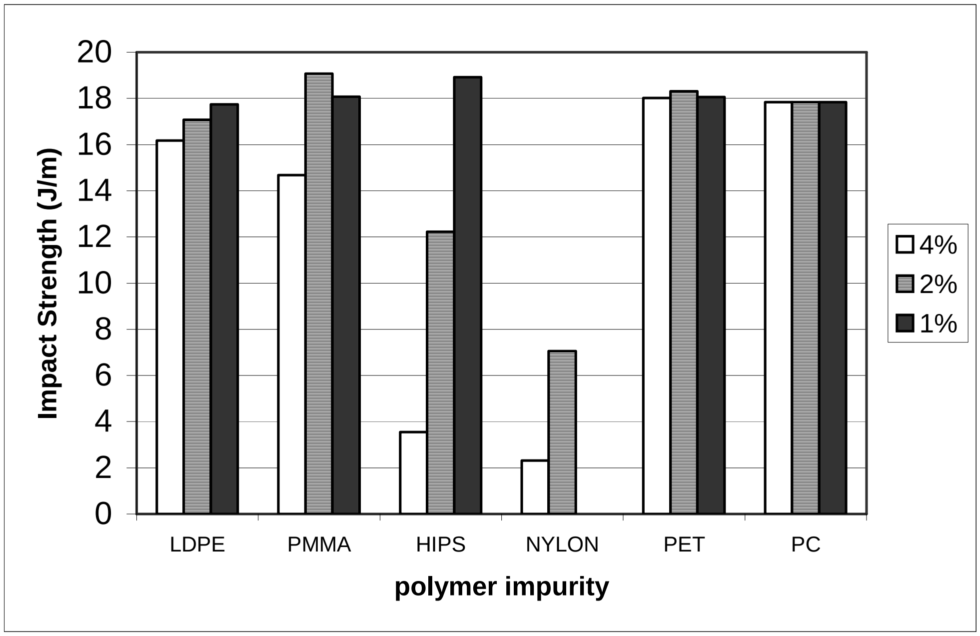


Figure 17. Effect of polymer impurities on the impact strength of virgin polycarbonate.

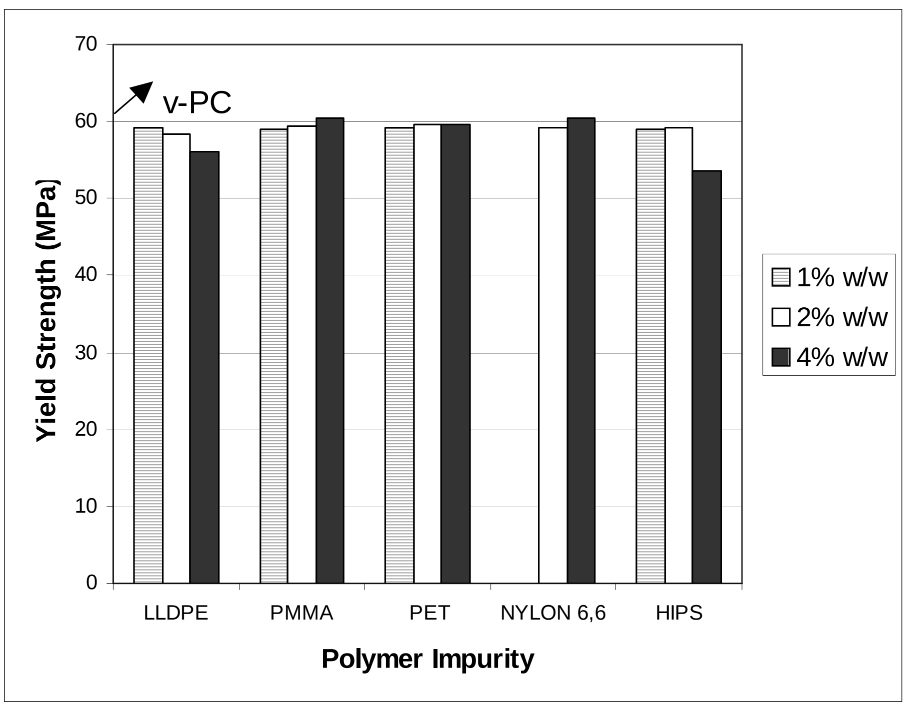


Figure 18. Effect of polymer impurities on the yield strength of virgin PC.

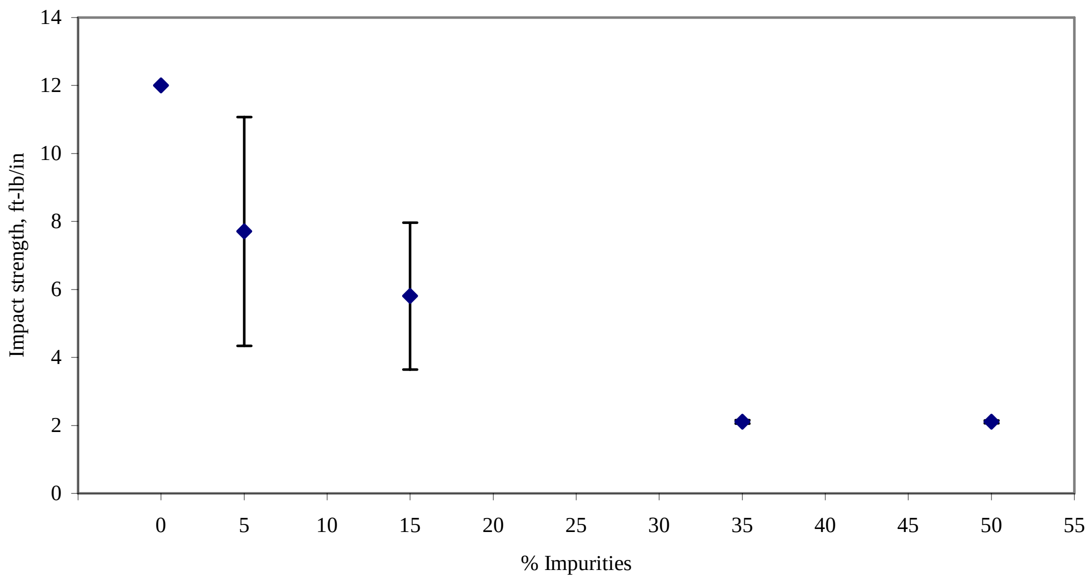


Figure 19: Effect of amount of impurities on the impact strength of virgin polycarbonate. Impurities are a blend containing equal amount of ABS, HIPS, LDPE, PET and Nylon 6,6.

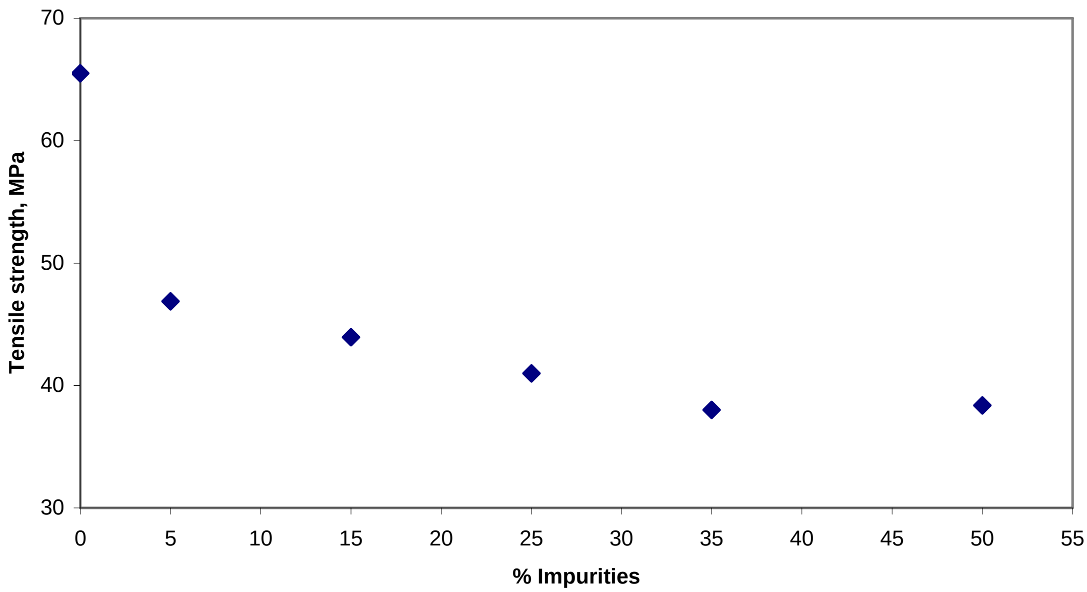


Figure 20: Effect of amount of impurities on the tensile strength of virgin polycarbonate. Impurities are a blend containing equal amount of ABS, HIPS, LDPE, PET and Nylon 6,6.

Appendix J: Task 2.4

Summary of the Research Work

(Published in SAMPE conference-May 11-14, 2003)

THERMO-MECHANICAL CHARACTERIZATION OF RECYCLED THERMOPLASTIC POLYMERS AGED UNDER HARSH ENVIRONMENT

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ABSTRACT

Characterization and application of recycled engineering thermoplastics referred to as electronic shredder residue (ESR), which is retrieved from discarded computers, monitors and printers are described in this paper. Mechanical characterization of virgin, blend of virgin and recycled, and 100% recycled polymers such as acrylonitrile butadiene styrene (ABS) and Polycarbonate (PC) conditioned under a harsh environment is carried out as a part of this research. Tension, bending, compression, impact, hardness and creep properties of the virgin, blend and recycled polymers are evaluated in this research. It was found that recycled polymers retain at least 70% of their tensile, bending and compressive strength after aging (conditioning) under harsh environment. Based on our test results it is concluded that recycled polymers have significant potential for high-volume infrastructure and automotive applications.

INTRODUCTION

The research results described in this paper focus on the evaluation of mechanical properties of ABS and PC thermoplastics obtained as ESR from computer and monitor housings in three forms, i.e., virgin, blend of virgin and recycled, and 100% recycled polymers. Since polymers alone may not have adequate strength or stiffness to meet special material property requirements for such applications as infrastructure or automobile parts, the polymers in this research are studied by adding fibers during the manufacturing process. Test samples were manufactured with and without glass fibers by special collaboration between CFC-WVU, Owens Corning Company, and PPG Industries.

OBJECTIVES

Objectives of this research are to:

- Characterize the strength of virgin and recycled polymers aged (conditioned) under harsh environment for a period of time, obtained from ESR after subjecting the specimens to 10 months of conditioning and test them in tension, compression and bending.
- Compare the tension, compression and bending strength, of virgin and recycled polymers and their blends before and after exposing them to aging process under harsh conditions.
- Characterize the impact and hardness properties of recycled and virgin polymers subjected to an aging process under harsh conditions.
- Characterize the long-term creep properties of fiber reinforced and non-reinforced thermoplastics.
- Evaluate the potential of recycled polymers and blends for infrastructure and automotive applications.

SCOPE

Recycled ABS and PC were evaluated for potential infrastructural and automotive applications based on their availability as ESR, suitability for mass production and cost consideration. More than 180 ABS and PC samples manufactured by Owens Corning were tested in tension, bending, compression, impact and creep. Testing and analysis of ABS and PC sample are continuing at CFC-WVU. The following sections provide: (1) materials and manufacturing, (2) test specimens and procedures, (3) results and analysis of tension, bending, compression, impact, hardness and creep tests, and (4) conclusions.

MATERIALS AND MANUFACTURING

Virgin and Recycled Polymers

Cycolac-GPM5500 ABS and Lexan-101 PC virgin resins evaluated in this study are manufactured by GE Plastics and have excellent impact strength, hardness, rigidity, and toughness properties. The resin grades of Cycolac ABS consist of elastomeric blends of polybutadiene or a butadiene copolymer and an amorphous thermoplastic component of styrene and acrylonitrile (SAN) and are easy to process (GE Plastics User's Guide, 1999). Lexan-101 polycarbonate resins have good electrical, optical, thermal, and mechanical properties including durability. The combination of these physical properties makes it one of the toughest, most versatile of all engineering thermoplastics (GE Plastics User's Guide, 1999).

ABS and PC recycled polymers were received as granulated shredded pellets and flakes with a size of 0.25" or less with a purity level above 95% from sources such as computer, monitor and printer housings. These were made available to the CFC-WVU research team by the MBA polymers, USA.

Glass Fibers

The 408A-14C CRATEC chopped strands supplied by Owens Corning with a length of 4mm, diameter of 14 μ and suitable sizing were blended with ABS. The 408A CRATEC strands have proven compatibility with many thermoplastic resins including ABS. The characteristics of the 408A CRATEC strands include optimized strand integrity, good glass dispersion, excellent mechanical properties, and excellent coupling with polymer systems.

Injection Molding

Injection molding of ABS samples was performed by Owens Corning while injection molding of the PC samples was performed by PPG. As shown in Table 1 six types of specimens were manufactured. Polymer pellets were uniformly blended by means of a screw extruder having L/D ratios of 24:1 and a compression ratio of 3.75:1) to achieve melt homogeneity and avoid material degradation and discoloration at transition sections. Melt temperature used for both the extrusion process and the injection molding was 530^{o} to 535^{o}F for ABS while for PC, the injection temperature was 300^{o}F to 315^{o}F and the molding temperature was 595^{o}F.

Table 1. Description of Different Types of ABS Specimens

Specimens	Description of Different Specimens
A1 – P1	Virgin ABS - PC polymer without fibers
A2 – P2	Virgin ABS - PC polymer with 25% (wt. %) chopped fibers
A3 – P3	100% recycled ABS - PC polymer without fibers
A4 – P4	100% recycled ABS – PC polymer with 25% (wt. %) chopped fibers
A5 – P5	ABS – PC: Recycled/virgin (20%/80%) blend without fibers
A6 – P6	ABS – PC: Recycled/virgin (20%/80%) blend with 25% (wt. %) fibers

Coupon specimens manufactured through injection molding allowed the researchers to conduct six types of tests, i.e., tension, compression, bending, impact, hardness and creep.

TEST SPECIMENS AND PROCEDURES

Test Specimens

The tension, bending, compression and impact test specimens were manufactured to the dimensions as per ASTM D638-94b (Type I specimen, showed in Fig.1), ASTM D790-92, ASTM standards D695-91 and ASTM D256-93a: method A, respectively. Dimensions of the 0.125” thick tension specimen are shown in Fig. 1. Bending specimens were rectangular with a length of 5", width of 0.5", and a thickness of 0.125". The compression specimens were rectangular with a cross-section of 0.5"x 0.25". Height of the specimens was 0.5”. Additional samples with heights 1" and 1.5" were also tested to establish the optimum height for minimizing and eliminating bending effects. Based on pilot testing, height of 0.5” was chosen, which provides an aspect ratio of 2. Dimensions of the impact test specimen including the notch are shown in Fig. 2. For creep test, tension test specimens were drilled with holes and the sustained load was applied by suspending known dead weights.

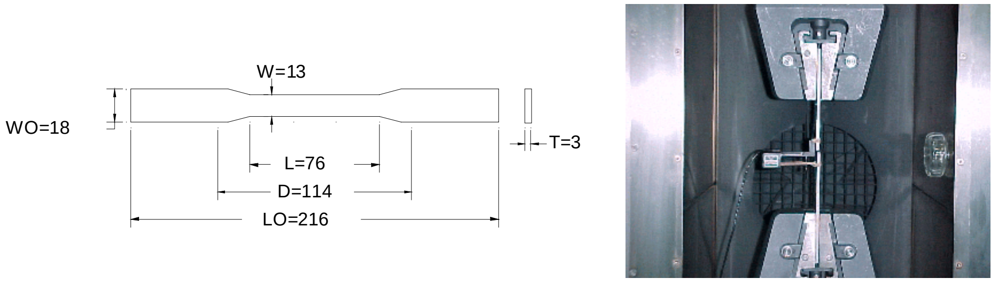

Figure 1. Tension Testing

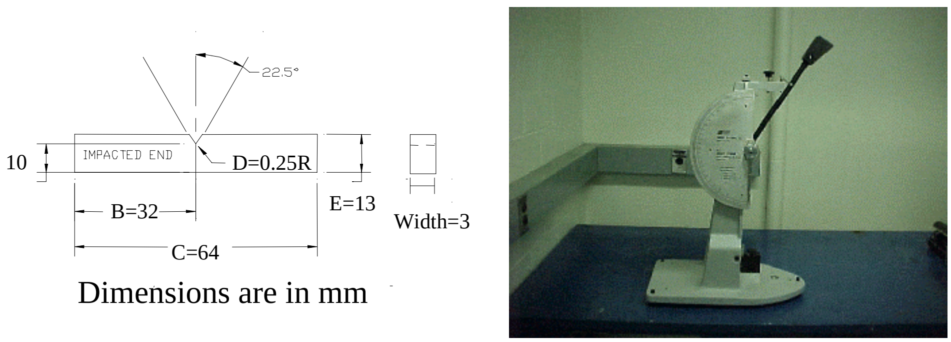

Figure 2. Impact Testing

Aging (Conditioning) of Samples

Samples have been kept immersed in a 3% NaCl (by weight) solution, in plastic containers placed inside an environmental chamber that runs the temperature cycle showed in figure 3, throughout the year. Samples were removed for testing at 2, 4, and 10 months of aging time. Compression specimens were only tested at 2 and 4 months. The study on Creep behavior does not include aged samples. Creep tests started on February 2000 and data have been recorded since then.

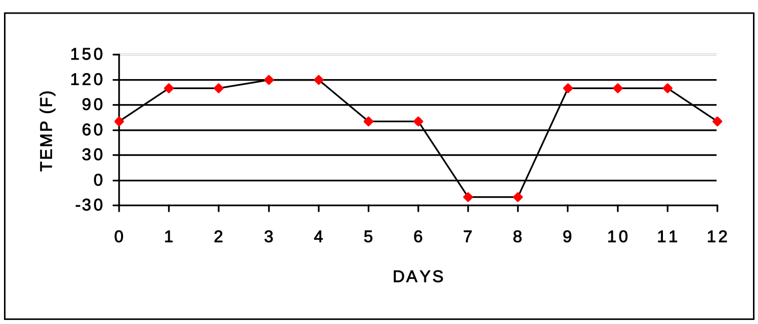

Figure 3. Conditioning Temperature Cycle

Test Set-up and Procedure
Each of the tension specimens was tested using an Instron Series 8500 Two-Column Load Frame as per ASTM D638-94b as shown in Fig. 1. The test was computer controlled at a load rate of 300 lbs./min using the 'wavemaker' software and the strains were automatically recorded with the use of extensometer having a gage length of one inch. For three-point bending tests, the rate of cross-head motion was set at 0.25 in./min. Tensile and compressive strains were recorded using a strain indicator at predetermined load intervals. The specimens were loaded to failure or until significant deflections in excess of 1/3 of the span were observed. For compression tests rate of cross-head motion was set at 0.05 in./min. The strains were recorded at predetermined load intervals. Each specimen was loaded to maximum load and beyond the yield zone. Maximum load, strain and reduction in length were recorded. The impact testing was conducted by using a BLI Series impact-testing machine at laboratory temperature of 72^0F. The final impact energy was obtained from the pointer reading and the type of break (i.e. H-hinge or C-complete) was recorded. The results were calibrated for pendulum friction and windage. The Hardness test was performed using a Duotronic Model 2000 hardness-testing machine as per ASTM D2240-91 with no weight. The hardness number was recorded from the Duotronic's visual display for each test. Creep test specimens were statically loaded at 20% and 50% sustained load, creep strains were recorded at regular intervals from strain gages placed at the middle of the specimens. Additional test procedure details are available in respective ASTM standards.

RESULTS AND ANALYSIS OF TENSION, BENDING, COMPRESSION, IMPACT, HARDNESS AND CREEP TESTS

Tension, bending, compression, and impact strength as well as hardness and creep properties results are compared to aged and non-aged samples and also between the specimens with and without fibers. The test data are summarized in Tables 2 to 6. Each result is an average of at least two specimens. Comparison values are at 10 months of aging, except compression, which was tested after 4 months of aging.

Tension

ABS: Reduction in tensile strength under conditioned state varied from 0.5% to 2.1% for specimens without fibers and 8.6% to 13.6% for specimens with fibers (Table 2). Strength gain of 2.4% was observed in fiber reinforced specimen A6 having a blend of recycled and virgin resins. Average reduction in tensile strength after 10 months of conditioning for samples with fibers was 11.1% as compared to 1.2% in samples without fibers (Table 2).

PC: Reduction in tensile strength under conditioned state was 3.8% for specimens without fibers and 17.7% to 22.2% for specimens with fibers (Table 2). Strength gain of 1.8% and 4.9% was observed in specimens P1 (100% virgin, no fibers) and P3 (100% recycled, no fibers) respectively. Average reduction in tensile strength after 10 months of conditioning for samples with fibers was 20.6% as compared to 3.8% in samples without fibers (Table 2).

In general, relatively higher reductions in tensile strength were observed for specimens containing blended (virgin and recycled) resins or 100% recycled resins, either with or without fibers.

Table 2. Tension Test Results and Comparison

Specimen Type	Max. Stress (psi)		% Change	Specimen Type	Max. Stress (psi)		% Change
	Original	Conditioned 10 months			Original	Conditioned 10 months	
A1	6174	6118	-0.9	P1	8664	8817	+1.8
A2	10299	9410	-8.6	P2	16479	12867	-21.9
A3	5578	5549	-0.5	P3	8566	8983	+4.9
A4	8800	7602	-13.6	P4	15213	12525	-17.7
A5	5916	5790	-2.1	P5	8926	8589	-3.8
A6	8911	9123	+2.4	P6	16555	12877	-22.2
Average reduction (-ve values only) without fibers (A1,A3,A5)			-1.2	Average reduction (-ve values only) without fibers (P1,P3,P5)			-3.8
Average change (+ve and –ve values) without fibers (A1,A3,A5)			-1.2	Average change (+ve and –ve values) without fibers (P1,P3,P5)			+1
Average reduction (-ve values only) with fibers (A2,A4,A6)			-11.1	Average reduction (-ve values only) with fibers (P2,P4,P6)			-20.6
Average change (+ve and –ve values) with fibers (A2,A4,A6)			-6.6	Average change (+ve and –ve values) with fibers (P2,P4, P6)			-20.6

Bending

ABS: Reduction in bending strength under conditioned state was 2.9% for specimens without fibers and 17.7% to 30.9% for specimens with fibers (Table 3). Strength gains of 18.4% were observed in specimen A1 having 100% virgin resin without fibers and 9.3% in specimen A5 having a blend of virgin and recycled resins with no fibers. Average reduction in bending strength after 10 months of conditioning for samples with fibers was 25.3% as compared to 2.9% in samples without fibers (Table 3).

Table 3. Bending Test Results and Comparison

Specimen Type	Max. Stress (psi)		% Change	Specimen Type	Max. Stress (psi)		% Change
	Original	Conditioned 10 months			Original	Conditioned 10 months	
A1	9080	10747	+18.4	P1	10242	14945	+45.9
A2	17771	14631	-17.7	P2	24566	25370	+3.3
A3	9187	8923	-2.9	P3	10363	17327	+67.2
A4	16740	12162	-27.4	P4	23198	28586	+23.2
A5	9558	10446	+9.3	P5	11168	15023	+34.5
A6	16509	11400	-30.9	P6	24886	23909	-3.9
Average reduction (-ve values only) without fibers (A1,A3,A5)			-2.9	Average reduction (-ve values only) without fibers (P1,P3,P5)			0
Average change (+ve and –ve values) without fibers (A1,A3,A5)			+8.3	Average change (+ve and –ve values) without fibers (P1,P3,P5)			+49.2
Average reduction (-ve values only) with fibers (A2,A4,A6)			-25.3	Average reduction (-ve values only) with fibers (P2,P4,P6)			-3.9
Average change (+ve and –ve values) with fibers (A2,A4,A6)			-25.3	Average change (+ve and –ve values) with fibers (P2,P4, P6)			+7.5

PC: No reduction in bending strength was observed except for 3.9% in specimen P6 with blended recycled and virgin resin with fibers (Table 3). Samples without fibers showed an average increase of 49.2% as compared to specimens without fibers that increased 7.5% (Table 3).

The results of Table 3 indicate higher reduction in strength for ABS specimens with fibers and reduced gains in strength for PC specimens with fibers.

Compression

ABS: Reduction in compressive strength under conditioned state was 1.4% for specimens without fibers and 10.9% to 19.9% for specimens with fibers (Table 4). Strength gains of 10.3% were observed in specimen A1 having 100% virgin resin, without fibers and 3.5% in specimen A5 having a blend of virgin and recycled resins, with no fibers. Average reduction in compressive strength after 4 months of conditioning for samples with fibers was 15.8% as compared to 1.4% in samples without fibers (Table 4).

PC: Reduction in compressive strength under conditioned state was 1.6% for specimens without fibers and 17.2% to 34.9% for specimens with fibers (Table 4). Strength gains of 10.1% were observed in specimen P3 having 100% recycled resin, without fibers and 4.3% in specimen P5 having a blend of virgin and recycled resins, with no fibers. Average reduction in compressive strength after 4 months of conditioning for samples with fibers was 28.5% as compared to 1.6% in samples without fibers (Table 4).

Table 4. Compression Test Results and Comparison

Specimen Type	Max. Stress (psi)		% Change	Specimen Type	Max. Stress (psi)		% Change
	Original	Conditioned 4 months			Original	Conditioned 4 months	
A1	8966	9886	+10.3	P1	10423	10259	-1.6
A2	1315	11698	-10.9	P2	20332	13539	-33.4
A3	8792	8670	-1.4	P3	10311	11348	+10.1
A4	14891	12440	-16.5	P4	20747	13509	-34.9
A5	8972	9287	+3.5	P5	10523	10979	+4.3
A6	13920	11151	-19.9	P6	21124	17500	-17.2
Average reduction (-ve values only) without fibers (A1,A3,A5)			-1.4	Average reduction (-ve values only) without fibers (P1,P3,P5)			-1.6
Average change (+ve and –ve values) without fibers (A1,A3,A5)			+4.1	Average change (+ve and –ve values) without fibers (P1,P3,P5)			+4.3
Average reduction (-ve values only) with fibers (A2,A4,A6)			-15.8	Average reduction (-ve values only) with fibers (P2,P4,P6)			-28.5
Average change (+ve and –ve values) with fibers (A2,A4,A6)			-15.8	Average change (+ve and –ve values) with fibers (P2,P4, P6)			-28.5

Impact

ABS: Reduction in impact strength under conditioned state was 1.5% to 25.7% for specimens without fibers and 16.4% to 25.7% for specimens with fibers (Table 5). Average reduction in impact strength after 10 months of conditioning for samples with fibers was 18.4% as compared to 13.6% in samples without fibers (Table 5).

PC: No reduction was observed in impact strength under conditioned state of specimens without fibers, However, reduction of 49.5% to 53.4% was observed for specimens with fibers (Table 5). Average reduction in impact strength after 10 months of conditioning for samples with fibers was 51.4%, average gain of 9.4% was observed for specimens without fibers (Table 5).

Table 5. Impact Test Results and Comparison

Specimen Type	Impact Stress (psi)		% Change	Specimen Type	Impact Stress (psi)		% Change
	Original	Conditioned 10 months			Original	Conditioned 10 months	
A1	3.49	3.44	-1.5	P1	14.15	14.59	+3.1
A2	1.58	1.32	-16.4	P2	3.01	1.40	-53.4
A3	2.17	-	-	P3	13.53	15.65	+15.9
A4	0.96	0.75	-21.7	P4	1.81	0.91	-49.5
A5	2.38	1.77	-25.7	P5	14.80	-	-
A6	1.20	1.00	-17.0	P6	2.67	1.32	-50.5
Average reduction (-ve values only) without fibers (A1,A3,A5)			-13.6	Average reduction (-ve values only) without fibers (P1,P3,P5)			0
Average change (+ve and –ve values) without fibers (A1,A3,A5)			-13.6	Average change (+ve and –ve values) without fibers (P1,P3,P5)			+9.4
Average reduction (-ve values only) with fibers (A2,A4,A6)			-18.4	Average reduction (-ve values only) with fibers (P2,P4,P6)			-51.4
Average change (+ve and –ve values) with fibers (A2,A4,A6)			-18.4	Average change (+ve and –ve values) with fibers (P2,P4, P6)			-51.4

Hardness

ABS: Reduction in hardness index under conditioned state was 0.9% for specimens without fibers and 2.7% to 3.6% for specimens with fibers (Table 6). Gain of 11.0% was observed in specimen A1 having 100% virgin resin, without fibers. Average reduction in hardness index after 10 months of conditioning for samples with fibers was 3.0% as compared to 0.9% in samples without fibers (Table 6).

PC: Samples without fibers showed an increase in index hardness of 1.9% to 4.7% and samples with fabrics showed an increase of 1.9 to 5.6% (Table 6). Average increase in hardness index after 10 months of conditioning for samples with fibers was 3.1% as compared to 3.8% in samples without fibers (Table 6).

Table 6. Hardness Test Results and Comparison

Specimen Type	Hardness Index		% Change	Specimen Type	Hardness Index		% Change
	Original	Conditioned 10 months			Original	Conditioned 10 months	
A1	10.90	12.10	+11.0	P1	10.60	11.10	+4.7
A2	11.30	11.00	-2.7	P2	10.70	11.30	+5.6
A3	11.10	11.10	0.0	P3	10.60	11.10	+4.7
A4	11.20	10.80	-3.6	P4	10.70	10.90	+1.9
A5	11.20	11.10	-0.9	P5	10.70	10.90	+1.9
A6	11.20	10.90	-2.7	P6	10.70	10.90	+1.9
Average reduction (-ve values only) without fibers (A1,A3,A5)			-0.9	Average reduction (-ve values only) without fibers (P1,P3,P5)			0
Average change (+ve and –ve values) without fibers (A1,A3,A5)			+3.4	Average change (+ve and –ve values) without fibers (P1,P3,P5)			+3.8
Average reduction (-ve values only) with fibers (A2,A4,A6)			-3.0	Average reduction (-ve values only) with fibers (P2,P4,P6)			0
Average change (+ve and –ve values) with fibers (A2,A4,A6)			-3.0	Average change (+ve and –ve values) with fibers (P2,P4, P6)			+3.1

Creep

For PC specimens at 50% of sustained load, specimens with and without fibers showed an average creep coefficient of 0.16 and 0.20, respectively, after 400 days. At 20% sustained load PC specimens with and without fibers showed an average creep coefficient of 0.20 and 0.23 after 400 days. Stress level increase from 20 to 50% didn’t appear to have major effect on the creep coefficient of PC specimens.

ABS specimens without fibers tested at 50% sustained load failed with a a maximum creep coefficient of 0.32 on 17^{th} day, whereas specimens with fibers failed with a maximum creep coefficients of 0.42 on 47^{th} day. At 20% sustained load, after 400 days, an average creep coefficient of 0.48 was observed for ABS specimens without fibers as compared to 0.21 in specimens with fibers.

Creep behavior in resins was more prominent at lower sustained load levels (20%) as compared to higher sustained load levels (50%). At higher sustained load levels, chopped fibers contributed towards creep control. At 20% of sustained loading, PC specimens without fibers showed half the creep coefficient of ABS specimens (0.23 vs. 0.48). However, with fiber addition, creep coefficient in PC and ABS specimens at 20% loading were similar, i.e., (0.21 vs. 0.20).

Both PC and ABS specimens were not subjected to conditioning. Further testing will be carried out by Constructed Facilities Center at West Virginia University, to observe the creep behavior of conditioned recycled thermoplastics with and without fibers.

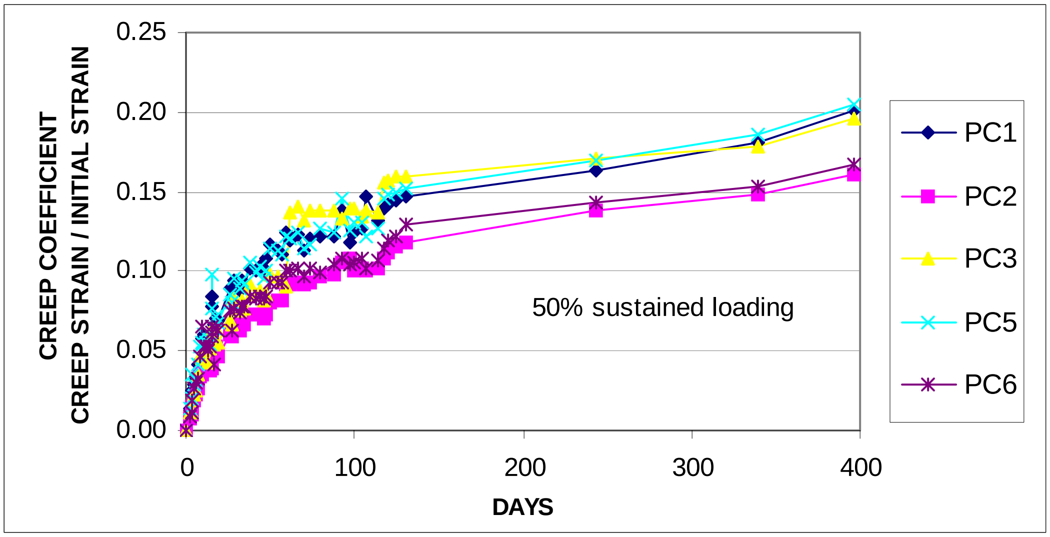

Fig. 5 Creep Curves with Fibers for PC (≈50% Ultimate Load)

For all of the above mechanical properties except creep, an increase in strength of some conditioned specimens after 10 months is attributed to possible secondary curing of the composite material. In addition, variation of results in some fiber-reinforced specimens is attributed to the random orientation of chopped fibers, which can affect the rate and magnitude of degradation depending upon fiber location, orientation and dispersion. It is reported that the water penetration at resin-glass interface of E-glass epoxy composite is reportedly 450 times faster than through resin alone (GangaRao et al., 1995; Springer, 1983). This indicates possible moisture penetration along the fiber/matrix interface to be between 2 to 3 orders of higher magnitude than the surface penetration. Hence, any short fibers at the surface of the specimens providing an easy interface for moisture penetration may cause higher mechanical property reduction.

CONCLUSIONS

Aging (conditioning) of fiber reinforced (chopped) and non- fiber reinforced thermoplastics ABS and PC manufactured from virgin and recycled electronic shredder residue (ESR) was carried out for a period of 10 months. After conditioning, the coupon specimens were tested to evaluate tension, bending, compression, impact, and hardness properties.

Tension, Bending and Compression Properties of Aged Recycled Polymers

- Reductions in tensile, bending, and compressive strength of ABS specimens were 1.2%, 2.9%, 1.4%, respectively, for specimens without chopped fibers. Reductions in tensile, bending, and compressive strength of PC specimens without chopped fibers were 3.8%, 0%, 1.6%, respectively.
- Average reductions in tensile, bending and compressive strength were a maximum of 3.8% for three categories of ABS and PC resins without fibers (virgin, 100% recycled, and blend of virgin and recycled).

- Reductions in tensile, bending, and compressive strength of ABS specimens were 11.1%, 25.3%, 15.8%, respectively, for specimens with chopped fibers. Reductions in tensile, bending, and compressive strength of PC specimens with chopped fibers were 20.6%, 3.9%, 28.5%, respectively.
- Average reductions in tensile, bending and compressive strength were a maximum of 28.5% for three categories of ABS and PC resins with fibers (virgin, 100% recycled, and blend of virgin and recycled).
- As expected, bending strength was found to be higher than the corresponding tensile values for all three types of polymers considered in this study.
- Higher reductions in strength of specimens with chopped fiber are due to existence of moisture "channels" that facilitate moisture diffusion along fiber/resin interface resulting in higher deterioration in specimens with chopped fibers. Use of continuous fibers or proper surface coating to seal off the open interfaces is expected to alleviate this problem.

Impact and Hardness Properties of Aged Recycled Polymers

- Average reductions in impact strength of ABS specimens with chopped fibers were 18.4% as compared to 13.6% for specimens without chopped fibers.
- Average reductions in impact strength of PC specimens with chopped fibers were 51.4% as compared to 0% for specimens without chopped fibers.
- Hardness properties of both ABS and PC specimens were not significantly affected in many of the specimens after conditioning.
- Reduction in impact strength for the blended, virgin and recycled polymers was more than the reductions in tensile, bending and compressive stresses.

Creep Properties of Aged Recycled Polymers

- For PC specimens at 50% of sustained load, specimens with and without fibers showed an average creep coefficient of 0.16 and 0.20, respectively, after 400 days. At 20% sustained load PC specimens with and without fibers showed an average creep coefficient of 0.20 and 0.23 after 400 days. Stress level increase from 20 to 50% didn’t appear to have any major effect on the creep coefficient of PC specimens.
- ABS specimens without fibers tested at 50% sustained load failed with a a maximum creep coefficient of 0.32 on 17th day, whereas specimens with fibers failed with a maximum creep coefficients of 0.42 on 47th day. At 20% sustained load, after 400 days, an average creep coefficient of 0.48 was observed for ABS specimens without fibers as compared to 0.21 in specimens with fibers.
- Creep in resins was more dominant at lower sustained load levels (20%) as compared to higher sustained load levels (50%). At higher load levels, chopped fibers contributed towards creep control.
- At 20% of sustained loading, PC specimens without fibers showed half the creep coefficient of ABS specimens (0.23 vs. 0.48). However, with fiber addition, creep coefficient in PC and ABS specimens at 20% loading were similar, i.e., (0.21 vs. 0.20).
- Sustained load level on ABS specimens is suggested to be limited to 20%. At 50% of sustained loading, PC specimens showed better capacity to carry sustained load than ABS specimens, either with or without fibers.

- Based on test results, chopped fiber reinforced recycled thermoplastic polymers were found to retain at least 70% of their tensile, bending and compressive strength when conditioned under harsh environment. Less than 4% reduction in tensile, compressive and bending strength was observed for specimens without fibers. In general, virgin polymers were less susceptible to harsh environment as compared to 100% recycled and blend of virgin and recycled resins. Impact strength was more sensitive to conditioning than bending, compressive and tensile strength. Hardness properties were not seriously affected for the recycled polymers after aging. Based on the test results, it is concluded that the recycled polymers can be appropriately used with chopped or continuous fibers for long term structural or automobile applications with suitable knock-down factors.

ACKNOWLEDGEMENTS

The authors would like to acknowledge and thank Dr. Carl Irwin of NRCCE, West Virginia University, Dr. Darren Arola of MBA Polymers, Dr. Kwan Hongladarom of GE Plastics, Mr. Bob Schweizer of Owens Corning Company and Mr. Bill Ferrell of PPG industries for their support during different phases of this ongoing research.

CONVERSION FACTORS (ENGLISH TO SI)

1 ksi = 1000 psi = 6.89 MPa
1 kip = 1000 lbs = 4.45 kN
1 msi = 1000 ksi = 6890 MPa
1 inch = 25.4 mm

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Appendix K: Task 2.4

POLYMER ALLIANCE ZONE PRE-EMPLOYMENT TRAINING

RECYCLE WORK FORCE DEVELOPMENT

Polymer Alliance Zone – Pre-employment Training (PAZ-PET) and West Virginia University Parkersburg (WVU Parkersburg)

The PAZ- PET is a consortium of Polymer Zone member companies, educational providers, PAZ and the WV Development Office whose mission was to train and establish a readily available pool of workers for the companies in the Polymer Alliance Zone counties of Wood, Jackson, and Mason in West Virginia.

The PAZ-PET was organized in October of 1999 and developed a curriculum that delivered training to prospective employees of the member companies. The training was delivered by industry trainers who were experienced Polymer company employees. The training offered was based on projected hiring in the member companies. Three classes were trained with 42 graduates and 13 of the graduates were hired.

The design of the program allowed the prospective employee to see and tour the work sites of the member companies. The training was high quality and provided the employers with a first hand look at potential employees while they are in the training environment.

In order to serve the needs of the PAZ this project was designed to expand the scope of the PAZ-PET to include the potential training of a workforce to support the anticipated de-manufacturing and recycle of end-of-life electronic equipment. This was an innovative application of polymer firm production and required an innovative design of curriculum; instead of “ready made” curriculum harvested from the training resources of member companies the recycle training program. The PAZ-PET/R required development of new materials and associated with support jobs that are not wide spread in the industry.

The PAZ-PET coordinators had expertise in development of the materials, and in the innovative delivery of the new designed curriculum. The project used current administrative structure, e.g. the PAZ-PET coordinator was the administrative coordinator and the WVU Parkersburg as the management service and fiscal agent. WVU Parkersburg had the resources to provide the needed expertise in training materials by drawing on current Polymer Industry knowledge, the training expertise of Business Industry and Development Services (BIDS) , and the vast store of knowledge in the marketplace.

PAZ-PET/R utilized a leadership team that was in place as the PAZ-PET using the expertise of the stakeholders as available and to develop additional expertise through research and development .

As a result of this effort, the PAZ-PET, the PAZ-PET/R, the PAZ, the “Recycle” Project, WVU Parkersburg improved the capacities for workforce development initiatives.

Project Priorities (goals, objectives, strategies)

Curriculums were developed for the projected jobs in the developing polymer EOL Electronics de-manufacturing and recycle industry. The project identified the job titles, duties, competencies and the level of need for training in the project geographic area. (Wood, Jackson, Mason counties in West Virginia)

Once the jobs were identified, teams worked to develop the task lists, job descriptions, and competencies required for the industry. Additional teams were designed to revise, and refine the curriculum for the jobs.

Regular leadership team meetings, that include status updates and progress reporting, were held to evaluate the project performance and direct the effort.

Coordination with Other Partners

WVU Parkersburg hired a PAZ-PET coordinator that partnered with key stakeholders in the PAZ and the Recycle project team to achieve the project objectives. Members of the PAZ-PET project management team attended various meetings of the larger project and had a working knowledge of the larger project and the contribution the job descriptions and the training curriculum of the total project.

WVU Parkersburg primary staff member for this project was David P. Bell, PH.D. Dean of BIDS. Members of the faculty and others were added as the project developed to fulfill the needs identified..

Evaluation Plan

Monthly progress reports to the PAZ-PET consortium were matched to the project and timeline. This ensured regular achievement of milestones throughout the project. A final report detailing the project measures of success and outcomes was developed at the conclusion of the effort. The following outcomes were achieved.

- Task lists, job descriptions and competencies for up to ten jobs needed in the polymer recycle industry.
- A selection process to select potential candidates for the training
- Curriculum supporting the workforce training needs for the polymer recycle jobs.
- Trainers and participants in a pilot training session
- Ongoing installed structure for the training of potential workers in the polymer recycle industry.

Slide 1

PAZ WORKFORCE DEVELOPMENT

- PAZ PRE EMPLOYMENT TRAINING PROGRAM (PAZ PET)

M& G Polymers USA, LLC

Concepts West

Star Plastics, Inc.

Ravenswood Polymer

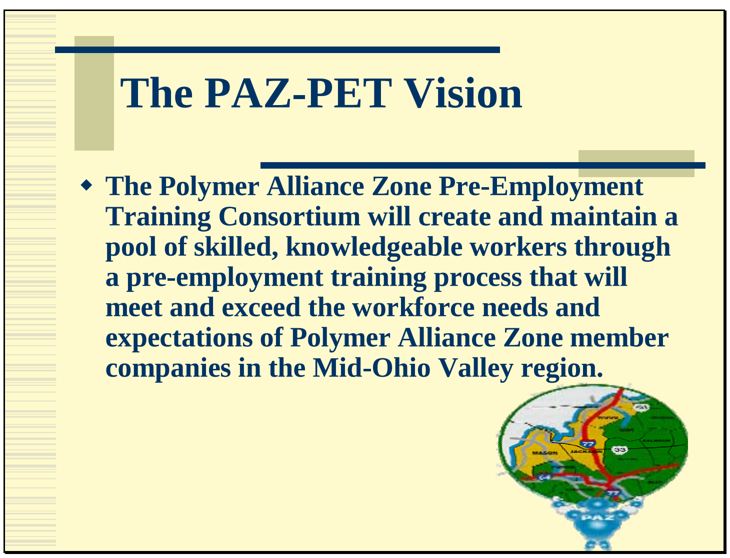
Slide 2

PAZ PET PARTICIPATING MEMBER COMPANIES

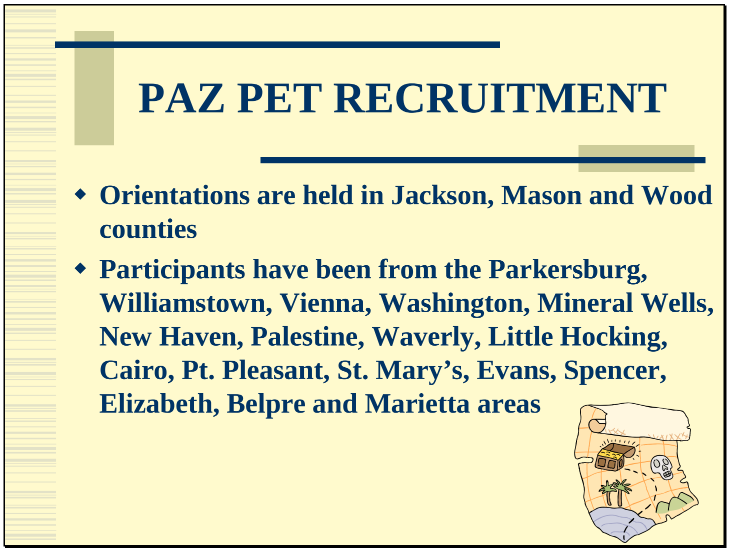
- Concepts West Corporation
- GE Plastics
- Greenpak, Inc.
- Ravenswood Polymer
- M & G Polymers
- SDR Plastics
- Star Plastics
- West Virginia Polymer Corporation

Slide 3

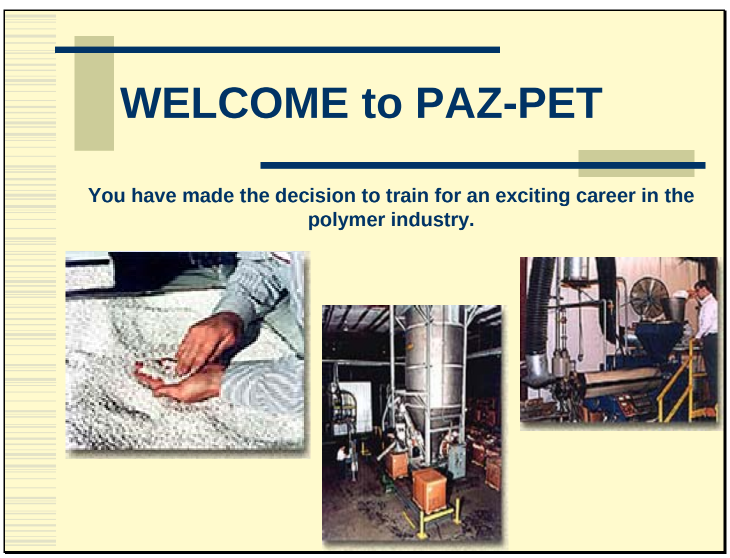
Slide 4



Slide 5



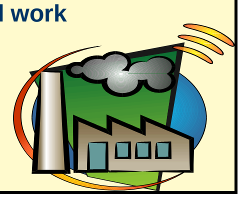
Slide 6



Slide 7

Successful graduates will demonstrate:

- A commitment to workplace safety & quality
- A strong work ethic
- Enthusiasm & adaptability
- A commitment to life-long learning
- Teamwork
- A knowledge of PAZ industrial work environments

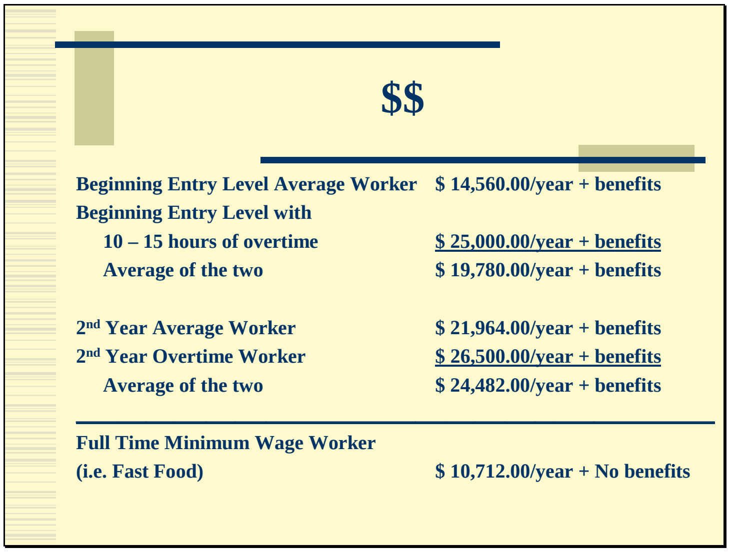


Slide 8

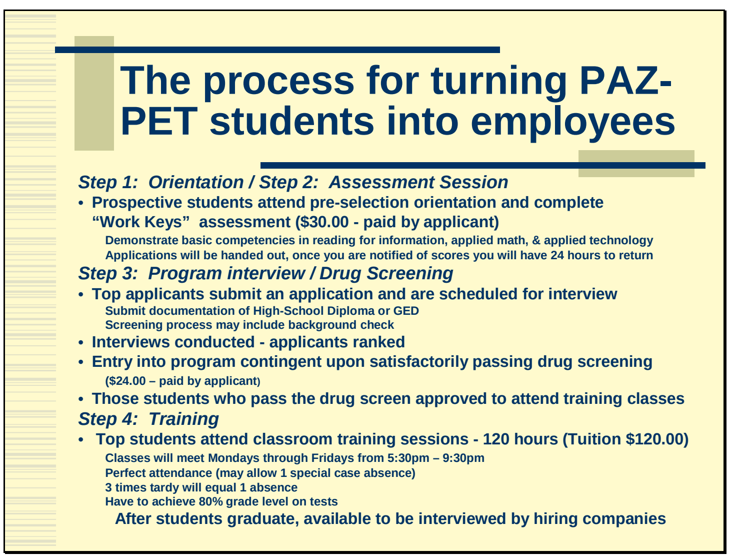
What is the polymer alliance zone pre-employment training (PAZ-PET) program?

- Designed to establish a labor pool continuum, providing work-ready entry level employees
- Administered through West Virginia University - Parkersburg's Business, Industry and Development Services
- With PAZ member companies providing curriculum and trainers to teach courses
- The program will operate based solely on the projected hiring demands of the member companies

Slide 9



Slide 10



Slide 11

PAZ PET CURICULUM

- Intro to Polymers – 8 hours
- Teamwork – 16 hours

- Quality – 16 hours
- Human Resources – 16 hours
- Safety – 24 hours
- Technology – 32 hours
- Plant Tours – 8 hours

Slide 12

ASSESSMENT SESSION TESTING SCORES

If you do not make the scores required for the Work Keys AND you would like to have additional training to help improve your work keys scores. Please contact one of the PAZ-PET members listed below:

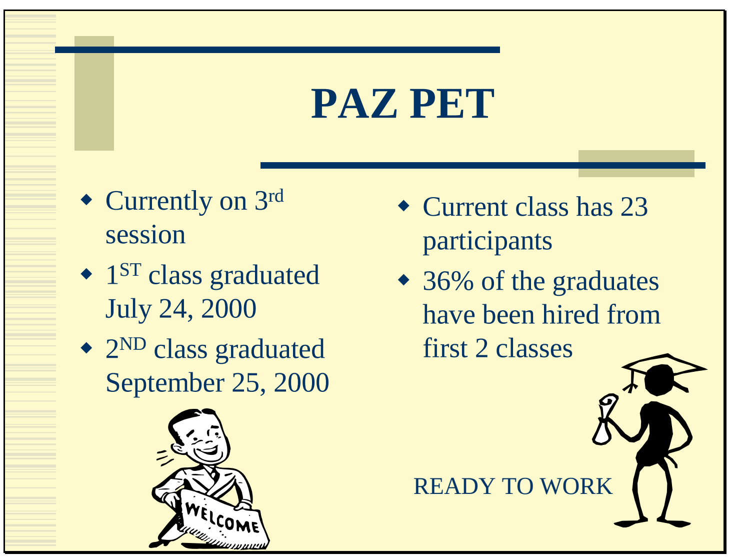
Mason County Career Center: Ruth Caplinger 304-675-3039

Roane Jackson Technical Center: Keith Winter 304-372-7335

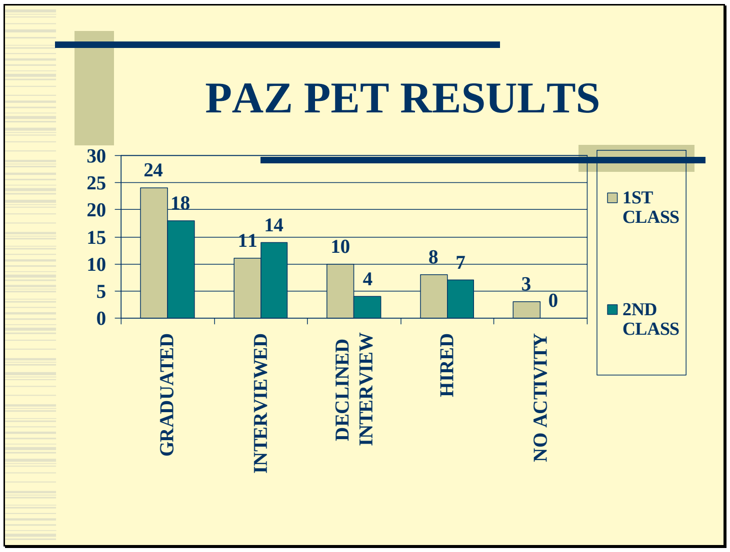
Wood County Adult Basic Education: Diane Flannigan

Slide 13

Slide 14



Slide 15


PAZ PET RESULTS
30
25
20
15
10
5
0
24
18
11
14
10
4
8
7
3
0
GRADUATED
INTERVIEWED
DECLINED INTERVIEW
HIRED
NO ACTIVITY
1ST CLASS
2ND CLASS

Appendix L: Task 2.6

Section 1

This appendix contains a list of all resources that have done articles or maintain links to the electronics recycling web portal developed under the MARCEE project.

American Plastics Council – Plastics from Electronics Update Vol 3. Summer 2001

Site can help find a new home for your old computer
Chicago Tribune; Chicago, Ill.; Jul 21, 2002; Mary Beth Breckenridge, Knight Ridder/Tribune;

Do It; Discarded Computers Mounting Up to Environmental Threat; * Government agencies and PC makers can help with recycling obsolete electronics equipment. [Home Edition] P.J. HUFFSTUTTER; The Los Angeles Times; Aug 9, 2001; pg. T.7

http://www.philly.com/mld/inquirer/2002/06/21/news/magazine/daily/3515300.htm - Philadelphia Inquirer article.

http://www.thestate.com/mld/state/living/home/3518880.htm - South Carolina Online Newspaper article.

http://www.pais.org/hottopics/2002/June/resources/web.stm - OCLC Public Affairs Information Service is a nonprofit publisher founded in 1914 and dedicated to providing better access to the literature of public affairs—current issues and actions that affect world communities, countries, people, and governments.

http://www.cyberstuff.net/worthwhile_archives.htm - Electronics Recycling article. CyberStuff is an Internet-based magazine whose charter is to explore the constantly changing digital world.

http://www.cis.utk.edu/wrap0602.html - University of Tennessee Center for Industrial Studies website. Electronics Recycling article.

http://dmoz.org/Business/Industries/Waste_Management/Recycling/Electronics/

http://www.co.mo.md.us/services/dep/Internet/recycling.htm - Montgomery County Maryland Department of Environmental Protection web site. Featured Site.

http://www.socrra.org/electronics.html - Southeastern Oakland County Resource Recovery Authority

http://www.usedcomputer.com/nonprof.html - List of resources.

http://www.web-of-life.com/connections.html - list of recycling resources.

http://www.resource-recycling.com/links.html - March 2002 article.

http://www.innovativemoves.com/pages/residentservices.htm - Information on electronics recycling page.

http://www.epa.gov/region02/p2/computer.htm - EPA region 2 page list of resources.

http://www.epa.gov/epr/products/eresources.html - US EPA product stewardship page.

http://www.epa.gov/reg5rcra/wptdiv/solidwaste/electronics.htm - US EPA Region 5

http://www.moea.state.mn.us/plugin/links.cfm - Minnesota Office of Environmental Assistance.

http://www.nxtcycle.com/consumerAwareness.php - Consumer Awareness site.

http://members.ptway.com/faic/computers.html - Benzie Shores Public Library Site.

http://www.michigan.gov/deq/1,1607,7-135-3585_4130-40945--,00.html - Michigan Department of Environmental Quality.

http://www.philly.com/mld/inquirer/2002/06/21/news/magazine/daily/3515300.htm - Philadelphia Inquirer article.

http://www.thestate.com/mld/state/living/home/3518880.htm - South Carolina Online Newspaper article.

http://www.mde.state.md.us/was/recycle/websites.html - Maryland Department of the Environment Office.

http://www.colby.edu/info.tech/green/directories.html - Education Site that lists resources on the web.

http://www.crra.com/rrarc/rrarcwebsites.htm - Resale, Reuse, Repair Council web resources page.

http://www.ohiodnr.com/recycling/research/ecycle/contacts.htm - Ohio Department of Natural Resources.

http://www.business2.com/webguide/0,1660,2244,FF.html - Web resources page.

http://www.electronicycle.com/other_resources1.htm - Electronic Recycling web resources page.

http://webtest.engr.scu.edu/related.htm - Santa Clara University Web Site.

http://www.analogzone.com/grnlinks.htm - GreenZone Links

http://www.oaklandpw.com/oakrecycles/links/ - Oakland Recycles web site.

http://www.ci.royal-oak.mi.us/dps/recytech.html - Consumer Support site.

http://www.pittsburghlive.com/x/tribune-review/living/homework/s_75099.html - Pittsburgh Tribune review.

http://www.acm.org/technews/articles/2001-3/0810f.html - ACM article on electronics recycling.

http://www.worldwise.com/reccomandpri.html - WorldWise web site on recycling.

http://www.computers4africa.org/old_computer.htm - Public Awareness site in Africa dealing with bridging the digital divide.

http://www.usedcomputer.com/nonprof.html - Information on how to recycling electronic equipment.

http://www.cis.utk.edu/wrap0602.html - University of Tennesee - Center for Industrial Services http://www.p2pays.org/electronics/ - Site with a page devoted to electronics recycling.

http://www.uoregon.edu/~recycle/electronics_text.htm - University of Oregon Computer Recycling Page

http://www.wastecapwi.org/resources.htm - Wisconsin Waste Reduction and Recycling Assistance Page.

http://www.thegreenscene.com/ - Environmental site with a section on electronics recycling

http://www.socrra.org/faq.html - Southeastern Oakland County Resource Recovery Authority

http://www.epa.gov/epaoswer/non-hw/reduce/wstewise/wrr/ceres.htm - EPA Waste Wise Site

http://dep.state.ct.us/wst/recycle/comprecy.htm - Conneticut Department of Environmental Protection Page.

http://www.wamu.org/computerguys/recycling.html - American University Radio Page

http://www.nxtcycle.com/consumerAwareness.php - Article on website relating to electronics recycling.

http://www.thegreenscene.com/links.html - Links to recycling related information

http://textonly.mde.state.md.us/Programs/LandPrograms/Recyling/links/index.asp - Maryland Department of the Environment

http://www.anjr.com/newsite/links/links.html - Association of New Jersey Recyclers

http://www.cyberstuff.net/worthwhile_archives.htm - Listed on their resources page.

http://www.epa.gov/epr/products/eresources.html - Product Stewardship page

http://www.moea.state.mn.us/plugin/links.cfm - Minnesota Office of Environmental Assistance Page.

http://www.zentech.org/links.html - Electronics Recycler located in Atlanta Georgia

http://www.epa.gov/reg5rcra/wptdiv/solidwaste/electronics.htm - EPA Region 5 Page

http://www.epa.gov/Region2/p2/computer.htm - EPA Region 2 Page

http://www.resource-recycling.com/links.html - North America's Recycling and Composting Journal

http://www.wired.com/news/print/0,1294,41996,00.html - Wired News Article

http://directory.google.com/Top/Business/Energy_and_Environment/Waste_Management/Recycling/Electronics/ - Google Web Directory

http://www.hotwired.co.jp/news/news/technology/story/20010816309.html - Japanese Digital Media News Site

http://www.envorgs.com/orgs/recycling.html - Environmental Organizations Online website.

http://www.excite.de/directory/Business/Industries/Waste_Management/Recycling/Electronics - Excite Search Engine in Germany

http://www.wgnradio.com/shows/kathy_judy/links.htm - WGN News and Talk Radio Segment (1/13/2003)

http://www.dnr.state.oh.us/recycling/research/ecycle/contacts.htm - Ohio Department of Natural Resources

http://www.usa.canon.com/templatedata/AboutCanon/stakeholderdialoguesrecyc.html - Canon OEM Article on Stakeholder Dialogue

http://www.business2.com/webguide/0,1660,2244,00.html - Business 2.0 web guide

Section 2

Statistics for ElectronicsRecycling.org

Domain Report for Month Ending December 2002

	Domain Name	Number of requests	Percentage of the bytes
1.	[unresolved numerical addresses]	47,892	35.12%
2.	.net (Networks)	30,265	26.84%
3.	.com (Commercial)	30,843	20.2%
4.	.edu (USA Higher Education)	3,727	3.83%
5.	.gov (USA Government)	1,144	2.42%
6.	.ca (Canada)	840	1.56%
7.	.us (United States)	1,417	1.24%
8.	.mil (USA Military)	600	0.87%
9.	.org (Non Profit Making Organizations)	970	0.84%
10.	.uk (United Kingdom)	659	0.83%
11.	.es (Spain)	227	0.56%
12.	.jp (Japan)	185	0.50%
13.	.be (Belgium)	80	0.41%
14.	.th (Thailand)	87	0.40%
15.	.mx (Mexico)	113	0.34%
16.	.fr (France)	62	0.33%

17.	**.ie (Ireland)**	**44**	**0.32%**
18.	**.ir (Iran)**	**14**	**0.30%**
19.	**.il (Israel)**	**15**	**0.30%**
20.	**.cz (Czech Republic)**	**99**	**0.30%**

Web Statistics for ElectronicsRecycling.org

Quick Summary for month ending December 2002

Quick Summary		Peak Entry	Value	%Total
1.	Most common search query	electronics recycling	104	0.9%
2.	Most common processing time range	0.2 -0.5	26,302	21.59%
3.	Virtual host causing the most redirections	www.electronicsrecycling.org	959	0.79%
4.	Most redirected request	**/menu2/industry/directory/registration1.asp**	719	0.60%
5.	Most active failed request	**/<rejected-by-urlscan>**	2,612	2.14%
6.	Most active organization	**66.109**	14,189	11.64%
7.	Most active failed referrer	**http://www.electronicsrecycling.net/menu2/industry/resources...**	175	0.14%
8.	Virtual host causing the most failures	www.electronicsrecycling.org	1,692	1.39%
9.	Most active browser type	**MSIE**	88,850	72.92%
10.	Most active day of the week	Monday	23,589	19.37%
11.	Most active browser	check_http/1.1.1.1 (nagios-plugins 1.3.0-alpha1)	11,297	9.28%
12.	Most active referrer URL	**http://www.electronicsrecycling.net/menu2/search/eiasearch.a...**	21,335	17.51%
1	Most active host	66.109.177.10	14,078	11.56%

3.				
14.	Most active hour of the day	16:00 - 16:59	8,915	7.31%
15.	Most requested directory	**/images/**	63,995	52.52%
16.	Most active redirected referrer	**http://www.electronicsrecycling.org/epa/eCyclingForms/SelectEvent.aspx**	35	0.2%
17.	Host causing the most redirections	crawl4.googlebot.com	172	0.14%
18.	Most requested search word	recycling	662	0.54%
19.	Most active domain	**[unresolved numerical addresses]**	48,050	39.43%
20.	Most popular operating system	**Windows**	91,710	75.28%
21.	Most active referrer site	**http://www.electronicsrecycling.org/**	44,051	36.16%
22.	Most requested file type	**.jpg [JPEG graphics]**	64,707	53.10%
23.	Most active virtual host	www.electronicsrecycling.org	104,790	86%

Web Statistics for ElectronicsRecycling.org

Organization Report for month ending December 2002

	Organization	Number of requests	Percentage of the bytes
1.	66.109	14,171	0.94%
2.	googlebot.com	8,103	0.28%
3.	12	7,657	7.33%
4.	aol.com	5,101	3.29%
5.	rr.com	2,934	2.89%
6.	comcast.net	2,282	2.30%
7.	cox.net	1,924	1.74%
8.	level3.net	1,899	1.78%
9.	pacbell.net	1,781	1.63%
10.	mindspring.com	1,362	1.8%
11.	attbi.com	1,299	1.27%
12.	uu.net	1,137	1.11%
13.	bellsouth.net	1,112	0.84%
14.	adelphia.net	1,023	0.84%
15.	fastsearch.net	1,014	0.2%
16.	uswest.net	954	0.89%
17.	swbell.net	931	0.86%
18.	dsl-verizon.net	764	0.72%
19.	verizon.net	762	0.62%
20.	ameritech.net	758	0.53%

Web Statistics for ElectronicsRecycling.org

Search Query Report for month ending December 2002

Search Query		Number of requests
1.	electronics recycling	104
2.	computer recycling	91
3.	pc recycle	27
4.	pc recycle bellevue	22
5.	computer recycle	22
6.	pc recycle seattle	20
7.	electronic recycling	20
8.	recycle electronics	19
9.	recycle computers	16
10.	refurbishment	16
11.	waste	14
12.	st vincent depaul seattle	14
13.	recycling electronics	13
14.	recycling information	13
15.	recycling computers	12
16.	computer recycling san diego	11
17.	electronicsrecycling.net	11
18.	how to register a company	10
19.	recycling	10
20.	san diego computer recycling	10

Appendix M: Task 2.7

Proceedings of the National Electronics Stewardship Workshop

National Conservation and Training Center
Shepherdstown, West Virginia

February 26 – 28, 2001

Sponsored by

Department of Defense
Department of Energy
Department of Interior
Environmental Protection Agency
United States Postal Service

Hosted by

Polymer Alliance Zone of West Virginia
West Virginia University

Acknowledgements

The National Electronics Stewardship Workshop was the culmination of the efforts of numerous individuals. The sponsors and hosts of the Workshop gratefully acknowledge the contributions of the guest speakers, panelists and participants. The credit for the planning and execution of this successful event goes to the following individuals.

Organizing Committee
Patricia Dillon, Tufts University
Kevin Doxey, Department of Defense
Mike Fanning, United States Postal Service
R.V. "Buddy" Graham, Polymer Alliance Zone of West Virginia
Gordon Hui, Environmental Protection Agency
Robert Jarcho, Department of the Interior
Clare Lindsay, Environmental Protection Agency
Jagdish Malhotra, Department of Energy
Alan Martin, West Virginia University
Tom Morehouse, Institute for Defense Analyses
Greg Pitts, Ecolibrium
Jeff Tucker, DN American
Ernest Woodson, Office of the Federal Environmental Executive

Workshop Logistics Support
Thelma Flynn, National Conservation Training Center
Pat Trentini, West Virginia University Conference Services

Professional Facilitation
Molly Mayo, Meridian Institute

Workshop Overview

On February 26-28, 2002 the Environmental Protection Agency (EPA), the Department of Defense (DoD), the Department of Energy (DOE), the Department of the Interior (DOI) and the United States Postal Service (USPS) convened the National Electronics Stewardship Workshop (NESW) in Shepherdstown, West Virginia. The workshop was hosted by the Polymer Alliance Zone of West Virginia and West Virginia University.

The sponsoring Federal Agencies entered into a Memorandum of Understanding (MOU) on Improving Environmental Management of Electronic Assets in the months preceding the workshop. The MOU committed these Agencies to developing a common strategy and practices to improve the quality, performance and environmental management of electronic assets throughout their lifecycle.

The NESW was a first step in executing the MOU. The purpose of the event was two-fold:

1) To discuss how the Federal government can better manage its own electronic products through innovative procurement strategies, effective disposition at end of life (e.g., recycling), and better federal program coordination; and
2) To discuss how the Federal government can help to advance the development of "greener" electronic products and increased reuse and recycling of electronics in the nation at large.

The two-day workshop combined presentations and panel discussions with breakout sessions on the following topics:

1) Current state of the art in recycling for industry and the federal government;
2) Emerging technologies to reduce electronics' environmental footprint;
3) Achieving best practices in government;
4) Policy and regulatory issues; and
5) The Federal government role in building the electronics recycling infrastructure.

Appendix A provides a detailed agenda.

The workshop actively engaged 140 representatives of the Federal government, states, the private sector and non-profit organizations. The Federal government and private sector predominated with over 50 attendees each. A list of participants is in Appendix B.

All participants received a background reference document (see Appendix C) at the meeting that included a copy of the Memorandum of Understanding between the sponsoring federal agencies and an overview of U.S. electronics stewardship activities, commissioned by the sponsor for this event. The overview summarizes current Federal procurement programs and initiatives to recycle end-of-life electronics, and Federal policies and programs designed to influence Federal Agencies as well as other constituencies. The reference document also includes a draft electronics recycling policy statement, authored by a non-profit agency, intended to promote an economically and environmentally sustainable recycling system for used electronics.

The workshop resulted in a series of recommendations for the Federal government, including:

Best Practices for Government Procurement and EOL Management of Electronics

- Need for consistent and coordinated high-level Agency-wide policies to provide leadership and accountability from acquisition through end-of-life (EOL) disposition, including minimum technical standards for providers of reuse, recycling and disposal services.
- Deploy a new Executive Order on Acquisition of Environmentally Preferable Electronics, and guide its development by:
    - Forming a Task Force to identify environmentally preferable attributes for electronic products and develop contract language for purchasing that takes EOL disposition into account.
    - Conducting pilot projects on purchasing environmentally preferable electronics in various Agencies.
- Provide grants and other partnership arrangements to recipients of Federal equipment donations to ensure intended use and proper EOL management.
- Develop recycler certification and pre-qualification program.
- Educate and communicate with Agencies on procurement options (e.g., leasing, take back, or trade in) and Total Cost Ownership/Life Cycle Cost management.
- Create a new Interagency Coordinator function to provide guidance to Agencies, coordinate education and communication, and help achieve economies of scale.

<u>Opportunities for Public-Private Sector Collaboration</u>

- Characterize and quantify the supply of EOL electronics and establish capacity needs for recycling infrastructure.
- Develop a materials declaration process to aid in procurement, EOL management and supply chain management.
- Research key alternative technologies (e.g., lead free, flame retardants).
- Initiate multi-state consumer electronics recycling pilot to test infrastructure capabilities and state and local coordination.
- Identify gaps and optimize the capabilities of the existing recycling infrastructure, while facilitating strategic alliances, where needed, to fill technology and capacity gaps.
- Invest in recycling technology research, specifically plastics.
- Develop environmentally preferable recycling strategies (e.g., for glass and plastics).
- Develop national industry-led recycling program with multi-stakeholder involvement.
- Develop consistent, coordinated and unambiguous regulation and remove regulatory barriers to recycling electronics.

A detailed summary of breakout group discussions and recommendations is in the next section.

Breakout Group Discussions and Recommendations

Below is a narrative summary of each breakout session. The summary presentations from each breakout session are in Appendix D. Originally, five breakout sessions were planned. Participants were allowed to choose which breakout session to attend. Due to the number of participants registered for breakout sessions 1 and 3, and the similarities in the topics, these sessions were combined.

Breakout Session 1: Best Practices for Effective and Efficient Management of End-of-Life Electronics by Government

This Breakout Session addressed two questions:

- What are the best EOL management practices for government?
  - e.g., procurement, reuse, recycling
- What is required to identify and implement best practices across agencies?

Twenty-three participants attended this session, characterized as a high quality, constructive and spirited discussion. The group was composed of 15 representatives from 7 government agencies (EPA, DOE, DOD, DOD, DOJ, GSA, USPS, DOI), 3 original equipment manufacturers, 3 recyclers and 2 research/academics.

The group discussed the sustainability of current government practices and the potential to "raise the bar" in the future. Some discussion focused on the positive and negative aspects of current donation practices. The group recognized that recyclers and re-manufacturers do not utilize the same procedures/techniques to process equipment, and that there is a need to consider the full range of electronic equipment (e.g., non-PC electronics, military and national security equipment) not just PCs.

It was agreed that the MOU was an appropriate and effective interagency coordinating charter. However, Agency participation should be expanded.

The Breakout Session provided a list of best practices for government, including:

- Consistent and coordinated high-level Agency-wide policies to provide leadership and accountability from acquisition through EOL disposition. These should include minimum technical standards for providers of reuse, recycling and disposal services, and provide flexibility to Agencies to accommodate unique missions and needs.
- Executive Order 12999 plus other donation mechanisms. Donations demonstrate good stewardship but are not a means of disposal. Grants and other partnership arrangements should be provided to recipients of donations to ensure intended use and proper EOL management.
- Recycler certification and pre-qualification.
- Education and communication of procurement options (e.g., leasing, take back, or trade in).
- Total Cost Ownership/Life Cycle Cost management
- Interagency coordinator to achieve economies of scale and education

Breakout Session 2: Internal Government Policies as a Driver for Better Product Design and Recovery

This breakout group tackled two questions:

1. how to include Design for the Environment (DFE) and other factors in government procurement (e.g., toxics use reduction, longer life, ease of reuse and recycling) and
2. how the government can improve its procurement and EOL management practices.

The group was quick to make distinctions between two categories of products that the government buys: 1) commercial, off-the-shelf products (of which computers are typical, but not the only type of such products); and 2) specialty products (usually those specified by the DOD and USPS for special purposes). In each case there are different opportunities to make a difference.

The group discussed how the “acquisition and logistics planning” process is the place to begin to include DFE and EOL considerations. All agreed that it is important to make sure that the appropriate stakeholders are brought in from the beginning, including acquisitions professionals, Chief Information Officers (CIO’s) and the property management professionals to make sure that all considerations are weighed and balanced upfront.

The group identified education about the need for better electronics design and end of life management as an important task for procurement and property management personnel in the government. Security issues were also acknowledged as potentially important constraints on the ability of the government to specify design changes and to require electronics reuse or recycling at end of life.

The recommendations of this breakout group centered on sending a strong assignment (combined with incentives and accountability) to Federal agencies to build environmental considerations into their purchase of electronics equipment. The first recommendation was to obtain a new Executive Order on Acquisition of Environmentally Preferable Electronics. This EO should be directed at Chief Information Officers (CIOs) and the Senior Acquisition officials in agencies. The requirements of this EO should then be folded into the FAR and the DFAR. To assist in developing such an EO, the agencies that signed the MOU on Electronics Stewardship should form a Task Force to identify environmentally preferable attributes for certain types of electronics. On this Task Force should be represented the OMB Office of Federal Procurement Policy as well as the procurement community from interested Federal agencies.

Pilot projects should be conducted on purchasing environmentally preferable electronics in various agencies and the result should be written up in case studies to inform the process of developing the EO. These case studies and other vehicles for educating agencies on how to identify and purchase environmentally preferable electronics should be developed.

The Task Force should also develop contract language for purchasing that would take into account end-of-life management right up front when electronics are purchased. Such contract language could require suppliers of electronics to take those products back when they are no longer needed.

The Task Force should also work with experts at GSA and other agencies to highlight the life cycle economic benefits of procuring and using and managing at end of life environmentally preferable electronics. Highlighting the economic benefits to agencies of seeking these kinds of products will serve as an incentive for agencies to move in this direction. As part of this, the Task Force should evaluate the costs and benefits of lease verses. purchase contracts.

Breakout Session 4: Public-Private Collaborations to Overcome Design, Technology and Other Challenges

The discussion in Breakout Session 4 focused on opportunities for government and non-government participants to share perspectives on how they can best work together to examine toxics associated with electronics products (and potential substitutes), demanufacturing and recycling technology challenges. The session also discussed how best to coordinate various Federal initiatives under different agencies and make sure these initiatives are meeting crucial public needs. Seventeen participants attended this session.

The session began with brief introductions of each of the participants, revisiting ground rules for the session and presentation of the key questions to be addressed, and an agreement on the process to answer the questions. The basic approach was to begin with a brainstorming session on issues and challenges.

The group addressed the following questions:

- What are the key needs in research, design, and technology development?
- How do we encourage multi-stakeholder collaboration?
- How do we better coordinate existing programs within the government?

Key Research Needs

- Quantify/characterize the supply of EOL electronics
  - Where is the stuff
  - What is in the old/existing equipment
    - Hazardous materials/waste levels and fate
- Develop recycling information on key products, e.g. displays
- Invest in recycling technology research, specifically plastics
  - Recyclers (small and private) need assistance
- Develop a materials declaration process
  - To aid recycling and supply chain management
- Understand toxicology of EOL electronics
- Multi-disciplinary involvement
  - Designers, manufactures, recyclers
  - Incorporate environment and life cycle on the front end
- Develop and implement DFE tools for manufacturers
- Establish capacity needs for recycling infrastructure
- Develop environmentally preferable recycling strategies (e.g. glass and plastics)
- Research key alternative technologies (e.g. to lead and BFRs)

The group suggested a focused effort that addresses these key needs, using the MOU to develop an action plan and multi-agency budget proposal.

How to Encourage Multi-stakeholder Collaboration

- Define benefits to all
- Funding - both public and private
- Structure (e.g., a consortium like SEMATECH or MCC)
- Multi-agency initiative under MOU
- Engage supply chain
- Strengthen recycler/OEM relationship (perhaps through IAER)
- Be focused (e.g., design competition - OEM, academia, NGO)

How to Coordinate Government Programs

- Increase government support of recycling infrastructure
- Multi-stakeholder knowledge base (who is doing what, access to results)
- Use MOU to convene multi-agency program review
- Reconvene Electronics Federal Asset Management Task Force
- Discussion of CRT handling under Universal Waste Rule
- Coordinate states regulation on EOL electronics

Many in the group pointed out that the persons in Agencies who are responsible for buying ubiquitous electronics (like computers, telephones etc.) tend to buy large quantities of new equipment without checking with the intended users of this equipment about whether they really need the "latest and greatest". The result is a lot of equipment is purchased that is not really needed and adds to the challenge of finding an appropriate disposition for used equipment.

Finally, the group recognized that, at least for civilian agencies, there may not be appropriate feedback to them on the costs of managing end of life electronics because they may not have to bear these costs. Many agencies send their retired equipment to GSA for final disposition. GSA has to pay to manage this material. Without charging back to the source agencies the costs of managing end of life electronics there is no visible incentive for agencies to buy less or to ask for take back by the suppliers or to lease rather than buy. The financial incentives to agencies have to be fixed in order to send the right messages.

Breakout Session 5: Public-Private Partnerships to Grow the Electronics Recycling Infrastructure in the US

The discussion in Breakout Session 5 focused on opportunities for the Federal government to partner with other stakeholders to grow the capacity and capabilities of the electronics recycling infrastructure. Thirty nine participants attended this session, including a balanced mix of representatives from federal, regional and state government, equipment manufacturers, trade associations, recyclers, not-for-profit organizations (advocacy and reuse organizations), and academic institutions.

Issues and Challenges: A Federal Government Role

To begin the session, participants were asked to identify key issues and challenges in electronics collection, reuse and recycling that would benefit from Federal government involvement or partnerships. Out of this process emerged a diverse set of issues, many of which were no surprise. The group was very interested in cooperative efforts and partnerships with the Federal government, and not "command and control" regulation. It was suggested that the federal government play a role in:

- identification and allocation of resources (including basic funding and existing resources) for electronics collection, reuse and recycling;
- clarification of existing regulatory systems (e.g., hazardous waste, transport, reclamation) and exploration of alternative systems and incentives, recognizing that any policies must be flexible enough to allow the industry and technology to evolve;
- coordination of national, state, and regional electronics collection and recycling programs in order to increase equipment volume and to foster communication and cooperation;
- identification and communication of best practices for recycling;
- coordination and support of recycling programs across federal agencies;
- determining whether the government should support an export market for materials, used products and components;
- procurement to drive product design changes and recycling practices;
- market development through incentives;
- ensuring that attention is focused on materials and components that pose a risk to public health and the environment (e.g., based on government and manufacturers lists of substances and products);
- challenging foreign government environmental policies that are not scientifically based or restrict trade;
- education and incentives for consumers, corporations and government (both generators and procurement);
- encouraging the development of efficient reverse logistics systems, for example, through the U.S. Postal Service; and
- removing subsidies for the extraction of virgin resources.

Potential Partnership Opportunities

The next charge to the participants in the Breakout Session was to brainstorm potential partnership opportunities, the goals of the partnership, and the role envisioned for the Federal government. Time was a limiting factor in the discussion. The ideas outlined below are not inclusive, nor do they represent a consensus on the priorities of participants.

Throughout the discussions, participants emphasized several fundamental concepts that the Federal government should consider when developing future partnership or initiatives.

- Partnerships should leverage existing resources and help contribute to the resolution of multiple problems (such as reduce wastes and create jobs).
- The electronics recycling infrastructure is an evolving, entrepreneurial industry. Care must be taken not to stifle innovation and creativity.
- The "industry" is comprised of multiple sectors (e.g., government, non-profits, private sector). Any efforts to grow the infrastructure should leverage off existing activities and

not unjustly favor one or more groups at the expense of others. Some participants voiced the opinion that the Federal government should not be a competitor itself or create competitors (through subsidies or basic funding) to the private sector.

- Education is needed at all levels: consumer, government and industry (particularly non-electronics).

Several participants provided examples of existing partnerships to illustrate possible partnership structures and participants. Examples included:

- Green Disk working with the U.S. EPA and the U.S. Postal Service with funding from the Small Business Administration;
- General Services Administration, District of Columbia, Per Scholas, and the US Postal Service;
- The State of Minnesota demonstration project with private industry (e.g., Sony, Waste Management and the American Plastics Council) to collect and process equipment;
- The Switzerland industry consortium, SWICO;

Participants proposed the following partnership opportunities for the Federal government. Again, these are preliminary ideas, and the list is by no means exhaustive. Time also did not allow for in depth discussion of each idea or the group to reach consensus on the goals of the partnership and the Federal government role.

Partnership Concept	**Issue Addressed**	**Goals**	**Role of Federal Government**
Multi-State Consumer Recycling Pilot	Coordination of recycling efforts at state and local level	• Test infrastructure capabilities & needs • Coordinate state approaches and issues • Industry involvement, similar to Minnesota	EPA to facilitate & provide leadership. EPA involvement gives states & local governments confidence that they are not acting contrary to EPA objectives and concerns, and that there will be consistency between local areas and states (e.g., data collection, regulations)
Optimize Capabilities of Existing Infrastructure	Identification and allocation of resources	• Infrastructure growth • Involvement across all sectors for economic and social optimization • Encourage free-market development	Facilitate strategic alliances and identify available resources (such as labor, buildings, reverse logistics, collection points)
Development of Industry-Led Recycling Program	Develop national recycling program	• Multi-stakeholder involvement • Consistent	• Regulatory clarification • EPA as facilitator to

		approaches and policies within U.S.	coordinate stakeholders & to identify high-level objectives for program • Promote a climate that would enable the development of such a program • Address regional differences (between states) to achieve as much unity as possible
Regulatory Initiatives	Regulations	• Remove barriers to recycling • Consistent approaches & policies within U.S. • Recognize that regulations need to change as system evolves	• Coordinate and facilitate process • Be sensitive to individual states issues
Build Capabilities of Charitable Organizations	Identification and development of existing resources	Utilize charitable organizations to help divert waste stream, similar to Massachusetts	• Consumer & corporate education • Grants to charitable organizations • Technical assistance

Appendix A

Agenda

National Conservation Training Center
Shepherdstown, West Virginia
February 26 – 28, 2001

Monday, February 26

3:00 **Complimentary tour - National Conservation Training Center**

4:00 - 6:00 **Registration**

6:30 **Introductory Dinner**

7:30 **Welcome**

*Debra Sonderman**, Director of the Office of Acquisition and Property Management, Department of the Interior***

8:30 **Informal Discussions**

Tuesday, February 27

6:30 **Breakfast**

8:00 **Welcoming Remarks**

Mona Womack, *Assistant Director, National Conservation Training Center*

8:15 **Opening Remarks by DOD, EPA and DOE**

Rear Admiral Daniel H. Stone, *Director, Logistics Operations, Defense Logistics Agency*

Michael Shapiro, *Acting Assistant Administrator, Environmental Protection Agency*

Robert Brown, *Assistant Manager for Asset Utilization, Oak Ridge*

Operations, Department of Energy

8:45 **Session 1: Current State of the Art in Recycling for Industry and Federal Government - Cost Effectiveness and Environmental Performance**

Industry Overview	***Diana Bendz,*** *Senior Location Executive, IBM*
Federal Government Overview	***David Drabkin,*** *Associate Administrator, General Services Administration*
Non-Profit Perspective	***Deborah MacFarlane,*** *President and CEO, Per Scholas*

10:00 **Break**

10:30 **Moderated Panel Discussion on the State-of-the-Art**

This session will address:

1. How the electronics recycling and demanufacturing industry operates. Specific issues include current reuse, recycling, demanufacturing techniques, business models, results, economics, environmental fate of materials, landfill and hazardous waste issues, differences among techniques and technologies, and other relevant factors influencing current operations.
2. The entirety of Federal Agency programs for electronics recycling, including procurement practices, disposition policies, collection methods, contracting for demanufacturing, economic considerations, scale of operation, problems, barriers, metrics, measuring results, compliance with existing environmental regulations, and other relevant program features.

Moderator

Greg Pitts	*Ecolibrium*

Panelists

Dennis Baca	*United States Postal Service*
Diana Bendz	*IBM*
Lauren Roman	*DMC*
David Drabkin	*General Services Administration*
Mark Hagerty	*NASA*
Deborah MacFarlane	*Per Scholas*
David Isaacs	*Hewlett-Packard*
James Wickemeyer	*Defense Logistics Agency*

11:45 **Lunch**

1:15 **Session 2: Emerging Technologies to Reduce Electronics' Environmental Footprint**

Moderated Panel Discussion on Emerging Technologies

This session will identify general trends in technology/products with potential environmental implications (positive and negative) and ongoing efforts to manufacture greener electronics, increase reuse and recycling, and improve demanufacturing technologies and techniques. Issues to address include economic, environmental and business implications and their applicability to Federal Agencies' programs.

Moderator

Tom Morehouse *Institute for Defense Analyses*

Panelists

David Bergman	*IPC*
Holly Evans	*Electronic Industries Alliance*
Mike Fisher	*American Plastics Council*
Nabil Nasr	*Rochester Institute of Technology*
Jackie Prince-Roberts	*Environmental Defense*
Mary Ellen Weber	*Environmental Protection Agency*

3:00 **Break**

3:30 **Session 3: The Evolving Playing Field – Policy and Regulatory Issues**

National Policy Initiatives: An Overview Presentation by EPA

Elizabeth Cotsworth, *Environmental Protection Agency*

4:00 **Moderated Panel Discussion**

This session will examine policy and regulatory changes worldwide, including procurement and disposition initiatives. The session will explore the economic and environmental implications of these policies, and the potential impact on Federal Agencies' programs and the growth of the electronics recycling infrastructure.

Moderator

Clare Lindsay *Environmental Protection Agency*

Panelists

Greg Cooper	*MA Department of Environmental Protection*
Elizabeth Cotsworth	*Environmental Protection Agency*
Gary Davis	*University of Tennessee*
Dewey Pitts	*IBM*
Lynn Rubinstein	*Northeast Recycling Council*
Doug Smith	*Sony*
Ted Smith	*Silicon Valley Toxics Coalition*

5:30 **Dinner**

7:30 **Informal Discussions**

Wednesday, February 28

8:00 **Session 4: Breakout Sessions**

Plenary discussion of Breakout Sessions

8:30 **Breakout Sessions (5 concurrent breakouts)**

1. **Best Practices for Effective and Efficient Management of End-of-Life Electronics by Government**: Opportunity for Government participants and others to discuss how Federal agencies could improve management of their own end-of-life electronics through such things as government-wide demanufacturing contracts, faster retirement procedures to increase resale possibilities, and better means of transferring electronics to schools.

   Moderator
   Mike Fanning *United States Postal Service*

2. **Internal Government Policies As a Driver for Better Product Design and Recovery**: Government participants can discuss with non-government participants ways that agencies can adjust their own procurement and other policies to encourage greener design of electronic products and more recovery of these products at end of life, and how such reforms can help save money and minimize administrative challenges for the government.

   Moderator
   Clare Lindsay *Environmental Protection Agency*

3. **Special Issues for Military and Non-Commercial Electronic Hardware and Software**: Discuss issues particular to the military, national security and other government sectors that involve sensitive equipment and data. Discuss

how these issues can be managed by affected government agencies to facilitate procurement of greener electronics for the government and greater recovery of these products at end of life.

Moderator
Tom Morehouse *Institute for Defense Analyses*

4. **Public-Private Collaborations to Overcome Design, Technology and Other Challenges**: Opportunity for government and non-government participants to share perspectives on how they can best work together to examine toxics associated with electronics products (and potential substitutes) and demanufacturing and recycling technology challenges. Also discuss how best to coordinate various Federal initiatives under different agencies and make sure these initiatives are meeting crucial public needs.

   Moderator
   Greg Pitts *Ecolibrium*

5. **Public-Private Partnerships to Grow the Electronics Recycling Infrastructure in the US**: Government and non-government participants discuss challenges to expanding collection, reuse and recycling of electronics and ways in which government can, in partnership with the private sector, help encourage increased collection and recycling of non-government electronic products while enhancing environmental performance.

   Moderator
   Patty Dillon *Tufts University*

10:00 **Break**

10:30 **Breakout Sessions** (continued)

11:30 **Lunch**

1:30 **Report of Breakout Sessions**

Rapporteur will have 10 minutes to report findings of session.

3:00 **Break**

3:30 **Session 5: The Federal Government Role in Building the Electronics Recycling Infrastructure**

Moderated Panel Discussion
This wrap-up session will discuss future steps for Federal Agencies and how Federal Agencies can better coordinate their various programs and work with

others outside the government to achieve common objectives. This session will elicit views from subject matter experts on ways to achieve better coordination of efforts, suggest new areas for cooperative effort, and better ways to exchange information. This session will also elicit suggestions to prioritize what can/should be done quickly and identify gaps that should be addressed and by whom.

Moderator

Molly Mayo	*Meridian Institute*

Panelists

Dennis Baca	*United States Postal Service*
Robert Brown	*Department of Energy*
David Drabkin	*General Services Administration*
Juan Lopez	*White House Task Force on Waste Prevention and Recycling*
Michael Shapiro	*Environmental Protection Agency*
Daryl White	*Department of the Interior*
James Wickemeyer	*Defense Logistics Agency*

4:30 Closing Remarks and Acknowledgments

R.V. "Buddy" Graham, *Polymer Alliance Zone of West Virginia*

5:00 Adjourn

Appendix B

National Electronics Stewardship Workshop

Participant List

Alexander, Michael	National Recycling Coalition
Alexander, Mary	US Postal Service
Allen, Derry	US Environmental Protection Agency
Amiro, Justin	Global Investment Recovery
Anthony, Diane	UNICOR, Federal Prison Industries Inc.
Aronson, Jesse	SAIC
Baca, Dennis	US Postal Service
Beling, Christine	USEPA New England
Bendz, Diana	IBM
Bergman, David	IPC
Beschen, David	GreenDisk
Boswell, Craig	HOBI International, Inc.
Bradley, Athena Lee	Oak Ridge Recycling Center
Bridgeman, Carolyn	Defense Logistics Agency
Brown, Robert	Department of Energy
Buffenbarger, Doug	Global Investment Recovery
Burlingame, Jack	Polymer Alliance Zone
Butler, Connie	Hewlett Packard
.Cassel, Scott	Product Stewardship Institute
Celorie, Jay	Hewlett Packard
Chang, Likow	Defense Logistics Agency
Cobb, Aaron	n/a
Collins, Lisa	DMC
Cooper, Greg	MA Department of Environmental Protection
Cotsworth, Elizabeth	US Environmental Protection Agency
Culver, Alicia	INFORM
Dastous, Andrew	Air Force Electronics Systems Center
Davis, Sheila	Materials for the Future
Davis, Willie	US Department of the Interior
Davis, Gary	University of Tennessee
Dellinger, Bob	US Environmental Protection Agency
Dillon, Patricia	Tufts University
Demiglio, Danny	US Postal Service
Doxey, Kevin	Office Secretary of Defense
Drabkin, David	US General Services Administration
Durbin, Marty	American Plastics Council
Evans, Holly	Electronic Industries Alliance
Fahey, Martin	SpaceFitters
Failor, James	Concurrent Technologies Corp
Fanning, Michael	US Postal Service

Fisher, Michael	American Plastics Council
Fotta, Mike	D.N. American
Fox, Elizabeth	Rochester Institute of Technology
Geiser, Ken	Lowell Center of Sustainable Production
Goldstein, Samantha	US Department of the Interior
Goode, Marilyn	US Environmental Protection Agency
Gorte, Julie	Calvert Group
Graham, R. V. "Buddy"	Polymer Alliance Zone, Inc.
Grogan, Terry	US Environmental Protection Agency
Grubb, Michael	Geo-Tech
Hainault, Tony	Minnesota Office of Environmental Assistance
Hagerty, Mark	NASA
Hanson, Bill	US Environmental Protection Agency
Hart, Kathy	US Environmental Protection Agency
Hayen, William	U S Postal Servcie
Heacock, Louis	NISH
Heston, Robin	NJ Department of Environmental Protection
Hui, Gordon	US Environmental Protection Agency
Isaacs, David	Hewlett Packard Company
Jacobson, Ray	US Postal Service
Jarcho, Robert	US Department of the Interior
Jordan, Charles	WV Solid Waste Management Board
Kantrowitz, Susan	US Environmental Protection Agency
Kenealy, Michael	SpaceFitters, Inc
Kirby, J. Ray	IBM Corporation
Kurtz, Kathy	National Industries for the Blind
Le, Van-Anh	Bae Systems
Lennon, Mark	Wuf Technologies
LeRoy, William	ECS Refining
Lindsay, Clare	US Environmental Protection Agency
Lobus, Ron	Envirocycle
Lopez, Juan D.	White House Task Force on Waste Prevention & Recycling
Lowery, Ruth Ann	Beveridge & Diamond, P.C.
MacFarlane, Deborah	Per Scholas
Malhotra, Jagdish	Department of Energy
Markgraf, Sharon	US Postal Service
Martin, Alan	West Virginia University
Martin, Cynthia	Defense Logistics Agency
Matza, Mark	Fortune Group
Matza, Sandra	Fortune Group
Mayo, Molly	Meridian Institute
McFarland, J. Don	Oak Ridge Recycling Center
Mikus, Tim	Texas Instruments
Mongiovi, Michael	US Army Industrial Ecology Center
Morehouse, Tom	Institute of Defense Analysis
Murphy, Cynthia	University of Texas

Nanton, Lori E.	NJIT
Naser, Ken	Department of the Interior
Nasr, Nabil	Rochester Instiitute of Technology
Naylor, Wayne	US Environmental Protection Agency, Region III
Nogas, Susan	US Environmental Protection Agency
Novicky, Larry	Federal Prison Industries
Osborn, Lory	West Virginia University
Patel, Nash	D.N. American
Pesachowitz, Alvin	Grant Thornton LLP
Pilkington, Steven	TAIC Inc.
Pitts, Greg	Ecolibrium
Pitts, Dewey	IBM Corporation
Prince-Roberts, Jacki	Environmental Defense
Reed, Claudette	US Environmental Protection Agency, Region III
Reitman, Jan	Defense Logistics Agency
Ritchie, Doug	SDR Plastics
Rosenbach, Julie	US Environmental Protection Agency
Rubinstein, Lynn	Northeast Recycling Council
Salazar, Viccy	US Environmental Protection Agency, Region X
Schall, Richard	US Postal Service
Schuck, Carl	Concurrent Technologies Corp
Shapiro, Michael	US Environmental Protection Agency
Sharp, Mark	Panasonic
Sheridan, Mary Beth	US Environmental Protection Agency
Sherwood, Vicki	DuPont
Singh, Dipti	US Environmental Protection Agency
Silverberg, Dana	NJ Department of Environmental Protection
Skurnac, Steve	Micro Metallics Corporation
Small, Mark	Sony
Smith, Doug	Sony
Smith, Joan	Javits-Wagner-O'Day Program
Smith, Ted	Silicon Valley Toxics Coalition
Stone, Rear Admiral David	Defense Logistics Agency
Sutton, David	Lockheed Martin
Tinder, Shelly	D.N. American
Tonetti, Robert	US Environmental Protection Agency
Trentini, Pat	West Virginia University
Tucker, Jeff	D.N. American
Varney, Norm	Lockheed Martin Corporation
Vickers, Maria	US Environmental Protection Agency, Region III
Voorhees, Greg	Envirocycle
Walker-Hall, Arlene	US Postal Service
Watson, Butch	Dell Computer
Weber, Susan	Department of Energy
Weber, MaryEllen	US Environmental Protection Agency
Wetzel, Roger	Energetics, Inc.

White, Daryl	US Department of the Interior
Wickemeyer, James	Defense Logistics Agency
Williams, Harold	Pitney Bowes
Wilson, Bill	US General Services Administration
Wolfson, George	Waste Management Asset Recovery Group
Womack, Mona	National Conservation Training Center
Woodson, Ernest	Whitehouse Task Force

Appendix C

Reference Document for

The National Electronics Stewardship Workshop

Memorandum of Understanding: Improving Environmental Management of Electronic Assets

The USPS, DoD, DOE, DOI and EPA are entering into this MOU to develop a common strategy for using environmentally preferable and energy efficient technologies and practices to improve the quality, performance, and environmental management of electronic assets throughout their life cycle.

<u>Overview of U.S. Electronics Stewardship Initiatives</u>

This paper was principally authored by Patricia Dillon for NESW. It provides an overview of current Federal procurement programs and initiatives to manage its end-of-life (EOL) electronic equipment. It then turns from internal management issues to Federal policies and programs designed to influence Federal practices as well as other constituencies, including industry, state and local governments and consumers.

Northeast Recycling Council (NERC) Regional Market Development Policy for Used Electronics

The NERC policy statement is intended to promote an economically and environmentally sustainable recycling system for used electronics, and to support reductions in the volume and toxicity of materials used to make electronic products.

Appendix N: Task 3.3.2

Summary of the Research Work

(Published in SAMPE conference-May 11-14, 2003)

THERMO-MECHANICAL CHARACTERIZATION OF RECYCLED THERMOPLASTIC POLYMERS AGED UNDER HARSH ENVIRONMENT

Vijay P.V., Hota V.S. GangaRao and Jose R. Basto
Constructed Facilities Center, College of Engineering and Mineral Resources
West Virginia University, Morgantown, USA

ABSTRACT

Characterization and application of recycled engineering thermoplastics referred to as electronic shredder residue (ESR), which is retrieved from discarded computers, monitors and printers are described in this paper. Mechanical characterization of virgin, blend of virgin and recycled, and 100% recycled polymers such as acrylonitrile butadiene styrene (ABS) and Polycarbonate (PC) conditioned under a harsh environment is carried out as a part of this research. Tension, bending, compression, impact, hardness and creep properties of the virgin, blend and recycled polymers are evaluated in this research. It was found that recycled polymers retain at least 70% of their tensile, bending and compressive strength after aging (conditioning) under harsh environment. Based on our test results it is concluded that recycled polymers have significant potential for high-volume infrastructure and automotive applications.

INTRODUCTION

The research results described in this paper focus on the evaluation of mechanical properties of ABS and PC thermoplastics obtained as ESR from computer and monitor housings in three forms, i.e., virgin, blend of virgin and recycled, and 100% recycled polymers. Since polymers alone may not have adequate strength or stiffness to meet special material property requirements for such applications as infrastructure or automobile parts, the polymers in this research are studied by adding fibers during the manufacturing process. Test samples were manufactured with and without glass fibers by special collaboration between CFC-WVU, Owens Corning Company, and PPG Industries.

OBJECTIVES

Objectives of this research are to:

- Characterize the strength of virgin and recycled polymers aged (conditioned) under harsh environment for a period of time, obtained from ESR after subjecting the specimens to 10 months of conditioning and test them in tension, compression and bending.
- Compare the tension, compression and bending strength, of virgin and recycled polymers and their blends before and after exposing them to aging process under harsh conditions.
- Characterize the impact and hardness properties of recycled and virgin polymers subjected to an aging process under harsh conditions.
- Characterize the long-term creep properties of fiber reinforced and non-reinforced thermoplastics.
- Evaluate the potential of recycled polymers and blends for infrastructure and automotive applications.

SCOPE

Recycled ABS and PC were evaluated for potential infrastructural and automotive applications based on their availability as ESR, suitability for mass production and cost consideration. More than 180 ABS and PC samples manufactured by Owens Corning were tested in tension, bending, compression, impact and creep. Testing and analysis of ABS and PC sample are continuing at CFC-WVU. The following sections provide: (1) materials and manufacturing, (2) test specimens and procedures, (3) results and analysis of tension, bending, compression, impact, hardness and creep tests, and (4) conclusions.

MATERIALS AND MANUFACTURING

Virgin and Recycled Polymers

Cycolac-GPM5500 ABS and Lexan-101 PC virgin resins evaluated in this study are manufactured by GE Plastics and have excellent impact strength, hardness, rigidity, and toughness properties. The resin grades of Cycolac ABS consist of elastomeric blends of polybutadiene or a butadiene copolymer and an amorphous thermoplastic component of styrene and acrylonitrile (SAN) and are easy to process (GE Plastics User's Guide, 1999). Lexan-101 polycarbonate resins have good electrical, optical, thermal, and mechanical properties including durability. The combination of these physical properties makes it one of the toughest, most versatile of all engineering thermoplastics (GE Plastics User's Guide, 1999).

ABS and PC recycled polymers were received as granulated shredded pellets and flakes with a size of 0.25" or less with a purity level above 95% from sources such as computer, monitor and printer housings. These were made available to the CFC-WVU research team by the MBA polymers, USA.

Glass Fibers

The 408A-14C CRATEC chopped strands supplied by Owens Corning with a length of 4mm, diameter of 14 μ and suitable sizing were blended with ABS. The 408A CRATEC strands have proven compatibility with many thermoplastic resins including ABS. The characteristics of the 408A CRATEC strands include optimized strand integrity, good glass dispersion, excellent mechanical properties, and excellent coupling with polymer systems.

Injection Molding

Injection molding of ABS samples was performed by Owens Corning while injection molding of the PC samples was performed by PPG. As shown in Table 1 six types of specimens were manufactured. Polymer pellets were uniformly blended by means of a screw extruder having L/D ratios of 24:1 and a compression ratio of 3.75:1) to achieve melt homogeneity and avoid material degradation and discoloration at transition sections. Melt temperature used for both the extrusion process and the injection molding was 530^o to 535^{o}F for ABS while for PC, the injection temperature was 300^{o}F to 315^{o}F and the molding temperature was 595^{o}F.

Table 1. Description of Different Types of ABS Specimens

Specimens	Description of Different Specimens
A1 – P1	Virgin ABS - PC polymer without fibers
A2 – P2	Virgin ABS - PC polymer with 25% (wt. %) chopped fibers
A3 – P3	100% recycled ABS - PC polymer without fibers
A4 – P4	100% recycled ABS – PC polymer with 25% (wt. %) chopped fibers
A5 – P5	ABS – PC: Recycled/virgin (20%/80%) blend without fibers
A6 – P6	ABS – PC: Recycled/virgin (20%/80%) blend with 25% (wt. %) fibers

Coupon specimens manufactured through injection molding allowed the researchers to conduct six types of tests, i.e., tension, compression, bending, impact, hardness and creep.

TEST SPECIMENS AND PROCEDURES

Test Specimens

The tension, bending, compression and impact test specimens were manufactured to the dimensions as per ASTM D638-94b (Type I specimen, showed in Fig.1), ASTM D790-92, ASTM standards D695-91 and ASTM D256-93a: method A, respectively. Dimensions of the 0.125” thick tension specimen are shown in Fig. 1. Bending specimens were rectangular with a length of 5", width of 0.5", and a thickness of 0.125". The compression specimens were rectangular with a cross-section of 0.5"x 0.25". Height of the specimens was 0.5”. Additional samples with heights 1" and 1.5" were also tested to establish the optimum height for minimizing and eliminating bending effects. Based on pilot testing, height of 0.5” was chosen, which provides an aspect ratio of 2. Dimensions of the impact test specimen including the notch are shown in Fig. 2. For creep test, tension test specimens were drilled with holes and the sustained load was applied by suspending known dead weights.

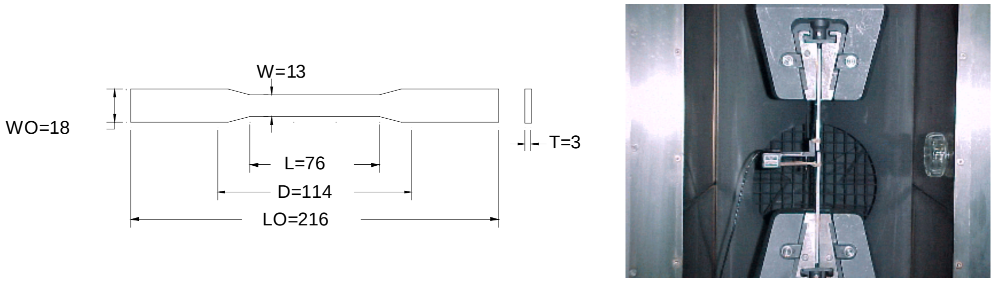


Figure 1. Tension Testing

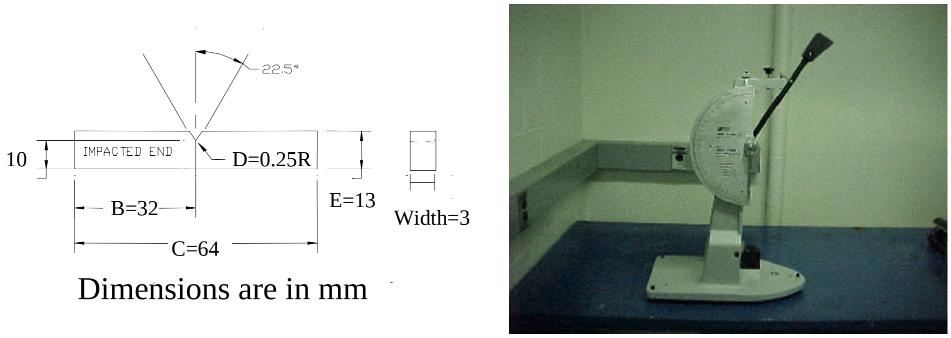


Figure 2. Impact Testing

Aging (Conditioning) of Samples

Samples have been kept immersed in a 3% NaCl (by weight) solution, in plastic containers placed inside an environmental chamber that runs the temperature cycle showed in figure 3, throughout the year. Samples were removed for testing at 2, 4, and 10 months of aging time. Compression specimens were only tested at 2 and 4 months. The study on Creep behavior does not include aged samples. Creep tests started on February 2000 and data have been recorded since then.

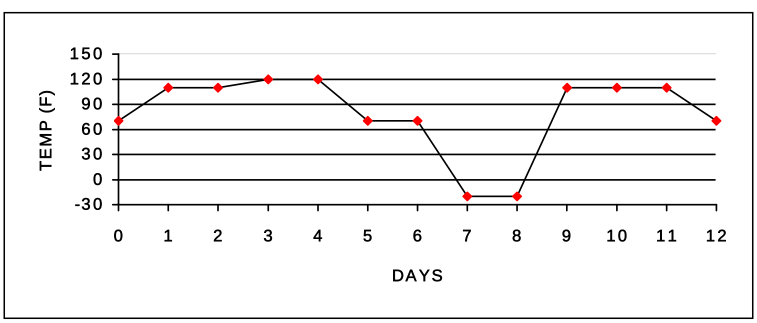


Figure 3. Conditioning Temperature Cycle

Test Set-up and Procedure

Each of the tension specimens was tested using an Instron Series 8500 Two-Column Load Frame as per ASTM D638-94b as shown in Fig. 1. The test was computer controlled at a load rate of 300 lbs./min using the 'wavemaker' software and the strains were automatically recorded with the use of extensometer having a gage length of one inch. For three-point bending tests, the rate of cross-head motion was set at 0.25 in./min. Tensile and compressive strains were recorded using a strain indicator at predetermined load intervals. The specimens were loaded to failure or until significant deflections in excess of 1/3 of the span were observed. For compression tests rate of cross-head motion was set at 0.05 in./min. The strains were recorded at predetermined load intervals. Each specimen was loaded to maximum load and beyond the yield zone. Maximum load, strain and reduction in length were recorded. The impact testing was conducted by using a BLI Series impact-testing machine at laboratory temperature of 72^0F. The final impact energy was obtained from the pointer reading and the type of break (i.e. H-hinge or C-complete) was recorded. The results were calibrated for pendulum friction and windage. The Hardness test was performed using a Duotronic Model 2000 hardness-testing machine as per ASTM D2240-91 with no weight. The hardness number was recorded from the Duotronic's visual display for each test. Creep test specimens were statically loaded at 20% and 50% sustained load, creep strains were recorded at regular intervals from strain gages placed at the middle of the specimens. Additional test procedure details are available in respective ASTM standards.

RESULTS AND ANALYSIS OF TENSION, BENDING, COMPRESSION, IMPACT, HARDNESS AND CREEP TESTS

Tension, bending, compression, and impact strength as well as hardness and creep properties results are compared to aged and non-aged samples and also between the specimens with and without fibers. The test data are summarized in Tables 2 to 6. Each result is an average of at least two specimens. Comparison values are at 10 months of aging, except compression, which was tested after 4 months of aging.

Tension

ABS: Reduction in tensile strength under conditioned state varied from 0.5% to 2.1% for specimens without fibers and 8.6% to 13.6% for specimens with fibers (Table 2). Strength gain of 2.4% was observed in fiber reinforced specimen A6 having a blend of recycled and virgin resins. Average reduction in tensile strength after 10 months of conditioning for samples with fibers was 11.1% as compared to 1.2% in samples without fibers (Table 2).

PC: Reduction in tensile strength under conditioned state was 3.8% for specimens without fibers and 17.7% to 22.2% for specimens with fibers (Table 2). Strength gain of 1.8% and 4.9% was observed in specimens P1 (100% virgin, no fibers) and P3 (100% recycled, no fibers) respectively. Average reduction in tensile strength after 10 months of conditioning for samples with fibers was 20.6% as compared to 3.8% in samples without fibers (Table 2).

In general, relatively higher reductions in tensile strength were observed for specimens containing blended (virgin and recycled) resins or 100% recycled resins, either with or without fibers.

Table 2. Tension Test Results and Comparison

Specimen Type	Max. Stress (psi)		% Change	Specimen Type	Max. Stress (psi)		% Change
	Original	Conditioned 10 months			Original	Conditioned 10 months	
A1	6174	6118	-0.9	P1	8664	8817	+1.8
A2	10299	9410	-8.6	P2	16479	12867	-21.9
A3	5578	5549	-0.5	P3	8566	8983	+4.9
A4	8800	7602	-13.6	P4	15213	12525	-17.7
A5	5916	5790	-2.1	P5	8926	8589	-3.8
A6	8911	9123	+2.4	P6	16555	12877	-22.2
Average reduction (-ve values only) without fibers (A1,A3,A5)			-1.2	Average reduction (-ve values only) without fibers (P1,P3,P5)			-3.8
Average change (+ve and –ve values) without fibers (A1,A3,A5)			-1.2	Average change (+ve and –ve values) without fibers (P1,P3,P5)			+1
Average reduction (-ve values only) with fibers (A2,A4,A6)			-11.1	Average reduction (-ve values only) with fibers (P2,P4,P6)			-20.6
Average change (+ve and –ve values) with fibers (A2,A4,A6)			-6.6	Average change (+ve and –ve values) with fibers (P2,P4, P6)			-20.6

Bending

ABS: Reduction in bending strength under conditioned state was 2.9% for specimens without fibers and 17.7% to 30.9% for specimens with fibers (Table 3). Strength gains of 18.4% were observed in specimen A1 having 100% virgin resin without fibers and 9.3% in specimen A5 having a blend of virgin and recycled resins with no fibers. Average reduction in bending strength after 10 months of conditioning for samples with fibers was 25.3% as compared to 2.9% in samples without fibers (Table 3).

Table 3. Bending Test Results and Comparison

Specimen Type	Max. Stress (psi)		% Change	Specimen Type	Max. Stress (psi)		% Change
	Original	Conditioned 10 months			Original	Conditioned 10 months	
A1	9080	10747	+18.4	P1	10242	14945	+45.9
A2	17771	14631	-17.7	P2	24566	25370	+3.3
A3	9187	8923	-2.9	P3	10363	17327	+67.2
A4	16740	12162	-27.4	P4	23198	28586	+23.2
A5	9558	10446	+9.3	P5	11168	15023	+34.5
A6	16509	11400	-30.9	P6	24886	23909	-3.9
Average reduction (-ve values only) without fibers (A1,A3,A5)			-2.9	Average reduction (-ve values only) without fibers (P1,P3,P5)			0
Average change (+ve and –ve values) without fibers (A1,A3,A5)			+8.3	Average change (+ve and –ve values) without fibers (P1,P3,P5)			+49.2
Average reduction (-ve values only) with fibers (A2,A4,A6)			-25.3	Average reduction (-ve values only) with fibers (P2,P4,P6)			-3.9
Average change (+ve and –ve values) with fibers (A2,A4,A6)			-25.3	Average change (+ve and –ve values) with fibers (P2,P4, P6)			+7.5

PC: No reduction in bending strength was observed except for 3.9% in specimen P6 with blended recycled and virgin resin with fibers (Table 3). Samples without fibers showed an average increase of 49.2% as compared to specimens without fibers that increased 7.5% (Table 3).

The results of Table 3 indicate higher reduction in strength for ABS specimens with fibers and reduced gains in strength for PC specimens with fibers.

Compression

ABS: Reduction in compressive strength under conditioned state was 1.4% for specimens without fibers and 10.9% to 19.9% for specimens with fibers (Table 4). Strength gains of 10.3% were observed in specimen A1 having 100% virgin resin, without fibers and 3.5% in specimen A5 having a blend of virgin and recycled resins, with no fibers. Average reduction in compressive strength after 4 months of conditioning for samples with fibers was 15.8% as compared to 1.4% in samples without fibers (Table 4).

PC: Reduction in compressive strength under conditioned state was 1.6% for specimens without fibers and 17.2% to 34.9% for specimens with fibers (Table 4). Strength gains of 10.1% were observed in specimen P3 having 100% recycled resin, without fibers and 4.3% in specimen P5 having a blend of virgin and recycled resins, with no fibers. Average reduction in compressive strength after 4 months of conditioning for samples with fibers was 28.5% as compared to 1.6% in samples without fibers (Table 4).

Table 4. Compression Test Results and Comparison

Specimen Type	Max. Stress (psi)		% Change	Specimen Type	Max. Stress (psi)		% Change
	Original	Conditioned 4 months			Original	Conditioned 4 months	
A1	8966	9886	+10.3	P1	10423	10259	-1.6
A2	1315	11698	-10.9	P2	20332	13539	-33.4
A3	8792	8670	-1.4	P3	10311	11348	+10.1
A4	14891	12440	-16.5	P4	20747	13509	-34.9
A5	8972	9287	+3.5	P5	10523	10979	+4.3
A6	13920	11151	-19.9	P6	21124	17500	-17.2
Average reduction (-ve values only) without fibers (A1,A3,A5)			-1.4	Average reduction (-ve values only) without fibers (P1,P3,P5)			-1.6
Average change (+ve and –ve values) without fibers (A1,A3,A5)			+4.1	Average change (+ve and –ve values) without fibers (P1,P3,P5)			+4.3
Average reduction (-ve values only) with fibers (A2,A4,A6)			-15.8	Average reduction (-ve values only) with fibers (P2,P4,P6)			-28.5
Average change (+ve and –ve values) with fibers (A2,A4,A6)			-15.8	Average change (+ve and –ve values) with fibers (P2,P4, P6)			-28.5

Impact

ABS: Reduction in impact strength under conditioned state was 1.5% to 25.7% for specimens without fibers and 16.4% to 25.7% for specimens with fibers (Table 5). Average reduction in impact strength after 10 months of conditioning for samples with fibers was 18.4% as compared to 13.6% in samples without fibers (Table 5).

PC: No reduction was observed in impact strength under conditioned state of specimens without fibers, However, reduction of 49.5% to 53.4% was observed for specimens with fibers (Table 5). Average reduction in impact strength after 10 months of conditioning for samples with fibers was 51.4%, average gain of 9.4% was observed for specimens without fibers (Table 5).

Table 5. Impact Test Results and Comparison

Specimen Type	Impact Stress (psi)		% Change	Specimen Type	Impact Stress (psi)		% Change
	Original	Conditioned 10 months			Original	Conditioned 10 months	
A1	3.49	3.44	-1.5	P1	14.15	14.59	+3.1
A2	1.58	1.32	-16.4	P2	3.01	1.40	-53.4
A3	2.17	-	-	P3	13.53	15.65	+15.9
A4	0.96	0.75	-21.7	P4	1.81	0.91	-49.5
A5	2.38	1.77	-25.7	P5	14.80	-	-
A6	1.20	1.00	-17.0	P6	2.67	1.32	-50.5
Average reduction (-ve values only) without fibers (A1,A3,A5)			-13.6	Average reduction (-ve values only) without fibers (P1,P3,P5)			0
Average change (+ve and –ve values) without fibers (A1,A3,A5)			-13.6	Average change (+ve and –ve values) without fibers (P1,P3,P5)			+9.4
Average reduction (-ve values only) with fibers (A2,A4,A6)			-18.4	Average reduction (-ve values only) with fibers (P2,P4,P6)			-51.4
Average change (+ve and –ve values) with fibers (A2,A4,A6)			-18.4	Average change (+ve and –ve values) with fibers (P2,P4, P6)			-51.4

Hardness

ABS: Reduction in hardness index under conditioned state was 0.9% for specimens without fibers and 2.7% to 3.6% for specimens with fibers (Table 6). Gain of 11.0% was observed in specimen A1 having 100% virgin resin, without fibers. Average reduction in hardness index after 10 months of conditioning for samples with fibers was 3.0% as compared to 0.9% in samples without fibers (Table 6).

PC: Samples without fibers showed an increase in index hardness of 1.9% to 4.7% and samples with fabrics showed an increase of 1.9 to 5.6% (Table 6). Average increase in hardness index after 10 months of conditioning for samples with fibers was 3.1% as compared to 3.8% in samples without fibers (Table 6).

Table 6. Hardness Test Results and Comparison

Specimen Type	Hardness Index		% Change	Specimen Type	Hardness Index		% Change
	Original	Conditioned 10 months			Original	Conditioned 10 months	
A1	10.90	12.10	+11.0	P1	10.60	11.10	+4.7
A2	11.30	11.00	-2.7	P2	10.70	11.30	+5.6
A3	11.10	11.10	0.0	P3	10.60	11.10	+4.7
A4	11.20	10.80	-3.6	P4	10.70	10.90	+1.9
A5	11.20	11.10	-0.9	P5	10.70	10.90	+1.9
A6	11.20	10.90	-2.7	P6	10.70	10.90	+1.9
Average reduction (-ve values only) without fibers (A1,A3,A5)			-0.9	Average reduction (-ve values only) without fibers (P1,P3,P5)			0
Average change (+ve and –ve values) without fibers (A1,A3,A5)			+3.4	Average change (+ve and –ve values) without fibers (P1,P3,P5)			+3.8
Average reduction (-ve values only) with fibers (A2,A4,A6)			-3.0	Average reduction (-ve values only) with fibers (P2,P4,P6)			0
Average change (+ve and –ve values) with fibers (A2,A4,A6)			-3.0	Average change (+ve and –ve values) with fibers (P2,P4, P6)			+3.1

Creep

For PC specimens at 50% of sustained load, specimens with and without fibers showed an average creep coefficient of 0.16 and 0.20, respectively, after 400 days. At 20% sustained load PC specimens with and without fibers showed an average creep coefficient of 0.20 and 0.23 after 400 days. Stress level increase from 20 to 50% didn't appear to have major effect on the creep coefficient of PC specimens.

ABS specimens without fibers tested at 50% sustained load failed with a a maximum creep coefficient of 0.32 on 17th day, whereas specimens with fibers failed with a maximum creep coefficients of 0.42 on 47th day. At 20% sustained load, after 400 days, an average creep coefficient of 0.48 was observed for ABS specimens without fibers as compared to 0.21 in specimens with fibers.

Creep behavior in resins was more prominent at lower sustained load levels (20%) as compared to higher sustained load levels (50%). At higher sustained load levels, chopped fibers contributed towards creep control. At 20% of sustained loading, PC specimens without fibers showed half the creep coefficient of ABS specimens (0.23 vs. 0.48). However, with fiber addition, creep coefficient in PC and ABS specimens at 20% loading were similar, i.e., (0.21 vs. 0.20).

Both PC and ABS specimens were not subjected to conditioning. Further testing will be carried out by Constructed Facilities Center at West Virginia University, to observe the creep behavior of conditioned recycled thermoplastics with and without fibers.

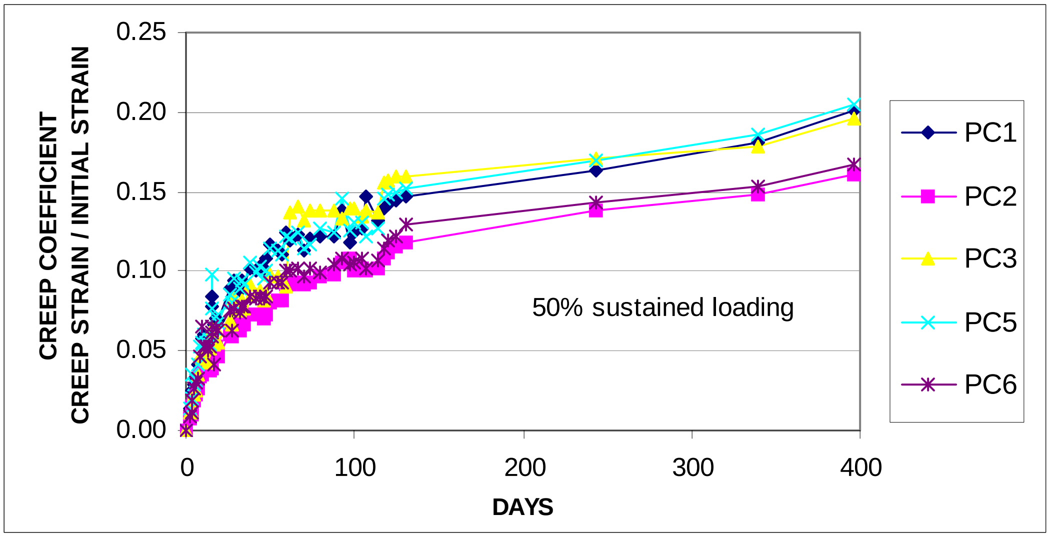


Fig. 5 Creep Curves with Fibers for PC (≈50% Ultimate Load)

For all of the above mechanical properties except creep, an increase in strength of some conditioned specimens after 10 months is attributed to possible secondary curing of the composite material. In addition, variation of results in some fiber-reinforced specimens is attributed to the random orientation of chopped fibers, which can affect the rate and magnitude of degradation depending upon fiber location, orientation and dispersion. It is reported that the water penetration at resin-glass interface of E-glass epoxy composite is reportedly 450 times faster than through resin alone (GangaRao et al., 1995; Springer, 1983). This indicates possible moisture penetration along the fiber/matrix interface to be between 2 to 3 orders of higher magnitude than the surface penetration. Hence, any short fibers at the surface of the specimens providing an easy interface for moisture penetration may cause higher mechanical property reduction.

CONCLUSIONS

Aging (conditioning) of fiber reinforced (chopped) and non- fiber reinforced thermoplastics ABS and PC manufactured from virgin and recycled electronic shredder residue (ESR) was carried out for a period of 10 months. After conditioning, the coupon specimens were tested to evaluate tension, bending, compression, impact, and hardness properties.

Tension, Bending and Compression Properties of Aged Recycled Polymers

- Reductions in tensile, bending, and compressive strength of ABS specimens were 1.2%, 2.9%, 1.4%, respectively, for specimens without chopped fibers. Reductions in tensile, bending, and compressive strength of PC specimens without chopped fibers were 3.8%, 0%, 1.6%, respectively.
- Average reductions in tensile, bending and compressive strength were a maximum of 3.8% for three categories of ABS and PC resins without fibers (virgin, 100% recycled, and blend of virgin and recycled).

- Reductions in tensile, bending, and compressive strength of ABS specimens were 11.1%, 25.3%, 15.8%, respectively, for specimens with chopped fibers. Reductions in tensile, bending, and compressive strength of PC specimens with chopped fibers were 20.6%, 3.9%, 28.5%, respectively.
- Average reductions in tensile, bending and compressive strength were a maximum of 28.5% for three categories of ABS and PC resins with fibers (virgin, 100% recycled, and blend of virgin and recycled).
- As expected, bending strength was found to be higher than the corresponding tensile values for all three types of polymers considered in this study.
- Higher reductions in strength of specimens with chopped fiber are due to existence of moisture "channels" that facilitate moisture diffusion along fiber/resin interface resulting in higher deterioration in specimens with chopped fibers. Use of continuous fibers or proper surface coating to seal off the open interfaces is expected to alleviate this problem.

Impact and Hardness Properties of Aged Recycled Polymers

- Average reductions in impact strength of ABS specimens with chopped fibers were 18.4% as compared to 13.6% for specimens without chopped fibers.
- Average reductions in impact strength of PC specimens with chopped fibers were 51.4% as compared to 0% for specimens without chopped fibers.
- Hardness properties of both ABS and PC specimens were not significantly affected in many of the specimens after conditioning.
- Reduction in impact strength for the blended, virgin and recycled polymers was more than the reductions in tensile, bending and compressive stresses.

Creep Properties of Aged Recycled Polymers

- For PC specimens at 50% of sustained load, specimens with and without fibers showed an average creep coefficient of 0.16 and 0.20, respectively, after 400 days. At 20% sustained load PC specimens with and without fibers showed an average creep coefficient of 0.20 and 0.23 after 400 days. Stress level increase from 20 to 50% didn’t appear to have any major effect on the creep coefficient of PC specimens.
- ABS specimens without fibers tested at 50% sustained load failed with a a maximum creep coefficient of 0.32 on 17th day, whereas specimens with fibers failed with a maximum creep coefficients of 0.42 on 47th day. At 20% sustained load, after 400 days, an average creep coefficient of 0.48 was observed for ABS specimens without fibers as compared to 0.21 in specimens with fibers.
- Creep in resins was more dominant at lower sustained load levels (20%) as compared to higher sustained load levels (50%). At higher load levels, chopped fibers contributed towards creep control.
- At 20% of sustained loading, PC specimens without fibers showed half the creep coefficient of ABS specimens (0.23 vs. 0.48). However, with fiber addition, creep coefficient in PC and ABS specimens at 20% loading were similar, i.e., (0.21 vs. 0.20).
- Sustained load level on ABS specimens is suggested to be limited to 20%. At 50% of sustained loading, PC specimens showed better capacity to carry sustained load than ABS specimens, either with or without fibers.

Based on test results, chopped fiber reinforced recycled thermoplastic polymers were found to retain at least 70% of their tensile, bending and compressive strength when conditioned under harsh environment. Less than 4% reduction in tensile, compressive and bending strength was observed for specimens without fibers. In general, virgin polymers were less susceptible to harsh environment as compared to 100% recycled and blend of virgin and recycled resins. Impact strength was more sensitive to conditioning than bending, compressive and tensile strength. Hardness properties were not seriously affected for the recycled polymers after aging. Based on the test results, it is concluded that the recycled polymers can be appropriately used with chopped or continuous fibers for long term structural or automobile applications with suitable knock-down factors.

ACKNOWLEDGEMENTS

The authors would like to acknowledge and thank Dr. Carl Irvine of NRCCE, West Virginia University, Dr. Darren Arola of MBA Polymers, Dr. Kwan Hongladarom of GE Plastics, Mr. Bob Schweizer of Owens Corning Company and Mr. Bill Ferrell of PPG industries for their support during different phases of this ongoing research.

CONVERSION FACTORS (ENGLISH TO SI)

1 ksi = 1000 psi = 6.89 MPa
1 kip = 1000 lbs = 4.45 kN
1 msi = 1000 ksi = 6890 MPa
1 inch = 25.4 mm

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Appendix O: Task 3.3.3

FINAL REPORT

MANUFACTURING AND EVALUATION OF STRUCTURAL PRODUCTS WITH RECYCLED POLYMERS

CFC 05-101

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Submitted to:
The National Energy Technology Laboratory
(NETL), US Department of Energy (DOE)

January 2005

Abstract

The rapid growth of Wastes from Electrical and Electronic Equipment (WEEE) can be attributed to the rapid developments in technology, leading to reduction in service life to less than 2 years in certain products. Thermoplastics such as Acrylonitrile-Butadiene-Styrene (ABS) and Polycarbonate (PC) form a significant percent of the Electronic Shredder Residue (ESR) that were used in this research to manufacture and evaluate structural products with recycled polymers.

In this research, offset blocks for highway and bridge guardrail systems were developed using recycled polymers reinforced with glass fabric as shell and discarded tire strips/wood as core materials. Optimum compression molding process parameters for typical manufacturing core block modules (12.5” × 4.5” × 2”) were 20 minutes of preheating followed by 15 tons of load application at 450° F for about 15 minutes, however, prototype offset block were preheated for about 30 minutes at 450° F followed by applying 30 tons of load for about 30 minutes at the same temperature. These blocks were successfully manufactured and installed near the Star city bridge, Morgantown, WV in 2004 and found to be in excellent shape after 8 months of installation based on visual inspection.

In order to evaluate mechanical properties of recycled polymers (ABS) used to manufacture offset blocks, coupon specimens were manufactured conforming to ASTM standards, with and without glass fabrics and tested in compression, tension, bending, and impact. A limited comparison was made with vinyl ester (thermoset) specimens with and without glass fabric and with specimens cut from a field-installed wooden offset block.

Use of chopped fibers reduced its impact resistance while use of continuous fabric increased the impact resistance of pure ABS whereas use of continuous fibers increased the impact resistance of pure ABS. ABS specimens with continuous fabric (bi-directional fibers) showed higher impact strength than the specimens cut from a field installed wooden offset block.

In order to study heat propagation in thermoplastics (ABS) during processing, a sliced section of a guardrail-offset block manufactured at CFC-WVU was tested for its heat conduction properties using infrared thermography. A finite element model was created to represent the manufactured specimen and analyzed under the effect of thermal loading. Results from FEM and thermography support the amount of time used to manufacture offset blocks.

Additional composite products like angle plates and dowel bars were manufactured using recycled ABS and their properties were evaluated under 3-point bending test. Optimum process temperature and pressure were suggested for laboratory manufacture.

Use of recycled polymer resins (thermoplastic ABS) for manufacturing structural/non-structural composite products and their mechanical property evaluation indicate significant potential for wide range of applications. Finally, recommendations based on this research and suggestions for future research have been provided.

ACKNOWLEDGMENT/ DISCLAIMER

The National Energy Technology Laboratory (NETL), US Department of Energy (DOE), sponsored this work. The contents of this report reflect the views of the authors who are responsible for the facts and accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of either the NETL or the DOE. This report does not constitute a standard, specification or regulation. Trade or manufacturers names that may appear herein are cited only because they are considered essential to the objectives of this report. The United States Government and the State of West Virginia do not endorse products or manufacturers.

Prepared for the National Energy Technology Laboratory (NETL), US Department of Energy (DOE).

MANUFACTURING AND EVALUATION OF STRUCTURAL PRODUCTS WITH RECYCLED POLYMERS

chapter 1

INTRODUCTION

General Remarks

Approximately 1 billion pounds of plastics are being produced in the United States each year, and used for various applications like packaging (29%), building (15%), consumer products (14%), transportation (5%), furniture (4%), electrical (4%), exports (13%), and others (16%) (Stevens, 2002). Plastic waste streams from post-consumer products such as electronic, automotive and appliance industries often contain high value plastics. Separating these mixed plastics and using them for manufacturing industrial products have reduced their deposition in the landfills.

Environmental concerns and reduction in the available landfill capacity have promoted recycling of plastics from disposal of electrical and electronic equipment such as computer casings, housings, switchboards, keyboards and other similar components known as electronic shredder residue (ESR). The automotive industry is another substantial source for recycled engineering plastics (ABS, PP, and PC). Shredder residues recovered from obsolete appliances, disassembled car parts, industrial scrap plastics and consumer electronics mainly consist of polycarbonate (PC), polypropylene (PP), and acrylonitrile-butadiene-styrene (ABS). PC, PP and ABS filled streams represent about 85% of the plastic content being recovered (Kobler, 2002). The recovered resins are mixed with adequate amount of modifiers, stabilizers and compatibilizers during extrusion to improve process ability to approach virgin-material specifications.

Recycled polymers have been a cheap source of material for manufacturing several plastic and composite products used in numerous applications. The applications of thermoset composites have been widely demonstrated in construction, marine/waterfront structures, repair and rehabilitation of highways, bridges and beams, corrosion reduction, and other structural alternatives (Busel, 1995). Designing, developing, manufacturing and implementing recycled thermoplastic composite products will help the crucial issue of disposing plastic materials.

In order to manufacture and evaluate recycled thermoplastic composite products for highway and automotive applications, this research focused on various factors such as materials, manufacturing techniques, structural integrity, and design requirements. Development of offset blocks for highway and bridge guardrail systems using recycled thermoplastics is one of the main goals of this study. This work on thermo-mechanical property characterization of recycled thermoplastics is a part of the ongoing research at Constructed Facilities Center, West Virginia University (CFC-WVU) (Bargo 2000, Basto 2002).

Objectives

The objectives of this research are to:

- Refine the design and manufacturing process of guardrail offset blocks with discarded rubber tire core and recycled polymer shell with glass reinforcement that was previously developed by Basto (CFC-WVU) to satisfy field installation requirements in terms of:
    - Dimensional requirements
    - Connection details
    - Use of pre-manufactured thermoplastics inserts
    - Constituent/Component integrity
    - Single vs. multiple offset block modules
- Identify processing parameters in terms of temperature, pressure and time for manufacturing the offset block with recycled polymers including optimum quantity of materials for manufacturing.
- Carry out finite element analysis on a section of manufactured offset block with thermal loading for identifying temperature profile within the sample and evaluate temperature increase with respect to time.
- Determine heat propagation in a coupon sample cut from the manufactured block exposed to a constant heat source through infrared imaging.
- Characterize strength and stiffness values of recycled ABS coupons (recovered from ESR) under tension, bending, compression and impact with and without glass fabric and make limited comparison with thermoset vinyl ester polymers.
- Carry out field installation of offset blocks manufactured with recycled polymers.
- Manufacture additional composite products such as angle plates (used as signpost, utility pole etc.) and dowel bars using recycled ABS, and characterize their mechanical properties.
- Evaluate manufacturing of composite products with new breed of thermoplastic-coated glass fibers composites (Twintex) and discuss its utilization for structural applications.

Scope

Coupon specimens

Tensile, bending, impact and compressive tests were carried out on coupon specimens made of recycled thermoplastic (ABS) and thermoset vinyl ester with and without glass fibers to observe and compare their mechanical properties. Limited comparison was made with thermoset vinyl ester-glass composite specimens and conclusions were drawn. Tests were also done on coupon specimens cut from a field installed wooden guardrail offset block and compared with those made of recycled polymers that were used to manufacture offset blocks for highway guardrail applications. Long-term performance of these specimens due to aging is not considered in this study.

Guardrail offset block

Offset block connects post and rail of a guardrail system (Figure 1-1). Single or two-stage manufacturing was used to produce prototype-offset block during this research. Recycled polymer comprising ABS, and PC recovered from computer casings (ESR), were used with discarded rubber tires as core material to manufacture offset blocks. In addition to rubber tire strips, wood was also used as a core material in some of the blocks.

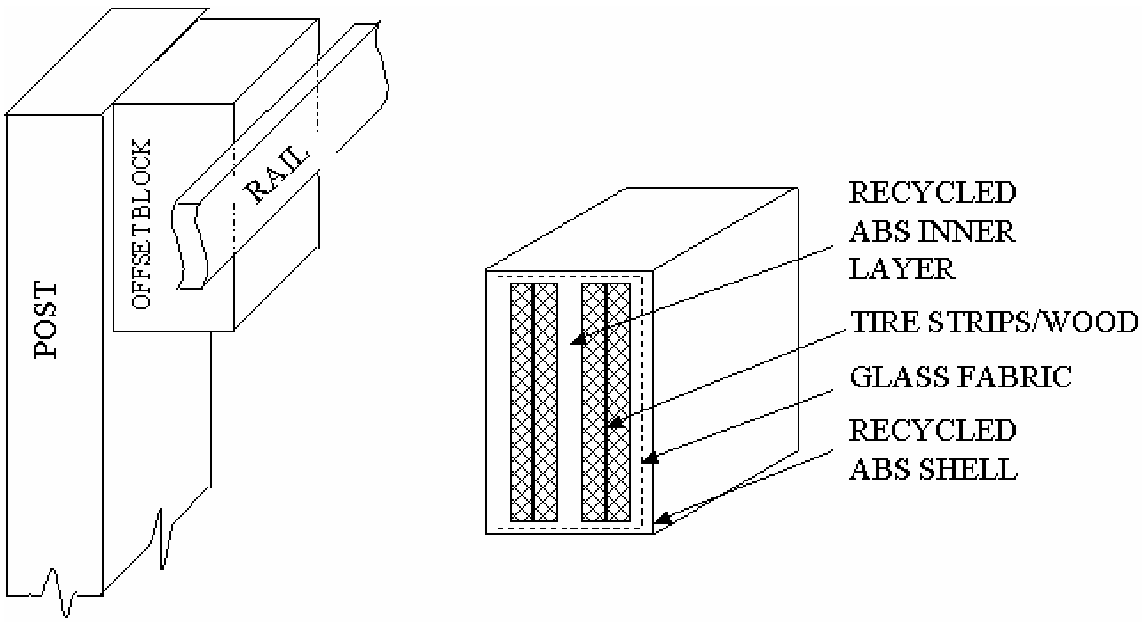


Figure 1-1 Guardrail system and cross-section of an offset block

Single offset block modules of thickness 6” to 8” thick were manufactured (Basto 2002). Processing parameters such as temperature, pressure and time were determined for manufacturing blocks or modules of different sizes. Several compression-molding trials were carried out to determine processing parameters for obtaining a good block with regard to uniformity in blending of resin pellets. Establishing and refining the manufacturing details for a final WVDOT specified dimension of 14”×6”×6” offset block was carried out, about 25 blocks were manufactured. Few of these blocks were installed in field near Star City Bridge, Star City, WV.

Heat conduction properties of guardrail-offset block were evaluated using infrared imaging technique by testing a sliced section and studying temperature profile with respect to time. A finite element model was created representing the offset block section used in the experiment and analyzed under the effect of thermal loading with respect to time.

Recycled composite products

Additional composite products such as angles and dowel bars were manufactured using recycled thermoplastics, mainly ABS through compression molding process. About 6 angles were manufactured using recycled ABS and glass fabric reinforcement and optimum process parameters in terms of temperature, pressure and time were determined after several trial of compression molding.

This report is organized into following chapters: Chapter 2 briefly discusses recycled materials, recycling methods, processing of polymers, application of recycled polymer composite products in various fields, including infrastructure. Chapter 3 includes details of the materials necessary to manufacture coupon specimens, their preparation and testing procedures used in this research. Chapter 4 explains manufacturing of guardrail offset blocks and provides process details. Chapter 5 presents test results of the specimens described in Chapter 3. Chapter 6 presents the manufacturing procedure for angles and dowel bars. Some of the tests performed on recycled polymer products are also discussed in this chapter.

Chapter 7 discusses application of infrared thermography, a non-destructive testing method to observe the heat flow pattern from mold to offset block specimen during manufacturing. Chapters 8 discusses results from finite element thermal analysis conducted on a sliced section of the offset block manufactured with recycled ABS reinforced with glass fabric, and discarded rubber tire strips. Chapter 9 provides conclusions drawn from this study and recommendations for future study.

CHAPTER 2
LITERATURE REVIEW

Recycling of plastics

Plastic recycling has become an established national industry with an expanding market for recycled plastic products. There are more than 1300 plastic products with recycled content known from the updates in Recycled Plastic Products Source Book by The American Plastics Council (Plastics Recycling, 2000). Potential recycling includes high-volume consumer products like soft drink bottles, discarded appliances, computers, and automotive wastes.

Waste management and recycling have been initiated due to the benefits as given below:

- Reduction in the need for disposal capacity
- Reduction in litter and improper disposal
- Reductions in energy use
- Reduction in manufacturing process impacts long-term value of conservation of raw materials

The process of waste reduction through recycling has many other advantages. Recycling reduces costs, creates jobs and businesses, and improves the environment and public health. By minimizing disposals in landfills, recycling helps in conserving global material resources.

The recyclable items reasonably viable in terms of technology and economics today are:

- Newspapers
- Aluminum and steel cans
- Glass bottles and jars
- Plastic beverage containers
- Electronic shredder residue
- Automotive wastes

It is important to realize that the recovery and reuse of waste materials, residue, or scrap is constantly changing and expanding. Technology continues to advance and new ways are being found to process and make use of discarded materials that were formerly part of the waste stream.

Electronic waste is considered to be one major source of plastics recovery through the recycling process. Recyclers process more than 1.5 billion pounds of electronics equipment, annually and it is further accelerated by environmental conscious designs, take-back programs (Descul, 2004). An analysis commissioned by the Microelectronics and Computer Technology Corporation (MCC) estimated that the total electronics plastic scrap amounted to more than 1 billion pounds per year.

Plastics recycling require good knowledge in following four areas viz.,

1) Collection of plastics

2) Separation
3) Reprocessing technology, and
4) Markets for recycled products.

Identification and recovery of plastic constituents

Individual component of the recycled plastic supply stream are separated using techniques such as grinding, washing, and rinsing the shredder residue followed by skin floatation in which air bubbles attach to specific materials and enable the polymers with overlapping densities to be separated. The process of separation begins with tearing the incoming materials by shredding them through a pulper. Various mechanisms like magnetic separator, eddy current device, disc screen, trommel screens, traveling chain screen, and an air classifier are used for the separation process (Bargo, 2000).

Different types of separation techniques based on material type, size and physical properties are:

- Recover ferrous material: Magnetic separator
- Recover aluminum material: Eddy current device
- Separate smaller from larger material: Disc screen, Trommel screen.
- Separate material according to mesh size: Vibrating screen, Oscillating screen.
- Separate according to density difference: Traveling chain curtain
- Separate light material from heavy material: Air Classifier

Some of the separation methods used for separation of recycled material stream are:

Manual separation: The method is used at the incoming feed belt to scavenge easily separable items like paper, cardboard, glass containers and so on. It is one of the oldest techniques with little importance in modern plants (Figure 2-1).

Gravity separation: Vibrating tables, ballistic separators, and inclined conveyors for removal of stones and other heavy particles and fluidized bed separators are the commonly used gravity separators (Figure 2-2).

Electrostatic separation: This method relies on the ability of some materials like plastics or paper, to acquire and hold an electrostatic charge. The particles are attracted to a charged roll or belt, or are deflected in an electrostatic field (Figure 2-3)

Figure 0-1 Manual separation of solid waste
(Ref: http://www-cee.engr.ucf.edu/classes/env4341/char6.htm)

Figure 0-2 Gravity separator
(Ref: http://www.garrattindustries.com/separator_410B.html)

Figure 0-3 Electrostatic separator
(Ref: http://www.vaec.gov.vn/ ITRRE/TTTK.htm)

Color separation: This method may find use in the separation of colored plastics, in sorting of glass, according to color.
Air classification: Size, shape and specific gravity of the particles make this process possible. Air is fed through columns in different directions depending upon the degree of separation.

End use market research programs continues to focus on and expand the market utilization of the full range of polymers from waste stream including poly-ethylene terephthalate, high density poly-ethylene, poly-vinyl chloride (PVC), poly-styrene, poly-propylene, poly-carbonates and acrylonitrile butadiene styrene. In the past decades a great deal of attention has been focused on recycling of plastics, both post-consumer commodity products, and engineering plastics as well. The global figure of dismantled cars was around 24 million in 1995, generating 2.2 million tons of plastic scrap (Liu, 1999).

Some of the recycled polymers and their market utility are described below:

Poly Ethylene Terephthalate (PET) – Growth of PET container recycling is continuing with a rapid increase in the use of plastic beverage containers. Major markets for recycled PET continue to be in carpeting, fiberfill, and unsaturated polyester, polyols for urethane foam, strapping, engineering plastics and extruded products. New applications like thermoformed products and textiles/geo-textiles also offer additional marketing opportunities. The major soft drink companies, Coca-Cola Co. and Pepsi Co, Inc., are trying to utilize recycled PET in soft drink containers.

Figure 0-4 Clear PET bottles
(Ref: http://www.trashtransformers.com.au/recycling_how_what.html)

High Density Poly Ethylene (HDPE) - Many communities are beginning to collect milk and water jugs and detergent containers for HDPE recycling. Products for recycled HDPE are soft drink base cups, plastic pipes, plastic lumber, and various containers including household chemical containers.

Figure 0-5 HDPE bottles
(Ref: http://www.belvac.com/)

Polypropylene (PP) – The list of products manufactured from recycled polypropylene PP resin include automotive batteries, bird feeders, furniture, pails, golf equipment, pallets, carpets to name a few.

Poly Vinyl Chloride (PVC) – Products not related to food or health care industries make excellent choices for manufacturing products from recycled (reprocessed) resins. Potential market includes downspouts, fencing and corrals, handrails, landscape timbers, sewer/drain pipe, telephone cables, window frames, refuse containers etc. A considerable amount of PVC is recycled as in-plant scrap.

Figure 0-6 Wheel barrow with green polypropylene hod
(Ref: http://www.easybarrow.co.uk/barrows/big_page_crs01.html)

Figure 0-7 Wilton woven with polypropylene fibers
(Ref: http://www.dencities.com/denmall/denmall-rugs5a.html)

Figure 0-8 PVC pipes
(Ref: http://www.fluorplast.fi/termoplastisetletkut.html)

Polystyrene (PS) – Some potential products that can be manufactured from recycled PS resin include insulation board, appliance housings, and various trays.

Acrylonitrile Butadiene Styrene (ABS) – ABS is recovered from automotive appliances as well as electronic shredder residue. Bumpers, body panels, lighting systems, computer component housings, switches, sockets, wiring harnesses and circuit boards form very reliable sources of ABS and few other plastics in commingled form.

Figure 0-9 ABS/PC major constituents in computer peripherals
(Ref: http://www.smc-alliance.com/gallery/gallery.html)

The polymers being recovered from computer casings, printer housings, and electronic applications providing electronic shredder residue comprises of combination of plastics, ABS and PC/ABS. The automotive shredder and electronic shredder residues are passed through a series of processing steps, which involve grinding, washing, and rinsing. Thermosets, polystyrene, nylon and other thermoplastics are removed by skin floatation stages. The effluent is treated and then discharged, while the recovered ABS, mixed plastics go to extrusion and pelletizing.

Previous research on recycled polymers

Dutta (1998) conducted an investigation of plastic composite materials for highway safety systems in 1998. Dutta's work on use of recycled polymers include highway barrier W-beam guardrail, posts, signposts, breakaway couplers, and crushable cushions for roadside sign or utility posts.

Guardrail systems for highway safety researched by Dutta included fiber reinforced polyester (FRP) and recycled plastics with saw dust as the fibrous additive. A 6.1 ft long fiber-reinforced plastic (FRP) composite W-beam is designed and studied. Three different thicknesses were produced and tested under bending and crash impact to lead the following results:

- Maximum tensile strength of 65,000 psi was obtained after producing a series of batches by trial and error, showing that this design process is more an "art than science".
- FRP showed higher fracture initiation energy than steel. Due to the brittle nature of FRP, lower post-fracture energy absorption was observed.
- Stiffness was about one third of steel's stiffness. But this was not considered as a problem, since original shape of FRP beams is effectively recovered after load application, even after fracture of specimens.
- Study suggests that thickness should be higher for the W-beam made of FRP as compared to steel and recommends further research on splicing and jointing mechanisms which are critical areas of research. The joints are known to have early failures in pullout tests.

Recycled composite bridge

The thermoplastic bridge in New Baltimore, New York utilized recycled plastics for field implementation. It is a single lane bridge, 11 ft wide with a 30 ft span, designed for AASHTO H-15 truck. Its primary load carrying deck (superstructure) was made out of fiber reinforced plastic lumber (FRPL) (McLaren, et.al. 2001). The material used for this bridge consisted of 70,000 recycled one-gallon milk jugs. The total weight of the superstructure was 11,000 lb with an addition of 5400 lb of steel connection plates.
Environment News Service(2003) describes first all-plastic vehicular bridge that used unreinforced I-beams and other components made from recycled plastics installed in New Jersey. The 42 ft single lane fire equipment access bridge over the Mullica River in Wharton State Park supports a loaded fire truck weighing 36,000 lbs. Post consumer recycled polymers like HDPE and Poly Styrene (PS) are used to develop a novel composite polymer material used for the bridge.

A recycled plastic bridge at Fort Leonard Wood, Missouri completed in 1998, on the Fort's Gammon Field used 13,000 pounds of recycled plastics. The structure was 25ft long and 26ft wide and supported by 6 steel beams that supported the original bridge and was designed to bear light-vehicles.

Engineers set I-beams made entirely from recycled plastics on a 42 foot span over the Mullica River in Wharton State Park, New Jersey.

—Photo courtesy of Rutgers University

Figure 0-10 Bridge over the Mullica River in Wharton State Park

Conclusions

Polymer recycling is an emerging technology that has gained a good pace in the recent years, to an extent that research on molecular design of more recyclable polymers and additives is being actively explored. Properly designed recycled products have a reasonable market in the industry.

Recycled polymer composites have great potential as highway structural and non-structural systems. Hence, manufacturing composite products using recycled thermoplastics and their mechanical property characterization were considered in this research.

Acrylonitrile Butadiene Styrene (ABS), the major constituent of ESR and ASR, was considered in this research. Compression molding process was used to manufacture recycled composite products. Guardrail offset blocks was considered as potential highway element that can be manufactured using recycled ABS reinforced with glass fabric and discarded rubber tire core. Other components such as angles and dowel bars were also considered as potential highway products made of recycled polymer composites.

CHAPTER 3
MATERIALS AND MANUFACTURING OF TEST COUPONS

Introduction

Mechanical characteristics of the recycled thermoplastics is very important especially when they are used as raw materials in the manufacture of structural and non-structural composite components related to different fields such as automotive, aerospace, construction and others. In a composite material, resins are combined with fibers to obtain products with specific properties such as high strength and stiffness. Fibers in a composite act as load-bearing elements whereas role of resin is to:

- Distribute applied loads to fibers
- Maintain fiber orientation
- Protect the fiber from environmental conditions

In this research, manufacturing process and processing parameters were determined based on the type of recycled thermoplastic resin (mainly ABS in our case). Glass fibers compatible with thermoplastic (ABS) resins were used to manufacture coupon specimens. In addition to ABS coupon specimens, vinyl ester specimens were prepared for comparison.

Description of the materials and summary of the testing procedure are provided in the following sections. Test specimens were manufactured in accordance with ASTM standards for tension, bending, compression, and impact tests.

Materials

Recycled polymers

Acrylonitrile Butadiene Styrene (ABS), Polycarbonate (PC), Polypropylene (PP) and recycled resins were made available for research by SDR Plastics, a recycling plant located in Ravenswood, West Virginia. Resins were available in the form of flakes/pellets and their average size was less than 0.25 in.

Glass fibers/fabric

Two types of glass fabric available from Owens Corning Company and BGF industries were used in this research. The fabric was cut to required shape and dimensions to suit the various molds used to manufacture coupon specimens. The glass fabric supplied by Owens corning consisted of long continuous fibers woven in 0^o, 90^o, and ±45°. The glass fabric supplied by BGF industries consisted of bi-directional weave, 0^o, and 90^o, compatible with thermoplastic resins. This glass fabric was used with both recycled ABS and vinyl ester to make coupon specimens. Two layers of fabric were used to mold samples for the tests.

Manufacturing of specimens

Molds complying with ASTM standards were designed individually for each type of test: tension, bending, compression, and impact. Due to fiber wetting problems observed with 1/8” thick specimens, molds were redesigned to obtain product thickness of 1/4”. Fiber volume fraction of 3.68% was maintained in tension, bending and impact test specimens, while fiber volume fraction of compression test specimens was 1.84%.

Tension test

Test specimen

Dimensions for the tension test specimen molded with recycled ABS, conform to ASTM D3039/D 3039M (Figures 3-1 and 3-2). Dimensions of the test specimen are presented in Table 3-1. A steel frame was designed to mold the tensile test specimens.

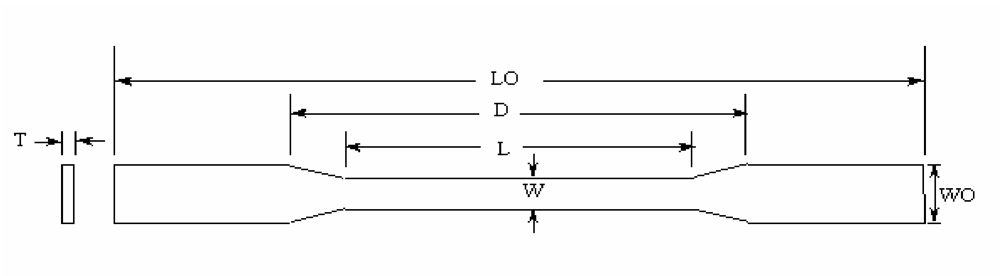


Figure 0-1 Dog-bone tension test specimen with recycled ABS

Table 0-1 Dimensions for tension test specimen

Width of narrow section (W)	0.5”
Width overall (WO)	0.75”
Length overall (LO)	8.5”
Thickness (T)	0.125”

To manufacture samples with fabric, fabric was cut in accordance with the shape and dimension of the slots in the mold. However, disorientation of fibers in the fabric was noted during the fabric cutting including loosening of fibers. Samples were made with and without fabric using recycled ABS and vinyl ester.

During later part of research, dog bone shape of the specimens was modified into rectangular shape. Steel tabs were attached to the ends of the rectangular test specimens to prevent slipping and crushing of the specimens at the grip location.

Specimen preparation

Test specimens were manufactured using compression molding equipment. Recycled ABS was filled into specific steel frame molds covered with aluminum plates (flash) for better surface finish and placed in between top and bottom plates of compression molding equipment. Surfaces of specimens were roughened at the ends for attaching steel plate grips using Pliogrip (adhesive).

Figure 0-2 Compression-molded tension test samples

Tension test setup and procedure

An Instron 8500 two-column load frame-testing machine was used for performing the computer controlled tension test (Figure 3-3). "Wavemaker" software provided by the loading frame manufacturer was utilized to carry out the tests. A constant head displacement rate of 0.2 in/min was applied to a test specimen and maximum 2" elongation was specified as the end point. Tests were done to find the load vs. elongation values including strain value measurement using extensometer.

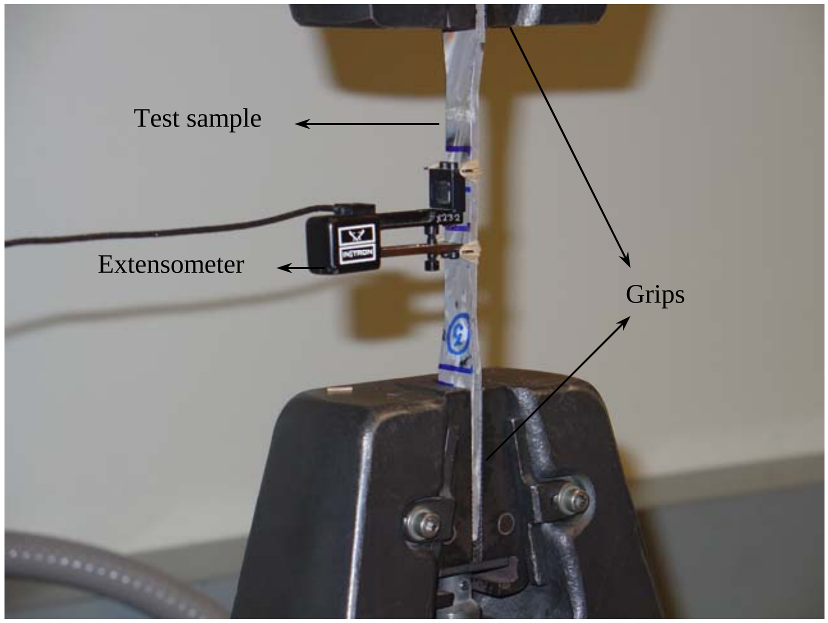


Figure 0-3 Tension test of recycled ABS specimen in Instron machine with extensometer

Bending test

Test specimen

Dimensions for bending test specimens molded from thermoplastic resin (ABS) were in accordance with ASTM D790-99 as shown in Table 3-2.

Table 0-2 Dimensions of bending test specimen

Width (W)	0.5”
Length overall (LO)	5”
Distance between the supports (L)	4”
Thickness (T)	0.25”

*Refer to Figure 3-4

Specimen preparation

A rectangular cross-sectioned 0.5”X 0.125” sample was molded according to ASTM standards, to a length of 5”. The thickness was increased to 0.25” to manufacture specimens with fabric. For further testing, specimens with dimension 10”×0.5”×0.25” (support span of 7.5” was maintained in all the tests) were molded with and without glass fabric using recycled ABS and vinyl ester.

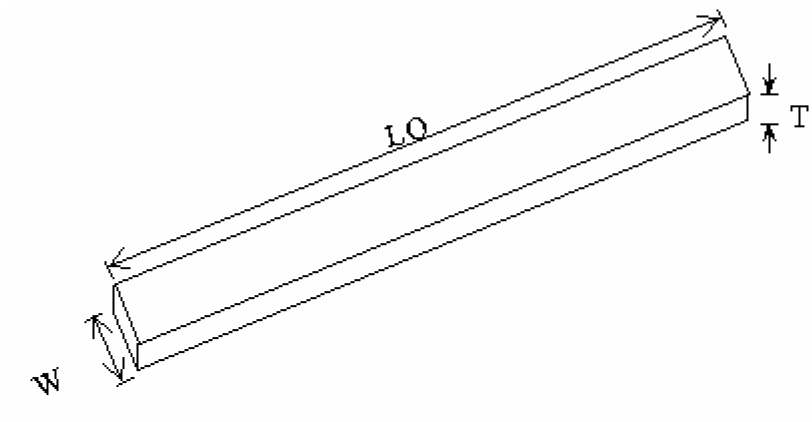


Figure 0-4 Bending test specimen with recycled ABS

Bending test set-up and procedure

Instron 8500 two-column load frame-testing machine was used for performing the computer controlled bending test (Figure 3-5). “Wavemaker” software provided by the loading frame manufacturer was utilized to carry out the tests while the strain data was recorded using a separate data acquisition apparatus installed with “Strain smart” software. Strain gauge was installed on the specimen at mid-span for strain measurement. A constant loading rate of 0.65 in/min was applied to specimen failure or until deflections greater than one third of the span were attained. The test was done to find load vs. deflection values of the specimens and test results are presented and analyzed in Chapter 5.

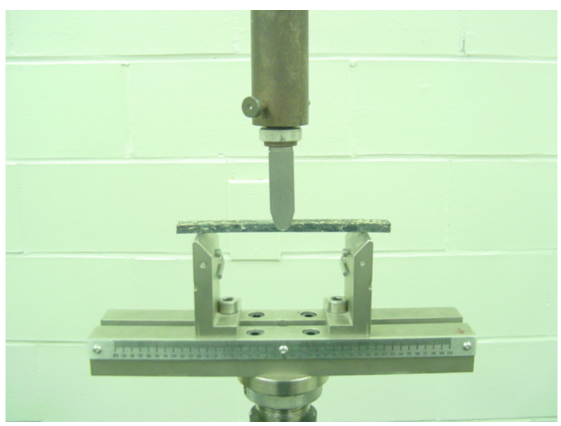


Figure 0-5 Bending test of ABS specimen with the loading head and supports

Compression test

Test specimen

Specimens with square cross section (0.5”) with height 1” were molded using thermoplastic resin (ABS). The dimensions were in accordance with ASTM D695-91 and an aspect ratio of 2 was maintained as shown in Figure 3-6.

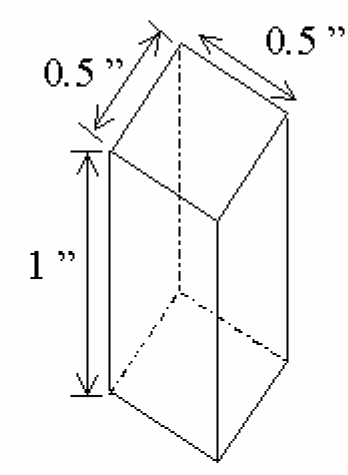


Figure 0-6 Compression test specimen

Compression test set-up and procedure

An Instron 8500 two-column load frame-testing machine was used to perform the computer controlled compression test (Figure 3-7). “Wavemaker” software provided by the loading frame manufacturer was utilized to carry out the tests. A constant loading rate of 0.01 in/min was applied to specimen until failure. The test was done to find the load vs. deflection values of the specimen.

Figure 0-7 Compression test set up for ABS specimen

Impact test

Test specimen

Specimens with rectangular cross section (0.5”× 0.125” ×2.5”) were molded with recycled ABS and were in accordance with ASTM D25-93A. The thickness was increased to 0.25” to manufacture specimens with fabric. Specimens with dimensions 0.5”×0.25”×2.5” were molded for further tests with and without glass fabric using recycled ABS and vinyl ester.

Specimen preparation

The molded specimens were notched at mid span, to a depth of 0.1” (Figure 3-8). The included angle in the notch was 45^o. Testing of the specimens was done after atleast 30 minutes for stress relaxation.

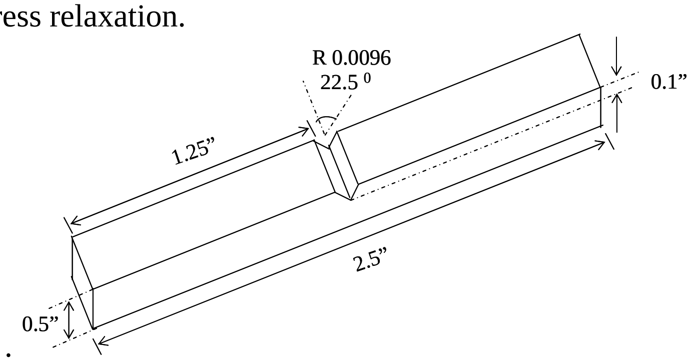


Figure 0-8 Impact test specimen with notch

Impact test setup and procedure

Izod type of testing was used, wherein a pendulum strikes the specimen and the impact strength value can be directly read from the scale attached. A BLI series impact-testing machine was used with no additional weights to the pendulum. A correction chart supplied by the manufacturer (BLI series manual, 1999) was used in accounting for pendulum friction and windage.

The pendulum was released freely without the specimen, and the pointer reading is noted. It is again released without setting back the pointer, until a steady value is obtained. These two values were plotted on the correction chart and a line as drawn to connect the both. Then, the values obtained from the specimens were plotted on this line to get the corrected values.

Summary

Dimensions of the test specimens and their manufacturing procedures were discussed in this chapter. The specimen preparation, test procedure and test instrumentation for compression, bending, tension and impact were also discussed in this chapter. The results of these tests were discussed in Chapter 5.

Chapter 4
MANUFACTURING OF THE GUARDRAIL OFFSET BLOCK

Introduction

Wooden offset blocks treated with Creosate oil were being used on guardrail systems on highways and bridges. Due to a potential attack of the on the groundwater table, research on use of alternate environmental-friendly materials (like recycled thermoplastics) were initiated. Offset blocks for the highway guardrail system were produced using recycled polymers with glass fabric reinforcement. Required design modifications were made to the recycled offset blocks previously manufactured at CFC-WVU to suit the type of steel post for guardrail system used by WV Department of Transportation. An offset block with recycled polymers consisted of energy absorbing core made of scrap rubber tires to absorb impact energy that was enclosed in a shell made of recycled thermoplastic pellets and reinforced with glass fabrics (Figure 4-1). Modified blocks manufactured in this research were installed near Star City Bridge, Morgantown, WV.

Figure 4-1 Guardrail offset blocks and constituents

Various sections in this chapter describe steps involved in arriving at the final manufacturing procedure for the guardrail-offset block including few subsequent modifications.

Descriptions of the recycled polymers, discarded tires and glass fabrics are provided in section 4.2. This is followed by description of the equipment details, i.e., about the compression press used for the manufacturing of various products during this entire research in section 4.3. Manufacturing process is discussed in section 4.4, which includes pre-molding operations to start the molding process, testing the resin compatibility by making sample plates, and using suitable resins for making blocks. Various stages involved in development of prototype guardrail offset block, along with the process outline for making blocks are also described as a part of section 4.4. After arriving at the final procedure for manufacturing guardrail offset block, procedure for making blocks with wooden and tire strips as core is described in section 4.5. Further modifications like introducing premolded pipes for product improvement/manufacturing is discussed in section 4.6. An overview of the entire process, along with few conclusions drawn from the study is provided in section 4.7.

Material overview

Recycled polymer resins

Manufacturing process was carried out using ABS recovered from various recycling sources. These thermoplastics were recovered mainly from Electronic Shredder Residue and Automotive Shredder Residue. Several batches of recycled resins were obtained by CFC-WVU during this research as listed below.

- Blend of ABS and PC with purity level above 90% as per supplier's MSDS sheet (SDR Plastics)
- Blend consisting of ABS of two grade purity
- ABS blend with few other polymers
- Polypropylene blend
- Polycarbonate blend

Coupon specimens manufactured from recycled polypropylene had large percentage of voids and was not considered for further research. Coupon specimens manufactured from polycarbonate had uniform blending, fusing between the pellets, and good surface finish and were used to make few offset blocks. However, ABS was selected as a good source for manufacturing offset blocks based on the ease of manufacturing, availability and excellent thermo-mechanical properties.

Initially, coupon specimens were made from different batches of recycled resin that were made available by SDR plastics to characterize its processability and manufacturability. Depending upon the degree of uniformity and blending observed from the coupon specimens, the resins were either accepted or rejected for making offset blocks. Compression molding process was used to verify the suitability of a given polymer stream for processability and usability as a structural component. Different recycled polymer blends consisted of ABS of two grades (purity) and ABS with few other polymers. Polypropylene was also tested as a possible resin for manufacturing structural products. However, it was not used due to its incompatibility in resin-blending (melting) and voids formation.

Glass fabric

Woven glass fabric was used to reinforce the recycled polymer shell encasing the rubber tire core. Glass fabric consisted of fibers in 90°, 0°, ±45°.

Rubber tires

Rubber used for the offset blocks was recovered from automobile tires, cut into suitable strips and stacked to constitute the core. Tire strips were cut from discarded automobile tires, with a reciprocating handsaw. Tire strips were used to form the offset block core for their energy absorption property and inherent strength/stiffness due to the presence of steel strands.

Scrap tires: Despite the fact that the scrap tires represent about 1.2% of all solid wastes, they present special disposal and reuse challenge because of their size, shape, and physicochemical nature. Since 1983, all new car and light truck tires, as well as replacement tires sold for passenger cars or light trucks, have been steel belted radials. Steel-belted radial heavy truck tires are beginning to replace bias ply heavy truck tires, which have been the norm in the trucking industry. The composition of a typical tire casting is given in Figure 4-2.

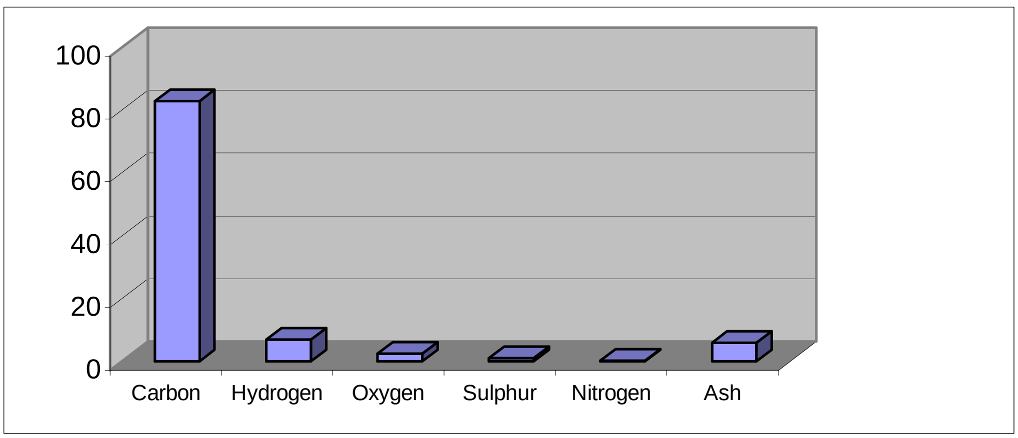


Figure 4-2 Percentage composition of typical tire casting

Nationally, recycling, reuse, and recovery practices for scrap tires currently consume about 34.5% of the tires discarded annually. The remaining 65.5% are land filled or stockpiled.

Size reduction of a scrapped tire is achieved through the process of chopping, shredding, grinding, or cutting. Cutting the tire into strips can be automated or done by running it through the cutting machine.

Equipment and accessories

Various equipment needed to carry out the manufacturing using compression molding process were:

Compression press: A schematic representation of pressure application in compression molding press is shown in Figure 4-3. PHI compression-molding machine (Figure 4-4) with a maximum load capacity of 50 tons and safe operable temperature up to a maximum of 600° F was used. The compression machine had platens of 18.5in × 12.5in size adequate to produce offset blocks of dimensions 14in × 8in × 6in in a single stage. Machine has an air purge and cooling water supply. Cooling water enables a uniform and faster cooling when compared to the air-cooling provided by a fan. Air purge was used to let off any remaining moisture/water content in the platens before heating for the next cycle. Molds designed to produce products ranging from small coupon plates to full size offset blocks.

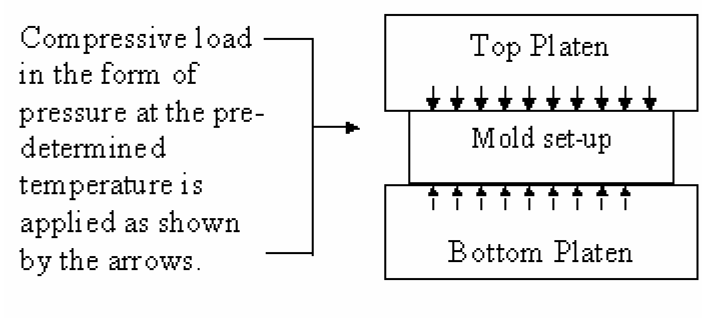


Figure 4-3 Representation of compression molding process

Figure 4-4 PHI Compression molding press with thermostat controls and temperature displays

Manufacturing process

Manufacturing sequence of the offset block consisted of following steps:

- Molding small plates (tabs) out of resin received from recycling plant and use of compatible resins for further research.
- Manufacturing core blocks using tire strips/wood and polymer resin.
- Manufacturing prototype size block.

- Refining processing parameters by varying magnitude of applied temperature, time and pressure.

Pre-molding operations

The platens were cleaned to ensure that there were no surface impurities, dust particles or oil. Aluminum foil (heavy duty) was wrapped over the platens to avoid possible deposition of the excess polymer oozing out of the mold during manufacturing. After ensuring that the cooling water supply was closed, air purge was applied until any moisture in the platen was driven out through the exit. Process temperature was set using thermostat controls before switching the heaters on.

The molds were cleaned to remove surface impurities. Aluminum flash was cut in the shape of the mold interior, and placed in the mold with a generous coating of de-molding agent (Tech Lube 25, Technick Products). The mold was then filled with its constituents and then compression molding was carried out.

Testing the compatibility of resins

Different polymer blends obtained were tested for mutual compatibility through compression molding process. Small plates (Figures 4-6 (a) to (h)) of 0.25 in thickness were made with a rectangular steel frame (Figure 4-5) using compression-molding process.

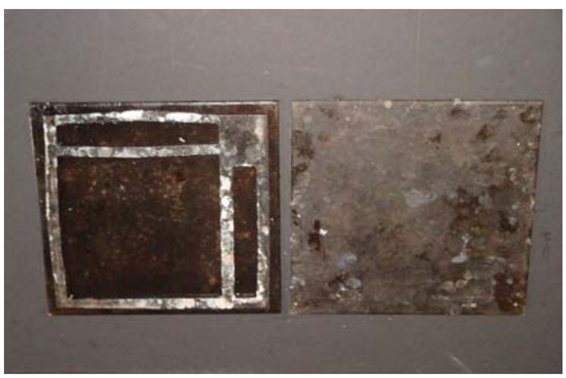
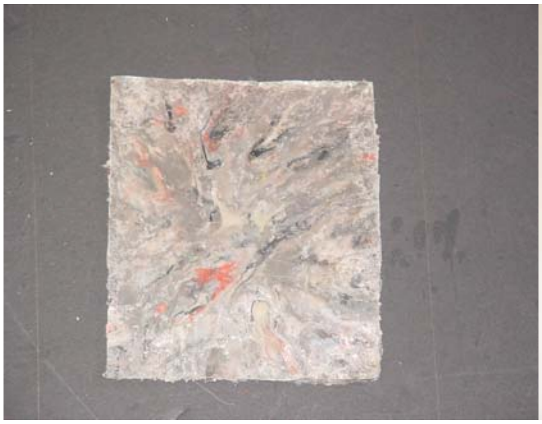
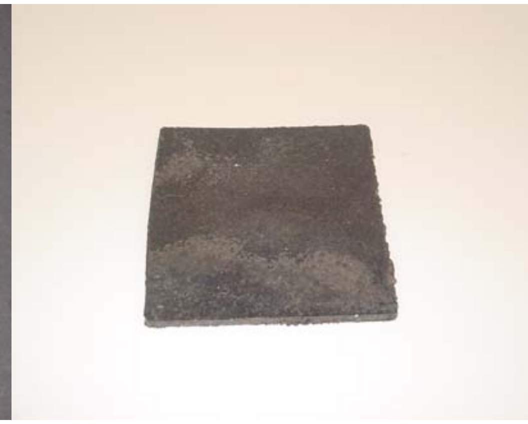


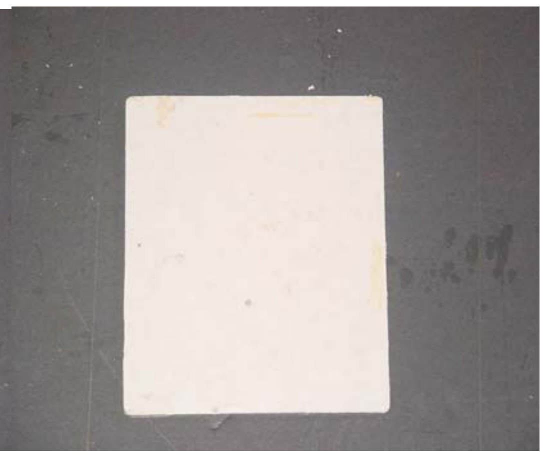
Figure 4-5 Steel frame for molding resin plates using compression molding

Process parameters like temperature and pressure were determined through trial and error technique by altering them during each molding cycle until desired degree of blending and uniformity was obtained. Temperatures from 400^o F to 500^o F, and load of 20 tons were used for producing the plates with recycled resins.

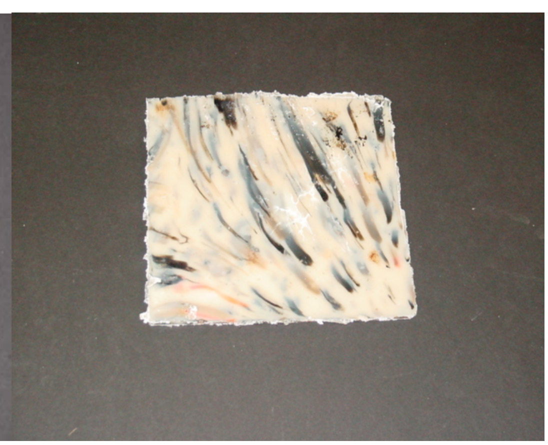




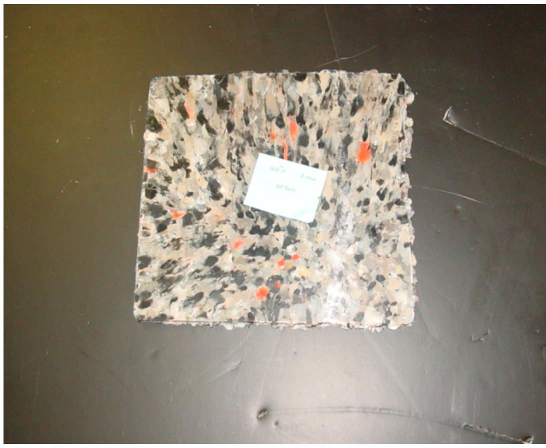
(a) 450º F (4 minutes) **(b) 560º F (5 minutes)**



(c) 430º F (5 minutes) **(d) 400º F (4 minutes)**



(e) 450º F (6 minutes) **(f) 420º F (4 minutes)**



(g) 345º F (11 minutes)

(h) 360º F (12 minutes)

Figure 4-6 Plates (6.5”×7.5” × 0.25”) made out of different recycled blends

Some recycled blends had significantly varying process temperatures for each polymer constituent that resulted in plates with: i) poor resin melting/blending, ii) non-uniform surface finish, and iii) void formation. Recycled blends with such incompatible polymers were found to be inefficient in terms of manufacturability. Reduction in temperature resulted in inadequate fusing of resin flakes, whereas increase in temperature resulted in burning odors and voids (Figures 4-6(a), (c) and (e)).

The recycled resins that showed better uniformity and blending were further used for manufacturing offset blocks and other composite products such as dowel bars and angle plates.

Process outline for manufacturing offset blocks

Manufacturing offset blocks consisted of four stages:

- Preheating: Preheating of the platens to desired temperature, 450° F (ABS).
- Load application: Twenty tons of load was applied on preheated mold consisting of resin, tire strips, and glass fabric for required duration.
- Cooling of the mold: In order to cool the mold, water was circulated through the platens until 120°F was attained.
- De-molding of offset block: Finally, offset block was taken out of the mold by unbolting all the mold parts.

Intermediate stages in determining final manufacturing procedure for offset block

Prior to final procedure, several modifications were made to obtain a good offset block with proper and uniform resin blending. These modifications carried out in several stages are described as follows:

In stage 1, four individual modules (blocks) each molded with recycled ABS and rubbers from discarded tires were combined using bolts to form final offset block. In stage 2 the number of modules were decreased from 4 to 2, by increasing their thickness and combining the two premolded modules by center bolt during on-site installation. In stage 3, manufacturing the final block in a single process cycle was attempted with partial success. In stage 4, a two-step process was followed to obtain a good product with uniformity and blending of resin pellets within the offset block.

4.4.4.1 Stage 1

Initially, four individual modules each measuring 14” × 6” × 2” were manufactured and joined using bolts to form final offset block. Several changes were proposed with regards to this process of forming the prototype offset block due to following reasons.

- A method was to be devised that would facilitate locking the individual units. To avoid no twisting or misalignment of four units, either 2 diagonal corners or 4 corners of the block modules had to be bolted in addition to using a central bolt to connect it to the post.
- Bolting the units on the 4 corners to form the complete block was an inefficient method of joining. On-site functioning of the prototype-offset block depended on effective alignment of these modules with respect to guardrail beam and post.
- Manufacturing 4 modules to make a single offset block was uneconomical and had to be modified.
- Process had to be modified for blocks of higher thickness since heat distribution within the mold was reduced and was non-uniform with increasing thickness.

Non-uniform heat distribution problem within the mold, mentioned above, as one of the problems was remedied to considerable extent by placing pre-molded tabs in the mold during manufacturing leading to better quality in the final product in subsequent stages.

4.4.4.2 Stage 2

A new mold was designed to reduce the number of individual units to form a complete offset block from 4 to 2, by increasing thickness of each unit to twice that of the original. The modification consisted of a rectangular recess along the length of one of the units at its center, 4 inch wide and 0.125inch deep, and a corresponding projection with the same profile on the other unit, thus facilitating locking of two units (Figure 4-7). Additional details of stage 2 are as follows:

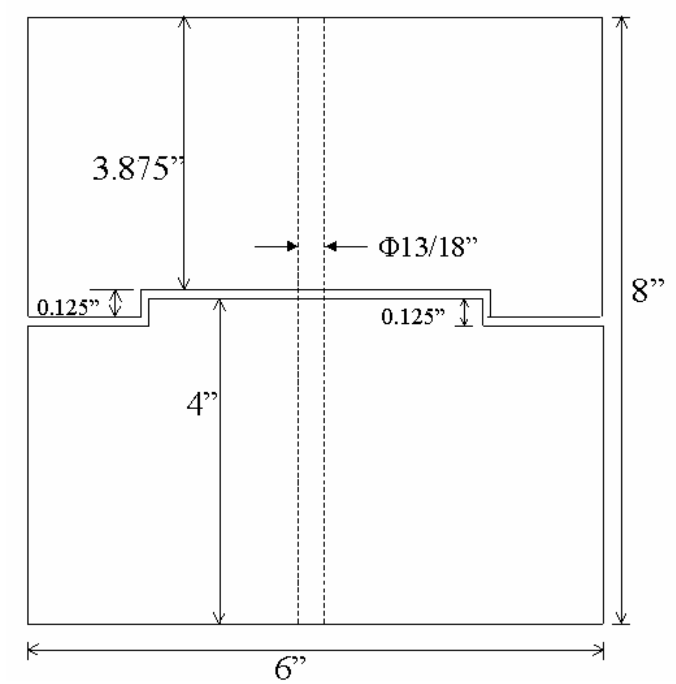


Figure 4-7 Offset block formed by bolting half blocks

- The core portions of the blocks were pre-molded half-inch thick plates, which were molded and placed on bottom and topsides of the tire strips and positioned in the mold. Thus, the tire strips were encased with glass fabric reinforced recycled ABS shell and molded to a thickness of 1.75in. Process parameters for the core modules were 15 minutes of preheating followed by application of 15 tons load for 15 minutes.
- Two such core modules were reinforced with glass fabric, and placed in the mold along with premolded resin end plates and additional resin pellets were heaped on the top, to manufacture the final offset block.
- Process parameters were 45 minutes of preheat followed by application of 20 tons of load for 45 minutes.

Heaters were switched off and mold was cooled under reduced load (20 tons reduced to 5 tons), with air-water circulation through the platens. Process was repeated to obtain the other half module using the designed mold. A center bolt was used to hold the two units together during on-site installation.

This design process was further modified to manufacture offset block as a single block to eliminate joining of independent modules described in stage 3.

The thickness of the block was changed from 8 inches to 6 inches to suit WVDOT requirements. The following options were considered in mold design for manufacture of final offset block:

- Mold for manufacturing the 14” × 6” × 6” block in single stage by accommodating additional heaters for the side plates

- Mold for manufacturing the 14” × 6” × 3” block, and bonding two such blocks with suitable adhesive such as Pliogrip
- Mold for manufacturing to produce the 14” × 6” × 2.75” core blocks, and then fusing two such blocks by a additional layer of the resin, thus making it a two-stage process to manufacture 14” × 6” × 6” block.

4.4.4.3 Stage 3

Compression molding trials were carried out to manufacture the final offset block in a single stage by placing all constituents in the mold and processing it at 450° F and less than 30 tons load. Improper heat propagation within the mold and irregular blending of resin pellets resulted in a product with unblended and unfinished surface as shown in Figures 4-8 and 4-9.

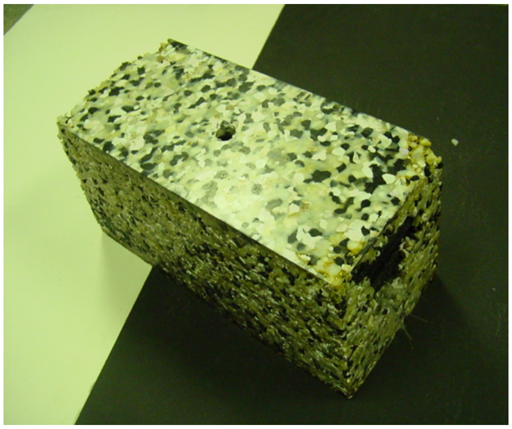


Figure 4-8 Unblended pellets on the block surface

Figure 4-9 Inadequate amount of resin at sides creates voids and gaps

Therefore, two- stage process was attempted by molding core modules in the first stage and molding two such modules reinforced with glass fabric with additional resin to obtain the final offset block. The details are described in stage 4.

4.4.4.4 Stage 4

A new mold was designed to produce core modules of size 12.5” × 4.5” × 2”. Two such core modules were joined using a stapling hammer and reinforced with glass fabric. This setup was placed in the 6” mold with resin pellets on all sides. Resin pellets were also heaped on the top to achieve maximum density in the final product.

Process parameters were 450° F temperature for recycled ABS (520° F for recycled PC), with preheating time of 30 minutes followed by application of 30 tons of load for 30 minutes.

The mold was left in the compression machine under 20% of the maximum applied load for cooling, and the final offset block was demolded after about 2 hrs. Figures 4-10 and 4-11 show final offset blocks made of recycled ABS and recycled PC, respectively. These blocks with good blending and uniform melting of the resins show that desired quality was attained using this manufacturing process and right process parameters were achieved.

Figure 4-10 Final offset block with recycled ABS blends

Figure 4-11 Final offset block with recycled PC blends

Blocks with wood/tire strips as core

Several blocks were manufactured using recycled ABS and PC resins with rubber strips from discarded tires or wood. Various steps involved in manufacturing final offset blocks with rubber and wood cores are explained in following sections.

4.5.1 Wood core

Wood blocks cut to the required dimension (12.5” × 4.5” × 1.5”), were surrounded with pre-molded plastic side plates, wrapped with glass fabric and then stapled to hold them in position as shown in Figures 4-12 and 4-13.

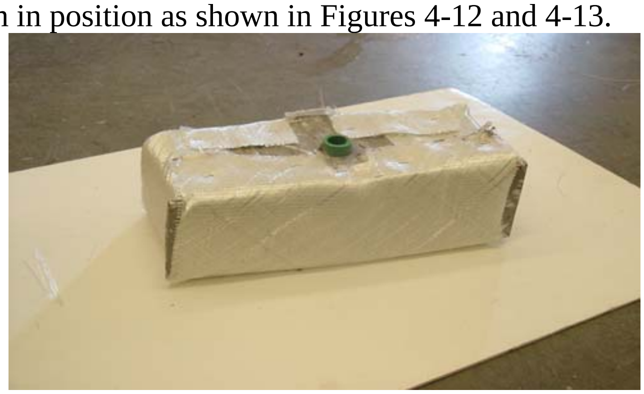
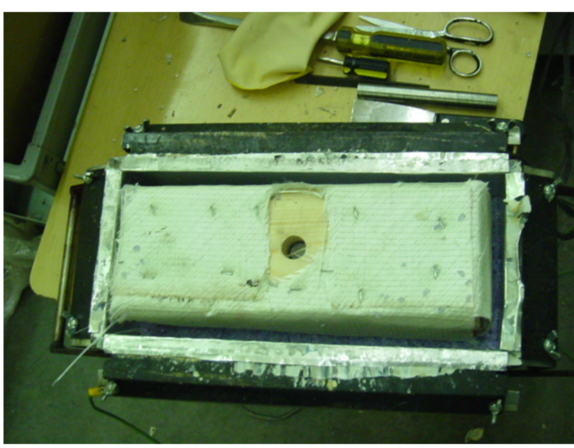


Figure 4-12 Core module wrapped with glass fabric

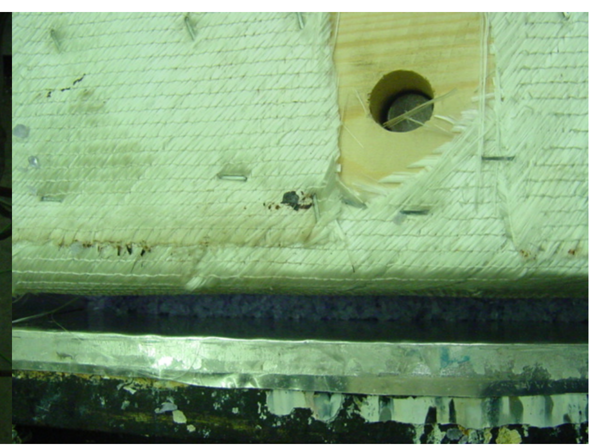
Figure 4-13 Glass fabric wrapped around wooden core with premolded polymer plates

Small amount of resin pellets were uniformly spread on bottom of the 6” mold and wood core wrapped in glass fiber mat was positioned in the mold with central circular shaft of the mold passing through its circular hole. The size of the circular hole in the wooden blocks was 0.8”, leaving very small clearance for plastic pellets between mold shaft and circular hole in the wood at the center. It was observed that absence of a heated central shaft resulted in no pellet fusing and exposure of wood that would be subjected to moisture ingress under field exposure.

The mold was heaped with excess amount of resin, about an inch and a half higher than the surface level of the mold edge to achieve maximum density. Figures 4-14 (a), (b), and (c) depict the resin filling process in the mold with the core module. This set up was placed in the compression molding machine. Process parameters were 450° F, preheating for about 30 minutes followed by application of 30 tons load for about 30 minutes. The product was demolded after cooling the mold in the press under load for about 3 hours.



(a) Core modules in 6” mold



(b) Close up view

(c) Resin heaped on the core modules

Figure 4-14 Positioning the core modules in the 6” mold with additional resins on all sides and heaped on top

4.5.2 Rubber tire core

Tire strips that were cut from the discarded tires were resized to obtain a regular and uniform shape with square edges to make their placement in the mold easier. The tire strips were then placed in a smaller mold with inner dimensions 12.5” × 4.5” × 2”.

Resin layer spread on bottom of the mold was covered with tire strips and additional resin was heaped on the top. This set-up was preheated for about 15 minutes at process temperature of the resin (450° F for ABS, 520° F for PC) and 15 tons load was applied for about 15 minutes. It was air cooled at ambient conditions and demolded to get the inner core block.

Two such core blocks were aligned one above the other and wrapped with glass fiber mat with circular holes cut in the fabric to match the mold shaft at the center. A hammer stapler was used to attach the glass fabric to the core and at FRP fabric folds. The set up was placed in the 6” mold with resin on all sides and top followed by placing the mold in the compression press. Process parameters were 450° F, preheating for about 30 minutes followed by application of 30 tons load for about 30 minutes. The product was demolded after cooling the mold in the press under load for about 3 hours.

Introducing new features in offset block production

Some problems observed despite achieving good degree of resin uniformity and blending in the final guardrail-offset block were solved as described below.

- Larger hole (Φ 1.5”) was drilled in core modules to fill resin pellets at their center in the second stage. These pellets were found to be unblended even after completion of 2-stage manufacturing process due to inadequate heat propagation through polymer resins and rubber tire strips.
- To avoid the above-mentioned problem, the holes in the core modules were resized (Φ 0.75”) so that no plastic was present in the center. It was resized with a

little clearance with respect to the bolt size (Φ 13/18”) used in the field to secure it to the post during the installation. This resulted in the exposure of the core (steel stranded rubber strips/wood) to environmental conditions that may lead to corrosion of steel strands and other problems.

The problems described above were mainly because of unblended resin pellets at the center of the block, which is due to inadequate heat propagation. If the resin pellets were to be melted, it would result in sealing the exposed core material thereby preventing corrosion. Three probable solutions were considered for this purpose:

- A pre-molded hollow circular cylinder made of a resin-compatible material was to be placed at the center of the block during manufacturing so that it would melt and fuse with resin at the top and bottom portions thus sealing the center portion of the block.
- A heater was to be incorporated at the center, into the cylindrical shaft in the mold such that heat transfer is initiated not only on the six faces of the mold but also at the center, thereby melting and fusing the plastic pellets at the center.
- Use a “dough” (charge-premelted resin) machine that would avoid preheating stage in the manufacturing process.

In order to place an additional heater at the center, a new mold had to be designed with a provision to let out its lead wires without touching the hot surfaces. Hence, placement of premolded pipes at the center was selected in this research.

4.6.1 Pre-molded pipes

Pre-molded plastic pipes were placed at the center of the mold along with the other constituents. PVC-pipes with internal diameter 0.75” were initially used for trial moldings. Blending of the PVC pipe with the resin at top and bottom of the block were uniform. However, PVC material due to its lower process temperature and incompatibility with ABS resin (Table 4-1) showed burn marks at the bottom face of the block. The PVC pipe was softened, buckled, burnt out, and collapsed within the hole in addition to being covered by a top layer of resin pellets. In the next batch of manufacturing, ABS pre-molded unthreaded compressed air pipes with internal diameter 0.8”and external diameter 1.05” were used. ABS pipes were cut to a length of 6.5”, a little higher than the 6” size of the final block to leave enough height for the ABS pipe to melt and fuse into the ABS resin at top and bottom in the mold. The following chart displays compatibility between various polymer resins.

Table 4-1 Compatibility of Polymers-Recycling Electronic and Electrical equipment Industry Council for Electronic Equipment Recycling, UK, 1997

	LLPE	LLDPE	ULDPE/VLDPE	EthyleneCopolymer	HDPE	PP	EPM/EPDM	PS(gen.purpose,high impact)	SAN	ABS	PVC	PA	PC	PMMA	PBT	PET	SBS
LLPE																	
LLDPE	1																
ULDPE/VLDPE	1	1															
EthyleneCopolymer	1	1	1														
HDPE	1	1	1	1													
PP	4	2	(1)	2	4												
EPM/EPDM	4	4	(1)	3	4	1											
PS(gen.purpose,high impact)	4	4	4	4	3	4	1										
SAN	4	4	4	4	4	4	4	4									
ABS	4	4	4	4	4	4	4	4	1								
PVC	4	4	4	(2)	4	4	4	4	2	3							
PA	4	4	4	(1)	4	4	(1)	4	4	4	4						
PC	4	4	4	4	4	4	4	4	2	2	4	4					
PMMA	4	4	4	(3)	4	4	4	4	2	2	2	4	2				
PBT	4	4	4	(2)	4	4	4	4	4	4	4	4	1	4			
PET	4	4	4	(3)	4	4	4	4	4	4	4	3	1	4	3		
SBS	4	4	4	4	4	4	4	1	3	2	3	3	4	4	4	4	

Key:
1 Excellent
2 Good
3 Fair
4 Incompatible
(n) Dependent on composition

Figure 4-15 Guardrail system with polymer offset block

Field Installation

Figure 4-15 shows the guardrail offset block made of recycled polymer shell reinforced with glass fabric and with discarded rubber tire core, installed successfully near Star City Bridge, Star City, WV. Previously, wood blocks were used as offset blocks for the guardrail system on the bridge, and were replaced by few blocks manufactured using recycled ABS reinforced with glass fabric and discarded tire strips.

Summary

Procedure for manufacturing guardrail-offset blocks in the laboratory with rubber or wood cores encased in fiber reinforced recycled thermoplastic shell, were determined for manufacturing offset blocks. Guardrail offset blocks manufactured using this procedure were installed near Star City Bridge, Star City, WV.

- The process parameters like temperature, pressure, and time for the manufacturing process of these blocks were determined after several trials.
- Core modules of size 12.5” × 4.5” × 2 were manufactured using 20 minutes of preheating followed by 15 minutes of load application at 450° F for recycled ABS (520° F for PC).
- Lowering load or time resulted in insufficient compacting and blending of the resins. Increasing in load or time resulted in burn marks on the product surface including blisters and holes.
- The process could be improved by introducing preheated resin into the mold. Use of preheated resin (charge) would eliminate problems of non-uniform heat distribution, inadequate resin flow and blending of pellets within the mold and result in shorter manufacturing duration of few minutes.

- By introducing required amount of preheated resin into the mold, number of blocks manufactured per unit time would increase, which is a major consideration for large-scale production.
- Processing of discarded tires could be modified before using them in manufacturing offset blocks. Reducing the curvature of the tires strips by “shear crimping” along the length at several sections would reduce voids/gaps in the final product.

This information could be used for mass manufacturing recycled composite offset blocks with suitable modifications knowledge gained in manufacturing offset block was used to develop recycled resin composite products such as angle plates and dowel bars described in Chapter 6.

CHAPTER 5

Test results of coupon specimens

Introduction

Results from various tests performed on the coupon specimens described in chapter 3 made from recycled thermoplastic (ABS), and thermoset resins (vinyl ester), with and without glass fabric are presented and analyzed in this chapter. Recycled ABS thermoplastic resins were provided by SDR recycling plant, Ravenswood, WV and glass fabrics (GFRP) were provided by BGF industries, Greensboro, NC. Glass fabric provided by BGF industries is 0.0046 in thick, and weighs 3.12 oz/yd^2.

Strength and stiffness values of ABS and vinyl ester specimens both with and without fabric under compression, tension, bending, and impact tests are shown in Tables 5-1 to 5-24. Specimen notation indicates the type of test, material and presence of reinforcing fabric followed by specimen number. For example, specimen TA-1 indicates T for tension test, A for ABS material. Similarly, F in specimen TAF-1 indicates fabric. Similarly other notations indicate B for bending test, C for compression test and I for impact test.

Compression test

Results of ABS specimens

Table 5-1 shows compressive strength and stiffness results for recycled ABS specimens with and without fabric. Average compressive strength and stiffness results for each type of ABS specimens are presented in Table 5-2.

Table 0-1 Compression test results of ABS specimens (0.5”×0.5”×1”) with and without glass fabric

Specimen type	Max. Compressive Stress (psi)	Compressive stiffness (× 10^6 psi)	Specimen type	Max. Compressive Stress (psi)	Compressive stiffness (× 10^6 psi)
Without fabric			**With fabric**		
CA-1	5489.38	0.1374	CAF-1	8445.93	0.1956
CA-2	7222.15	0.1663	CAF-2	8697.76	0.2217
CA-3	6992.14	0.1850	CAF-3	8531.11	0.2194
CA-4	6760.56	0.1790	CAF-4	8244.82	0.2247
Average	6616.06	0.1669	**Average**	8479.80	0.2153
Std dev.	13.16%	14.09%	**Std dev.**	2.23%	6.59%

Table 0-2 Average compressive stiffness and strength values of ABS specimens with and without glass fabric

ABS Compression test specimens			
Average values	**Without glass fabric**	**With glass fabric**	**% Increase**
Compressive Strength (psi)	6616.06±13.16%	8479.8±2.23%	28.16
Compressive Stiffness ($\times 10^6$ psi)	0.1669±14.09%	0.2153±6.59%	28.98

5.2.1.1 Analysis and discussion on ABS specimens

The following conclusions can be drawn from the results presented in Tables 5-1 and 5-2.

- Average compressive strength and stiffness increase of 28.16% and 28.98% respectively were observed for glass fabric reinforced ABS specimens.

Results of vinyl ester specimens

Table 5-3 shows compression strength and stiffness results for vinyl ester specimens with and without fabric. Average compressive strength and stiffness results for vinyl ester specimens are presented in Table 5-4.

Table 0-3 Compression test results of vinyl ester specimens (0.5”×0.5”×1”) with and without glass fabric

Specimen type	Max. Compressive Stress (psi)	Compressive stiffness ($\times 10^6$ psi)	Specimen type	Max. Compressive Stress (psi)	Compressive stiffness ($\times 10^6$ psi)
CV-1	11187.85	0.2278	CVF-1	13675.95	0.2820
CV-2	11754.93	0.2497	CVF-2	13947.92	0.2954
CV-3	10927.92	0.2327	CVF-3	15451.38	0.2969
CV-4	9343.599	0.2342	CVF-4	14618.86	0.2946
Average	10803.57	0.2361	**Average**	14423.52	0.2922
Std dev.	10.33%	3.9%	**Std dev.**	5.39%	2.41%

Table 0-4 Average compressive stiffness and strength values of vinyl ester specimens with and without glass fabric

Vinyl ester specimens			
Average values	**Without glass fabric**	**With glass fabric**	**% Increase**
Compressive Strength (psi)	10803.57±10.33%	14423.52±5.39%	23.75
Compressive Stiffness ($\times 10^6$ psi)	0.2361±3.9%	0.2922±2.41%	33.5

5.2.2.1 Analysis and discussion on vinyl ester specimens

Following conclusions are drawn from the results presented in Table 5-3 and 5-4.

- Average compressive strength and stiffness increase of 23.75% and 33.50% were observed, respectively for glass fabric reinforced vinyl ester specimens.

Summary of results

Table 0-5 Comparison of average compressive strength and stiffness values of ABS and vinyl ester samples with and without glass fabric respectively

Parameter from experimental results	ABS		Vinyl ester		% Increase ABS and Vinyl ester	
	Without glass fabric	With glass fabric	Without glass fabric	With glass fabric	Without glass fabric	With glass fabric
Avg. Compressive strength (psi)	6616.06	8479.80	10803.57	14423.52	63.29	70.09
Avg. Compressive stiffness ($\times 10^6$ psi)	0.1669	0.2153	0.2361	0.2922	41.43	35.70

- Average strength and stiffness increase of 63.29% and 41.43% were observed for ABS and vinyl ester without glass fabric respectively.
- Average strength and stiffness increase of 70.09% and 35.70% were observed for ABS and vinyl ester with glass fabric respectively.

Results of compression test specimens cut from wood guardrail offset block

Compression test specimens measuring 0.5”× 0.5”× 1” were cut from a field installed wooden guardrail offset block. Results are presented in Table 5-6.

Table 0-6 Compressive stiffness and strength values of wood specimens

Specimen type	Compressive Stress (psi)	Compressive Stiffness ($\times 10^6$ psi)
CW-1	5407.26	0.1399
CW-2	5163.99	0.1557
CW-3	5098.75	0.1483
CW-4	5210.34	0.1529
CW-5	5708.36	0.1500
Average	5317.74	0.1494
Std dev.	4.49%	4.13%

Average compressive strength and stiffness values of 5317.74 psi and 0.1491 $\times 10^6$ psi respectively were observed in case of wooden specimens cut (parallel to grain direction) from a field installed wooden guardrail offset block.

Conclusions

- Average compressive strength of ABS with glass fabric (8479.80 psi) is about 1.59 times higher than that of wood (5317.4 psi).
- Average compressive stiffness value of ABS with glass fabric specimens (0.2153×10^6 psi) is about 1.44 times higher than that of wooden specimens (0.1491×10^6 psi). This gives an idea on efficient use of recycled polymer composites for guardrail systems.
- Average compressive strength and stiffness values for recycled ABS with glass fabric vs. wood from previous study are 14891 psi vs. 8399 psi and 0.92×10^6 psi vs. 1.63×10^6 psi respectively.
- Test specimens from previous study were injection molded and they showed about 15% higher strength and stiffness values.

Tension test

Results of ABS specimens

Maximum tensile strength and stiffness results for recycled ABS specimens with and without fabric are shown in Table 5-7. The average tensile stress and stiffness results and their variations for ABS specimens are shown in Table 5-8.

Table 0-7 Tension test results of ABS specimens with and without glass fabric

Specimen type	**Max.Tensile Stress (psi)**	**Tensile stiffness ($\times 10^6$ psi)**	**Specimen type**	**Max.Tensile Stress (psi)**	**Tensile stiffness ($\times 10^6$ psi)**
Without fabric			**With fabric**		
TA-1	4347.06	0.3120	***TAF-1***	4123.43	0.3262
TA-2	4332.75	0.3126	**TAF-2**	4305.76	0.3856
TA-3	4495.03	0.3680	**TAF-3**	5135.76	0.3949
TA-4	4360.84	0.3156	**TAF-4**	4755.66	0.3833
TA-5	4532.39	0.2766	**TAF-5**	4378.01	0.3508
Average	4413.61	0.3170	**Average**	4643.80	0.3756
Std dev.	2.08%	10.08%	**Std dev.**	8.63%	8.22%

(Note: Specimens were 0.5” wide and 0.25” thick)

Table 0-8 Average tensile stiffness and strength values of ABS specimens with and without glass fabric

Average values	**Without glass fabric**	**With glass fabric**	**% Increase**
Tensile Strength (psi)	4413.61±2.08%	4643.80±8.63%	5.21
Tensile Stiffness ($\times 10^6$ psi)	0.3170±10.08%	0.3756±8.22%	18.49

5.3.1.1 Analysis and discussion on ABS specimens

Increase in tensile stiffness and strength values of ABS specimens due to glass fabric can be observed in Tables 5-7 and 5-8.

- Average tensile strength and stiffness increase of 5.21% and 18.49% were observed for glass fabric reinforced ABS specimens respectively.

Results of vinyl ester specimens

Table 5-9 shows the tensile strength and stiffness results for vinyl ester specimens with and without fabric. Average tensile strength and stiffness results for vinyl ester specimens are presented in Table 5-10.

Table 0-9 Tension test results of vinyl ester specimens with and without glass fabric

Specimen type	**Max.Tensile Stress (psi)**	**Tensile stiffness ($\times 10^6$ psi)**	**Specimen type**	**Max.Tensile Stress (psi)**	**Tensile stiffness ($\times 10^6$ psi)**
Without fabric			**With fabric**		
TV-1	4780.10	0.4674	***TVF-1***	7555.16	0.4731
TV-2	5795.66	0.3283	**TVF-2**	4503.75	0.5128
TV-3	5328.14	0.3413	**TVF-3**	6056.56	0.3186
TV-4	5153.11	0.3649	**TVF-4**	-	-
Average	5264.25	0. 3755	**Average**	6038.49	0.4348
Std dev.	7.99%	15.13%	**Std dev.**	27.4%	28.01%

(Note: Specimens were 0.5” wide and 0.25” thick)

Table 0-10 Average tensile stiffness and strength values of vinyl ester specimens with and without glass fabric

Vinyl ester tension specimens			
Average values	**Without glass fabric**	**With glass fabric**	**% Increase**
Tensile Strength (psi)	5264.25±7.99%	6038.49±27.4%	14.7
Tensile Stiffness ($\times 10^6$ psi)	0.3755±15.13%	0.4348±28.01%	15.8

5.3.2.1 Analysis and discussion on vinyl ester specimens

Following conclusions can be drawn from the results presented in Tables 5-9 and 5-10.

- Average tensile strength and stiffness increase of 14.7% and 15.8% were observed, respectively for vinyl ester specimens reinforced with glass fabric.

Results of tension test specimens cut from the wood guardrail offset block

Specimens 0.5” wide and 0.25” thick were cut from a field installed wood guardrail offset block and tested for tension. Results of the tests are presented in Table 5-11.

Table 0-11 Tensile stiffness and strength of wood test specimens

Specimen type	Max.Tensile Stress (psi)	Tensile stiffness (× 10^6 psi)
TW-1	6258.74	0. 6120
TW-2	2700.36*	0. 5462

* Presence of a knot in sample TW-2 (*) induced higher stress concentration resulting in a premature failure.

Summary of results

Table 0-12 Comparison of average tensile strength and stiffness values of ABS and vinyl ester samples with and without glass fabric respectively

Parameter from experimental results	*ABS*		Vinyl ester		% Increase ABS and Vinyl ester	
	Without glass fabric	With glass fabric	Without glass fabric	With glass fabric	Without glass fabric	With glass fabric
Avg. Tensile strength (psi)	4413.61	4643.80	5264.25	6038.49	19.27	30.03
Avg. Tensile stiffness (× 10^6 psi)	0.3170	0.3756	0.3755	0.4348	18.45	15.77

- There is 19.27% variation in average tensile strength and 18.45% variation in average tensile stiffness between ABS and vinyl ester without glass fabric.
- There is 30.03% variation in average tensile strength and 15.77% variation in average tensile stiffness between ABS and vinyl ester with glass fabric.
- The glass fabric was obtained from BGF industries. Manufacturer suggested ABS thermoplastic to be compatible with glass fabric, however no increase in tension strength was observed. Further tests need to be done using a glass fabric that is compatible with thermoplastic ABS.

Bending test

Results of ABS specimens

Table 5-13 shows bending strength and stiffness results for recycled ABS specimens with and without fabric. Average bending strength and stiffness results for ABS specimens are presented in Table 5-14.

Table 0-13 Bending test results of ABS specimens (0.5”× 0.25”) with and without glass fabric

Specimen type	**Max. Bending Stress (psi)**	**Bending stiffness (× 10^6 psi)**	**Specimen type**	**Max. Bending Stress (psi)**	**Bending stiffness (×10^6 psi)**
Without fabric			**With fabric**		
BA-1	12249.64	0.4129	BAF-1	19650.05	0.4866
BA-2	11928.60	0.3413	**BAF-2**	14042.71	0.4946
BA-3	11418.70	0.3922	**BAF-3**	17964.98	0.4734
Average	11865.64	0. 3822	**Average**	17219.24	0.4849
Std dev.	3.56%	10.09%	**Std dev.**	18.29%	2.22%

Note: Support span of 7.5” was used for bending tests conducted on all specimens

Table 0-14 Average bending stiffness and strength values of ABS specimens with and without glass fabric

ABS bending test specimens			
Average values	**Without glass fabric**	**With glass fabric**	**% Increase**
Bending Strength (psi)	11865.64±3.56%	17219.24±18.29%	45.11
Bending Stiffness (× 10^6 psi)	0.3822±10.09%	0.4849±2.22%	26.87

5.4.1.1 Analysis and discussion on ABS specimens

Following conclusions can be drawn from the results presented in Tables 5-13 and 5-14.

- Average bending strength, and stiffness increase of 45.11% and 26.87% were observed for glass fabric reinforced ABS specimens respectively.

Results of vinyl ester specimens

Table 5-15 shows bending strength and stiffness results for vinyl ester specimens with and without fabric. Support span of 7.5” was used for bending tests conducted on all specimens. Average bending strength and stiffness results for vinyl ester specimens are presented in Table 5-16.

Table 0-15 Bending test results of vinyl ester specimens (0.5”× 0.25”) with and without glass fabric

Specimen type	Max. Bending Stress (psi)	Bending stiffness (× 10^6 psi)	Specimen type	Max. Bending Stress (psi)	Bending stiffness (× 10^6 psi)
Without fabric			**With fabric**		
BV-1	16292.87	0.5710	***BVF-1***	19556.08	0.7973
BV-2	16025.02	0.7750	**BVF-2**	24669.96	0.8657
BV-3	17250.9	0.7550	**BVF-3**	26457.84	0.8643
Average	16522.93	0.7003	**Average**	23561.29	0.8425
Std dev.	3.83%	17.98%	**Std dev.**	16.59%	4.77%

Table 0-16 Average bending stiffness and strength values of vinyl ester specimens with and without glass fabric

Vinyl ester bending test specimens			
Average values	**Without glass fabric**	**With glass fabric**	**% Increase**
Bending Strength (psi)	16522.93±3.83%	23561.29±16.59%	42.59
Bending Stiffness (× 10^6 psi)	0.7003±17.98%	0.8425±4.77%	20.29

5.4.2.1 Analysis and discussion on vinyl ester specimens

Following conclusions can be drawn from the results presented in Tables 5-15 and 5-16.

- Average bending strength and stiffness increase of 42.59% and 20.29% were observed for glass fabric reinforced vinyl ester specimens respectively.

Results of bending test specimens cut from wood guardrail offset block

Specimens 0.5” wide and 0.25” thick were cut from a field wood guardrail offset block and tested for bending. A support span of 7.5” was maintained during the test. Results of the tests are presented in Table 5-17. Presence of a knot in sample BW-2 induced higher stress concentration resulting in premature failure.

Table 0-17 Bending strength and stiffness values for wooden specimens (0.5”× 0.25”)

Specimen type	Max. Bending Stress (psi)	Bending stiffness (× 10^6 psi)
BW-1	14791.91	0.5366
BW-2	4347.90*	0.7934

Note: * indicates premature failure of specimen due to presence of knot.

Summary of results

Table 0-18 Comparison of average bending strength and stiffness values of ABS and vinyl ester samples with and without glass fabric respectively

Parameter from experimental results	ABS		Vinyl ester		% Increase between ABS and Vinyl ester	
	Without glass fabric	With glass fabric	Without glass fabric	With glass fabric	Without glass fabric	With glass fabric
Avg. Bending strength (psi)	11865.64	17219.24	16522.93	23561.29	39.25	36.83
Avg. Bending stiffness ($\times 10^6$ psi)	0.3822	0.4849	0.7003	0.8425	83.24	73.74

- Average bending strength and stiffness increase of 39.25% and 83.24% were observed for ABS and vinyl ester specimens without glass fabric.
- Average bending strength and stiffness increase of 36.83%, and 73.74% were observed for ABS and vinyl ester samples with glass fabric.

Impact test

Results of ABS specimens

Tables 5-19, and 5-20 show the impact strength results for recycled ABS specimens with and without fabric. Maximum impact strength results for ABS specimens are tabulated.

Table 0-19 Impact test results of ABS specimens (2.5”×0.5”×´0.25”) without glass fabric

Specimen type	Impact strength (lbf/in)
IA-1	2.64
IA-2	2.24
IA-3	2.20
IA-4	2.96
IA-5	2.01
Average	2.41
Std dev.	15.38%

Table 0-20 Impact test results of ABS specimens (2.5”×0.5” ×0.25”) with glass fabric

Specimen type	Impact strength (lbf/in)
IAF-1	5.27
IAF-2	4.67
IAF-3	5.40
IAF-4	3.78
IAF-5	4.06
Average	4.63
Std dev.	16.123%

5.5.1.1 Analysis and discussion on ABS specimens

Following conclusions can be drawn from the results presented in Tables 5-19 and 5-20.

- Average Impact strength increased by about 1.91 times for ABS specimens reinforced with continuous glass bi-directional fabric when compared to those without glass fabric.
- Previous research results (Basto 2002) showed decrease in impact strength due to addition of chopped fibers.
- Use of continuous, particularly bi-directional fabric, has led to increase in impact strength in ABS specimens as per test results in this study.

Results of vinyl ester specimens

Tables 5-21 and 5-22 show the impact strength results for vinyl ester specimens with and without fabric. Maximum impact strength results for each type of the vinyl ester specimens are tabulated.

Table 0-21 Impact test results of vinyl ester specimens (2.5”×0.5” ×0.25”) without glass fabric

Specimen type	Impact strength (lbf/in)
IV-1	0.27
IV-2	0.29
IV-3	0.53
IV-4	0.27
IV-5	0.31
Average	0.33
Std. Dev.	25.29%

Table 0-22 Impact test results of vinyl ester specimens (2.5”×0.5” ×0.25”) with glass fabric

Specimen type	Impact strength (lbf/in)
IVF-1	0.72
IVF-2	0.6
IVF-3	0.74
IVF-4	0.66
IVF-5	0.60
Average	0.66
Std. Dev.	9.88%

5.5.2.1 Analysis and discussion on vinyl ester specimens

Following conclusions can be drawn from the results presented in Tables 5-21 and 5-22.

- Average Impact strength increased by about 1.96 times for glass fabric reinforced vinyl ester specimens when compared to those without glass fabric.

Results of impact test specimens cut from wood guardrail offset block

Table 5-23 shows the impact strength values of wood specimens cut from field installed guardrail offset block.

Table 0-23 Impact test results of wood specimens (2.5”×0.5” ×0.125”)

Specimen type	Impact strength (lbf/in)
IW-1	3.98
IW-2	3.08
IW-3	3.52
Average	3.19
Std dev.	12.97%

Summary of results

Table 0-24 Comparison of impact strength values of ABS, vinyl ester with and without glass fabric and wood specimens

Experimental parameter	ABS			Vinyl ester			Wood
	Without fabric	With fabric	% Increase	Without fabric	With fabric	% Increase	
Avg. Impact strength (lbf/in)	2.41	4.63	92.1	0.3394	0.6659	96.20	3.19

Conclusions

- From previous study (Basto, 2002) decrease in impact strength (2.17 lbf/in to 0.96 lbf/in) was observed in recycled ABS specimens due to addition of chopped glass fibers.
- In this study, recycled ABS resin used with continuous fabric having bi-directional fibers increased the impact strength (4.64 lbf/in from 2.41 lbf/in) due to better energy dissipation.
- Impact strength of recycled ABS specimens with continuous glass fabric was found to be 1.45 times more than specimens cut from field installed wood offset blocks.

Bending tests on dowel bars

Bending tests were conducted on pultruded dowel bars along with the one manufactured with ABS thermoplastic resin through compression molding process. Notation of the dowel bars tested in this research based on their color is shown in Table 5-25.

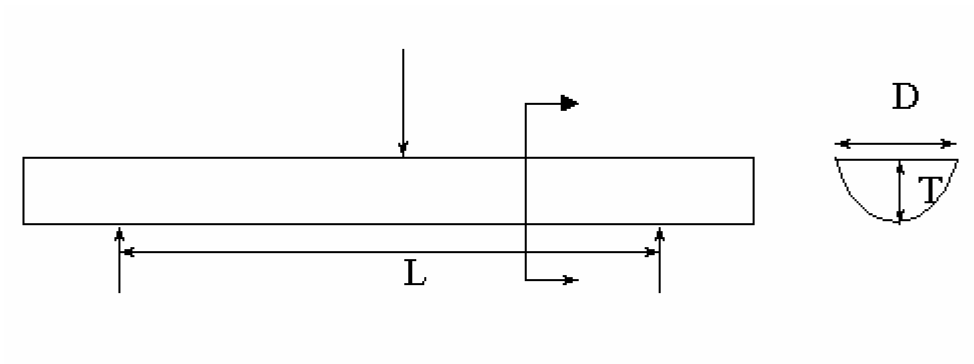


Figure 0-1 Cross-section view of dowel bar

Table 0-25 Notation of the dowel bars for bending test

Specimen	Description	Content
BRD-1	Pultruded bending test sample	Glass fibers with vinyl ester
BRD-2		
BGD-1	Pultruded bending test sample	Glass fibers with vinyl ester
BGD-2		
BWD	Compression molded bending test sample	Recycled ABS, no fiber

The fiber weight fractions of these dowel bars are 77.39% for green bar (BGD) and 69.11% for red bar (BRD). The volume fractions are 63.09% and 52.80% for BGD and BRD respectively.

Bending tests were conducted on dowel bars with the dimensions conforming to ASTM D4476-97 and the results are presented in Table 5-26.

5.7.1. Pultruded bending test sample-1 (BRD)

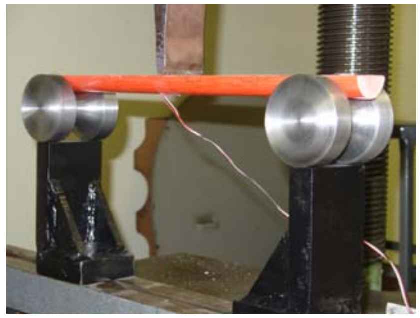


Figure 0-2 Dowel bar sample-1 (pultruded)

Parameters

L=Length of support span=15 in
D=Original diameter of the specimen=1.5 in
D1=Depth of the specimen taken as an average of values along the length of the bar=0.72 in
R=0.5D=0.75 in
γ=D1/R=0.96
A=$\sqrt{(\gamma\ (2-\gamma))}$= 0.99919968
B=1-γ=0.04
G=arc sine A, rad, =1.5307
H=2A.B=0.0799357
C=Distance of centroid to extremities=R $(1-(4A^3/(6G-3H)))$= 0.41541 in
I=Moment of Inertia =R^4 $[0.125(2G-H)(1+2A^3B/(G-0.5H))-(8/9)(A^4/(2G-H)]$=0.03021313 in^4
Maximum stress=116699.30 psi
Stiffness=5.6179 ($\times 10^6$) psi

5.7.2. Pultruded bending test sample-2 (BGD)

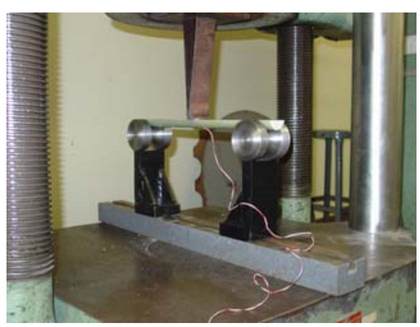


Figure 0-3 Dowel bar sample-2 (pultruded)

Parameters

L=Length of support span=15 in

D=Original diameter of the specimen=1.5 in
D1=Depth of the specimen taken as an average of values along the length of the bar=0.73 in
R=0.5D=0.75 in
γ=D1/R=0.97333
A=√(γ (2-γ))=0.999644381
B=1-γ=0.02666285
G=arc sine A, rad, =1.544126499
H=2A.B=0.053314367
C=Distance of centroid to extremities= R (1-(4A^3/(6G-3H)))= 0.420855446 in
I=Moment of Inertia = R^4 [0.125(2G-H) (1+2A^3B/(G-0.5H))-(8/9)(A^4/(2G-H)]=0.03170949 in^4
Maximum stress=173952.65 psi
Stiffness=6.3837 (× 10^6) psi

5.7.3. Compression molded bending test sample (BWD)

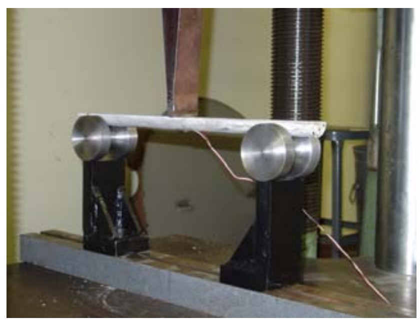


Figure 0-4 Dowel bar sample-3 (compression molded)

Parameters

L=Length of support span=15 in
D=Original diameter of the specimen=1.5 in
D1=Depth of the specimen taken as an average of values along the length of the bar=0.78133 in
γ=D1/R=1.041777
A=√(γ (2-γ))=0.999127
B=1-γ=-0.04178
G=arc sine A, rad, =1.529007
H=2A.B=-0.08348
C=Distance of centroid to extremities= R (1-(4A^3/(6G-3H)))= 0.4325 in
I=Moment of Inertia = R^4 [0.125(2G-H) (1+2A^3B/(G-0.5H))-(8/9)(A^4/(2G-H)]=0.028441 in^4
Maximum stress=10536.51 psi
Stiffness=0.4828 (× 10^6) psi

Table 0-26 Bending strength and stiffness values of the dowel bars

Specimen type	Max strength (psi)	Max stiffness (× 10^6) psi

BRD-1	116699.30	5.96
BRD-2	133523.92	6.24
BGD-1	173952.65	6.38
BGD-2	174706.23	8.15
BWD	10536.51	0.48

5.7.4. Summary

Dowel bar made of only recycled ABS pellets without any fiber/fabric reinforcement showed a bending strength of 10536.51psi and stiffness of 0.4828×10^6 psi. Based on the limited trials conducted in this research, dowel bars could be manufactured using recycled resins with appropriate modifications to manufacturing process and dowel bar constituents. Chopped fibers can be added to the recycled pellets to manufacture dowel bar to improve strength and stiffness.

Chapter 6
Recycled Composite Products

Introduction

The applications of composites have been widely demonstrated in construction, marine/waterfront structures, repair and rehabilitation, corrosion reduction, and structural alternative utilitie (Busel 1995). Composites are applied in various fields such as aerospace, automobiles, chemical industry, electrical, consumer and sports, and bio-medical equipments.

Growing concerns about pollution of the environment and decreasing capacity of the sanitary landfill sites, has enhanced the momentum of plastics recycling in the U.S. Recycled polymers have been a cheap source of material for numerous applications and appear in the market as composites, both with and in reinforcements.

For components with complicated geometry, compression molding is more suitable. Compression molded composites are used in many automobiles, appliances, construction and industrial applications (Mallick et al., 1990).

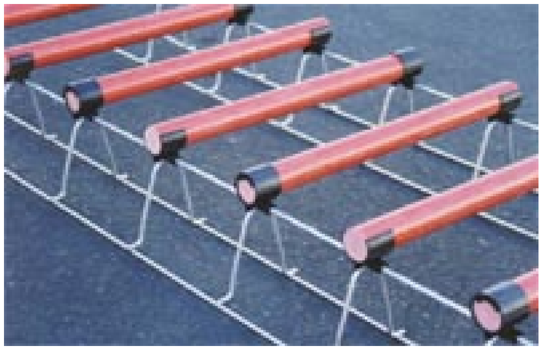
Various products that can be manufactured from recycled polymers are:

- Civil engineering: geotextile, urethane foam, curb stops, signs, traffic-barrier cones, guardrails, offset blocks, posts, pipes, building products etc.,
- Recreational: skis, surfboards, sailboat hulls, and toys etc.,
- Industrial: carpets, fence posts, fiberfill, fuel pellets, industrial paints, strapping, paint brushes, pallets, soft drink base cups, milk bottle carriers, matting, kitchen drain boards, drums/pails, trash cans etc.,

Compression molding has number of advantages over injection molding process. It is performed with no sprues, gates, and runners, resulting in very little wastage of material, with relatively lesser molding pressure application than the injection molding. While injection molding restricts the size of the fiber length to 3mm maximum and low fiber volume fractions, compression molding easily accommodates long fiber lengths and high fiber volume fractions. In general, better physical and mechanical properties can be achieved in compression-molded parts (Mallick, 1990). We have attempted to develop two products using glass reinforced recycled polymers using compression molding technique. The products are: Dowel bars and Angles.

Dowel bars

The repairs and replacements in the nation’s transportation infrastructure are due to the deterioration of the concrete pavements. The performance of the pavements is largely related to the performance of the joints. As opposed to inadequate structural capacity the failure at the joints can be attributed to stresses resulting from faulting, pumping, spalling, corner breaks, blowups, and mid-panel cracking. Dowels help in transferring the load across joints between two contiguous pavement slabs is the cause that highlights the use of Dowel bars (Figures 6-1 and 6-2).



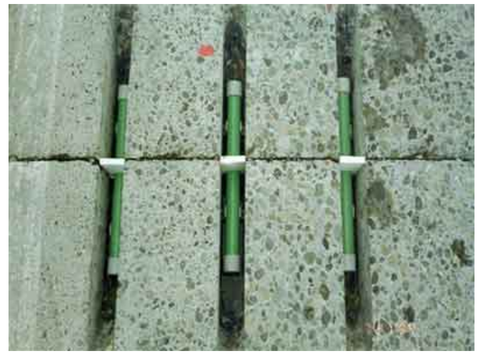


Figure 0-1 FRP dowel bars **Figure 0-2 Dowel bars in concrete slabs**

Normally, the dowel bars are made of steel, which are susceptible to deterioration due to de-icing salts. Corrosion of the steel dowels binds or locks the joints resulting in undesirable pavement performance. The corrosion resistance of GFRP makes it an ideal material for use as load transfer device (dowel) in concrete highway pavement slabs.

Manufacturing dowel bar with recycled ABS

Typically, FRP dowel bars are pultruded using continuous fiber filaments and resin. The filaments are drawn through a resin bath, sized by an appropriate die, to form the dowel. Dowels are typically 1.5” in diameter and 18” long for pavement slabs with a thickness of about 10”.

Proposed method of making Dowel: Manufacturing of dowels using recycled thermoplastics was experimented with considerably successful results. A new mold was designed to manufacture 18.5” long dowel bars using heated rectangular split aluminum molds with semi-cylindrical grooves. The mold enabled pressure application on resin pellets fed into the mold through a piston positioned at the end plate. Mold was heated to the required processing temperature and pressure was simultaneously applied to achieve a good product with respect to uniform melting and blending of the resin.

Details of the mold

A mold was designed to manufacture a dowel bar, 18.5” long and 1.5” in diameter, using recycled polymer reinforced with glass fibers. The mold comprised of long rectangular aluminum pieces with semi-circular grooves in each piece. A piston was positioned near the end plate for applying pressure. Initially, the mold was filled with only ABS resin pellets as a trial (Figure 6-3) and 2 heaters were used on the mold exterior for preheating the resin for about 20 minutes followed by pressure application for about 20 minutes.

Figure 0-3 Experimental mold setup for dowel bar manufacture

Pressure was applied using a mini jack with a load rating of 4 tons. Resin pellets were added intermittently into the mold, removing the piston to maximize resin density. Though resin pellets were not adequately bonded dowel bar appeared to be well compacted (Figure 6-4).

Figure 0-4 Unblended resin pellets in the dowel due to inadequate heat transfer

Then, several compression molding trials were carried out by keeping the pressure constant and varying both temperature and time. Two additional side heaters were mounted on the mold along with the two already existing on the mold to increase the heat transfer. Dowel bar with better surface finish and blending was obtained after 30 min of preheating followed by 45 minutes of pressure application, with intermittent addition of resin pellets.

Dowel bar manufacturing process

Proper compaction of the pellets and heat transfer were the keys to obtain a good dowel bar with respect to weight, surface finish and blending. Inadequate resin filling and compaction led to air voids and gaps in the dowel bar. Resin pellets were intermittently added by lifting the piston after first 10 minutes of heating. Additional pellets were added by compressing the softened resin.

Three process cycles each of 45-minute duration, each time with additional pellets along with the bar made from the earlier cycle were used to obtain a good dowel bar. Pellets were added at the bottom of the mold in each successive cycle, along with the bar made from previous process cycle (Figure 6-5 and 6-6).

Figure 0-5 Mold with dowel bar after first process cycle

Figure 0-6 Mold with additional pellets and premolded bar for following cycles

After 45 minutes of each cycle, the heaters were switched off and the mold was left for cooling for about 3 hours and then demolded. This process was repeated to obtain a dowel bar successfully (Figure 6-7).

Figure 0-7 Appreciable surface finish and blending in dowel, with increase in process time

Another dowel bar was also manufactured using commercial thermoplastic-coated 1" long fibers called "Twintex." Manufacturing trials to determine its process parameters indicated higher process temperature requirement than that is available with current set of heaters. In addition, use of extruded resins in a melted state would lead to a better dowel bar with significant reductions in manufacturing time.

Summary

Process parameters for obtaining a good dowel bar using recycled ABS were determined. These dowels were tested for strength and stiffness in bending, and the results were discussed in Chapter 5.

Introducing preheated resin into the mold would increase the uniformity and blending in the final product and the process time would decrease considerably. Resin with chopped fiber could be used to obtain products of higher strength/stiffness and tested subsequently for field installation.

Angles

Angles, manufactured using the glass fiber reinforced recycled polymers can be used to replace the wooden posts currently used for guardrail systems on highways and bridges. Also, creosote coated wooden guardrail posts are not favored by many environmentalists, because of the potential danger of the groundwater contamination by leached creosote. Fiber reinforced recycled polymer thus forms an alternative material for component of guardrail system, and reduce the demand for lumber supply.

Details of the mold

A new mold was designed with a v-groove cut along base plate, and closed by end plates. An inverted angle was bolted to the top plate such that the matched mold would give an angle of desired thickness as final product (Figure 6-10). Angles of different thickness could be produced by the same mold by additional inserts (plates) positioned in the bottom mold.

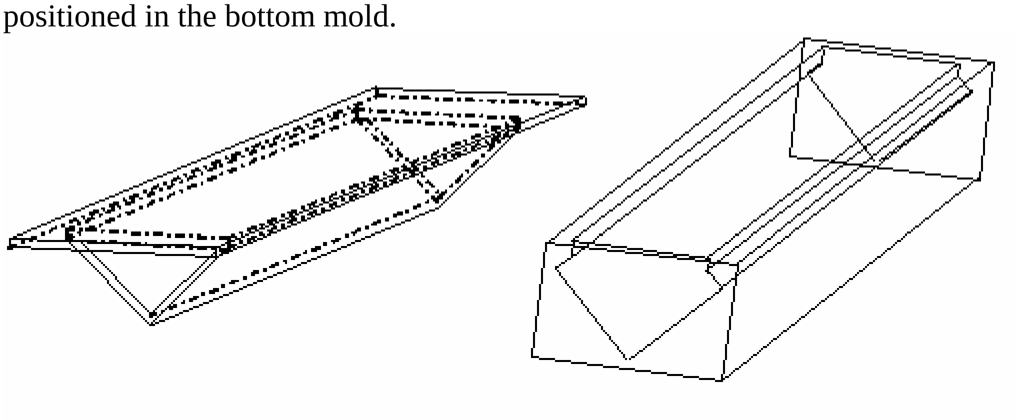


Figure 0-8 Angle mold top and bottom plates

Manufacturing process of angle

Proposed method: Angles were manufactured using compression molding with a specially designed mold (Figure 6-8). Flash was positioned between the resin and inner walls of the mold to provide better surface finish. Demolding agent (Tech Lube 25, Technick products) was coated on the flash for easier retrieval of the end product from the mold. The amount of recycled resin, initially filled in the mold was calculated keeping in view the volume of the end product and its density. The top plate was positioned on the bottom mold: whole mold was placed in the compression press preheated to the required temperature (450^{o} F). The side heaters were switched "ON" and resin was left for 25 minutes to preheat (polymer pellets after preheating becomes soft and mushy). The pressure was then applied gradually to compress the resin in the mold. Twenty tons of compression pressure was kept constant for 30 minutes and then dropped to around 5 tons for cooling.

Figures 6-9 to 6-12 show the sequential procedure in manufacturing an angle using Compression molding process. Figures 6-13 and 6-14 show the manufactured product and its cross section from a cut section.

Figure 0-9 Angle mold being filled with ABS resin

Figure 0-10 Angle mold filled with ABS resin reinforced with glass fabric

Figure 0-11 Mold compressed under pressure and temperature

Figure 0-12 Mold being cooled in the compression press under dead load

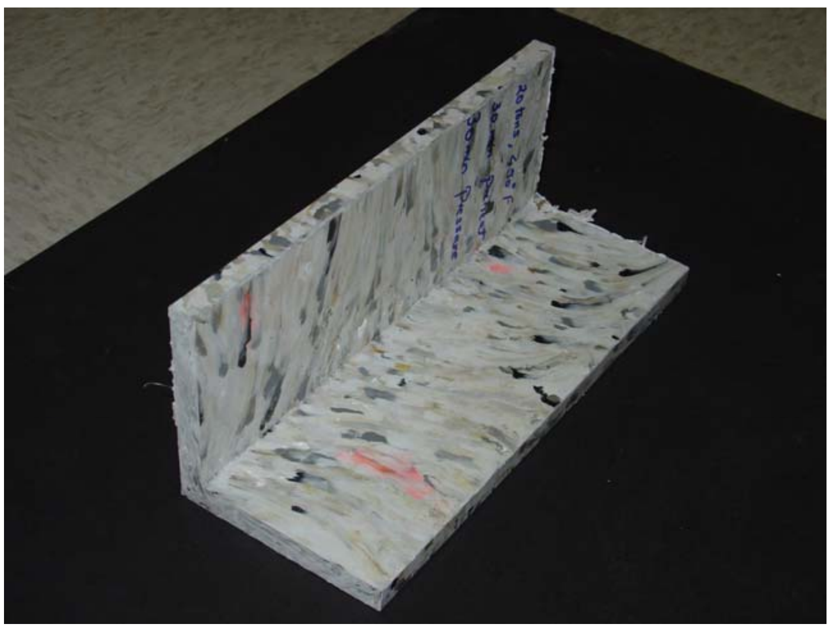


Figure 0-13 Angle made of recycled ABS

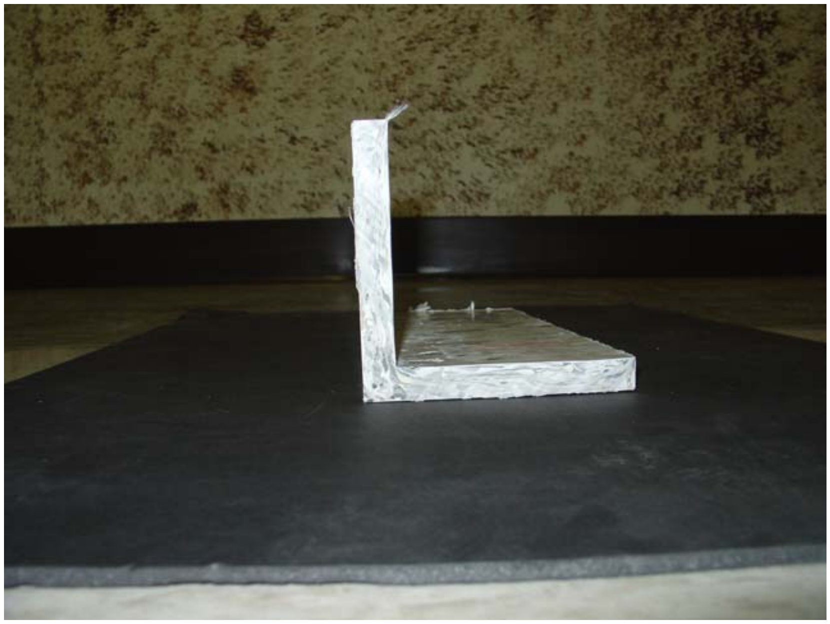


Figure 0-14 Cross-section of the angle

Test on angles

An angle specimen was made from compression molding using the procedure as described above. Specimens were cut from this sample in dog-bone shape for performing tension tests.

Test specimen

Dimensions of the cut specimens are presented in Table 6-1. The rectangular specimens were cut to obtain dog-bone shape (Figure 6-15) in accordance with the Type-3 specimen ASTM 638.

Table 0-1 Dimensions of the tension test specimens

Width Overall (WO)	1.13”
Width of the narrow section (W)	0.75”
Length Overall (LO)	14.5”
Thickness of the sample (T)	0.625”

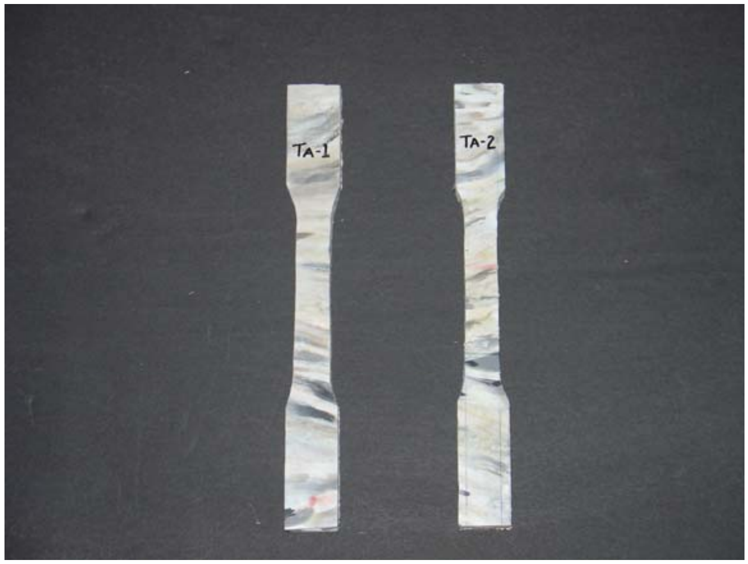


Figure 0-15 Tension coupons cut from angle

Specimen preparation

A strain gauge was installed on the sample at its mid-span in order to measure tensile strains. Surface preparation consisted of: sanding with a 320 grid paper, cleaning with degreaser, neutralizing with alkaline solution, followed by attaching the strain gauge by using M-bond adhesive.

Test procedure

Baldwin machine (UTM) was used to conduct the tension test on the samples cut from the angles. Load data was directly recorded from the Baldwin machine, whereas the strain data was recorded using data acquisition system (Figure 6-16). The test was computer controlled and the initial strain values were zeroed before starting the test. The specimens were loaded until failure.

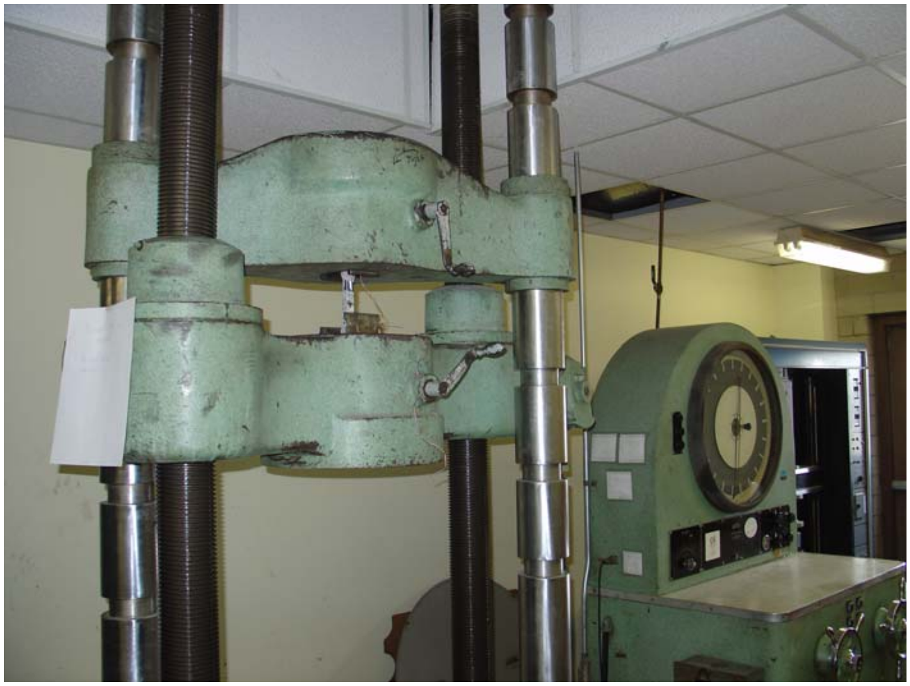


Figure 0-16 Tension test specimen in Baldwin machine

Figure 0-17 Close up of the Tension test setup

Results

Figure 6-18 shows the tensile stress vs. strain relation for the coupon cut from an angle specimen (Figure 6-15). Strength and stiffness values are presented in Table 6-2.

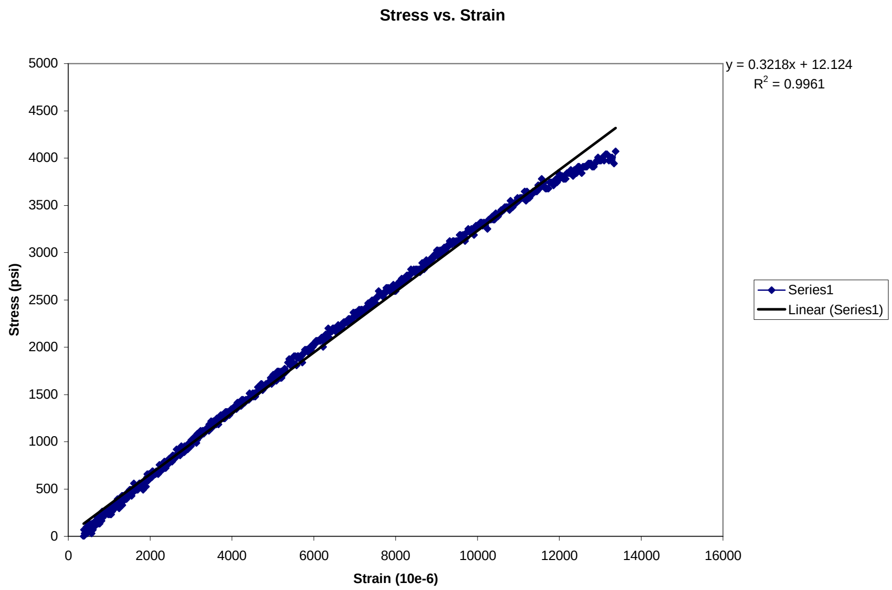


Figure 0-18 Stress vs. Strain graph of tension specimen-1 cut from the angle

Table 0-2 Maximum tensile strength and stiffness values for the tensile test samples

Specimen	Maximum stress (psi)	Stiffness ($\times 10^6$)
TAA-1	4072.533	0.3218

Note: TAA-1: Tension test ABS specimen #1 cut from the Angle

Remarks

The glass fabric used in manufacturing the angles was found to be incompatible with ABS thermoplastics resin. Thus, the coupon specimens cut from the molded angles when tested in tension gave low strength and stiffness values.

Summary

The processing parameters for the manufacture of composite dowel bars and angles made from recycled thermoplastic resins were determined. A sequential procedure was laid out for the manufacture of these composite products and this procedure could be modified to suit various specimen sizes. Structural strength and stiffness of these products could be improved with the use of compatible glass fabrics. These angles could be manufactured as prototype signposts and vertical posts for guardrail systems on bridges and highways.

CHAPTER 7
Thermo-mechanical properties of the offset block

Infrared Thermography

Introduction

Non-destructive methods have been gaining importance in the material testing techniques quite rapidly in comparison with the other testing methods (American Society of Non-destructive Testing). Non-Destructive Inspection and Evaluation (NDI&E) is a valuable tool in any phase of a product's design and manufacturing process, including materials selection, research and development, assembly, quality control and maintenance.

Some of the commonly used NDI techniques include liquid penetrant, magnetic particle, eddy current and radiographic inspection, ultrasonic and infrared inspection, tomography, real-time radiography, ground penetrating radar, and fiber optics.

Infrared imaging (thermography) used in this study is a non-contact optical method where an accurate two- dimensional mapping of steady or transient thermal profile is constructed from the measurement of infrared energy emitted by the target. By implementing real time infrared image acquisition and processing we can:

- Detect sub surface imperfections.
- Evaluate composition of materials and products in terms of structural discontinuities.

Infrared imaging can be carried out by portable hardware that provides rapid data acquisition of the infrared images that are easy to interpret. It utilizes the heat energy radiated by an object to characterize its subsurface conditions. The subsurface defects affect the rate of heat transfer through the thickness of the structural member and hence result in surface temperature differentials with respect to defect-free areas.
The areas of a specimen subjected to thermography are differentiated in varying colors and the color contour is explained with a color-temperature graph shown next to the image.

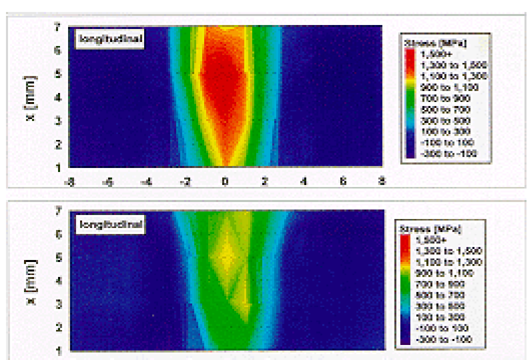


Figure 0-1 Sample infrared image with color-temperature graph

ThermaCAM™ S60

The ThermaCAM™ S60 (FLIR Systems) infrared condition monitoring system consists of an advanced digital infrared camera and associated image processing software. The ThermaCAM™ lightweight, portable camera (Figure 7.2) is a handheld unit with a built-in 24^{o} lens.

Some of its features are:

- An integral digital color camera, a laser pointer, a 4” color LCD.
- Measurable temperature ranges are +32 to +932^{o}F (0 to +500^{o}C), -40 to +248^{o}F (-40 to +120^{o}C) and +662 to +2732^{o}F (+350 to 1500^{o}C).
- Measurement accuracy of ±2 ^{o}C or ±2% of reading in ^{o}C.
- Images can be analyzed either in the field by using the real-time measurement markers built into the camera software, or in a PC using FLIR Systems software.

Figure 0-2 Infrared camera, ThermaCAM™ S60

Testing Procedure

7.1.3.1. Summary

Manufacturing process of the Guardrail Offset block was monitored with ThermaCAM™ S60 to study the temperature profile and heat distribution within the mold filled with ABS thermoplastic resin. Inadequate heat distribution within the block during compression molding process was suspected to be the main cause of improper resin pellet blending. Thus, thermal imaging technique was used to study the heat propagation within the mold filled with all ingredients of the block, i.e., resin, rubber strips, and glass fabric. Presence of rubber (insulator) tires along with low thermal conductivity of recycled plastics were some of the reasons for non-uniform heat propagation.

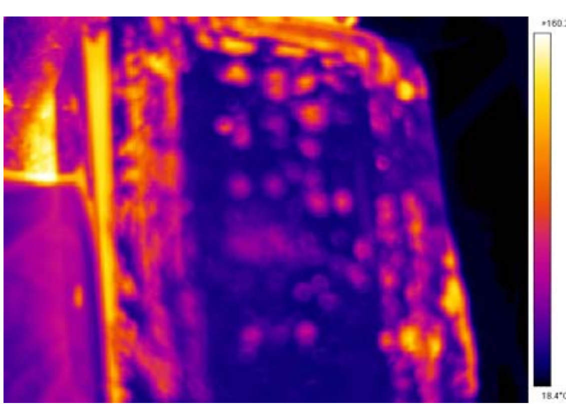
7.1.3.2. Approach

Manufacturing process of the block was monitored using infrared thermography to study heat propagation during the process. No external heating, other than the heaters of the press and side heaters on the mold needed for manufacturing the block, was used for this experiment. Existing temperature differences within the various mold constituents (rubber strips, resin pellets and glass fabric) were used to establish necessary temperature patterns. This approach is commonly used to assess or monitor the state of industrial process in the manufacturing stage (Maldague 2001).

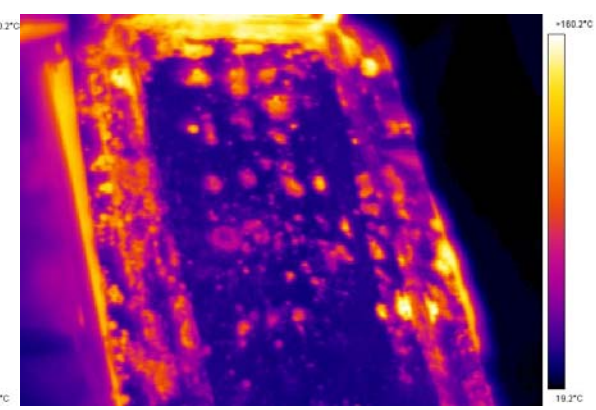
The infrared camera allows the images to be recorded first and then viewed at a later time with a different temperature/color intensity scale to improve the contrast. The temperature corresponding to any point could be obtained by using the spot temperature measurement option provided by the analysis software.

7.1.3.3. Process

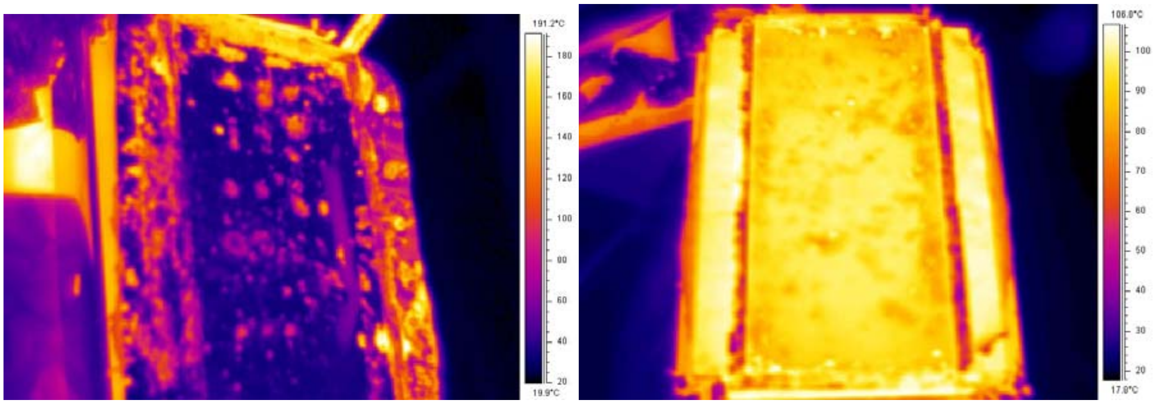
Composite manufacturing process was carried out along with the infrared imaging process to study the heat flow pattern during the process. A bench was positioned near the compression press so that the hot mold can be placed on it when it is intermittently taken out for the thermal imaging. The imaging set-up was positioned at a distance wherein clear images could be obtained. Images were taken at specific time intervals from the beginning of the manufacturing process and continued until the cooling phase. Figures 7-3 (a), (b), (c) and (d) are the thermal images taken during manufacturing process.



(a) End of preheating (30 min) at 450^o F



(b) End of 6 min of pressure (20 tons)



(c) End of 11 min of pressure (20 tons) **(d) Cooling phase-230° F (5tons)**

Figure 0-3 Thermal images of the hot mold taken at various time intervals during the manufacturing process of the block

Limitations of infrared imaging

The measurement of the surface temperature profile by infrared camera is effected by environmental parameters such as solar radiation, air temperature, wind, rain, surface stains and patches and shadows of adjacent structures and trees (Halabe et al. 1995). It is not possible to detect micro-cracks or very small defects using the infrared technique. It cannot detect the depth of the thickness of a defect.

Summary

The attempt of studying the heat propagation in the mold during the compression manufacturing process by taking thermal images using the infrared technique was partly successful owing to its decreasing accuracy in increasing depths. Surface temperature profile (Figure. 7-3 (a), (b), (c) and (d)) was studied as varying function of time as can be observed from the infrared images.

Characterization of thermal propagation properties

An experiment was carried out on a sliced section of the guardrail-offset block to find its heat conduction properties. The aim of the experiment was to find the heat transfer properties of the sample by measuring the temperature variation at different distances from heat source with respect to time when exposed to higher surface temperature.

7.2.1 Experimental set-up

Guardrail offset block was manufactured with rubber tire core and glass reinforced recycled Acrylonitrile Butadiene Styrene (ABS) plastic shell. The block was sliced to obtain its representative element, for the heat conduction experiment. The sliced portion was placed on the heated platen surface (250° F) of the press, with the rest of the platen insulated with wooden blocks, styrofoam and rubber tires to minimize heat losses. Infra red images of the sample were taken at every 5-minute interval for 60 minutes (heating phase). Then, the sample was removed from the heat source and placed on a table surface maintained at room temperature (about 70° F). Again, infrared images were taken at every 5-minute interval for about 60 minutes (cooling phase). Thus, heat transfer within the test sample was studied by observing the change in temperature at different distances from heat source with respect to time in the heating and cooling phases.

A finite element model was created with similar conditions and analyzed for prevailing temperature variations. The results from finite element analysis and infrared thermography are further discussed in Chapter 8.

Summary

Infrared imaging technique was used to study the guardrail-offset block surface temperature profile during manufacturing. Presence of non-conducting constituents in the block like rubber was evident from the low temperature zones observed in the thermal images. By using a better monitoring process, heat transfer/propagation at various points within the mold during manufacturing phase can be studied (analyzed) and methods to improve the manufacturing process could be suggested. Finite element analysis was conducted on a sliced section of the block and analyzed for the temperature profile at different distances from heat source with respect to time. Those results were compared with results from the experiment conducted as described earlier. These are discussed in detail in Chapter 8.

CHAPTER 8
Finite Element Analysis

Introduction

Finite element model of a sliced section of the guardrail-offset block was created and analyzed for its behavior under the application of surface thermal loads with respect to time. ABAQUS was used to analyze the offset block and FEMAP was used as pre/post processor. Material properties for the constituents of the block- resin (ABS) with glass fabric and rubber were used as inputs for creating the finite element model. The analysis aimed at studying the temperature profile at different distances from heat source in a sliced section of a guardrail-offset block with respect to time.

Creating the geometry

Initially, work plane dimensions were fixed to a required size and a rectangle with two inner rectangles was created. A solid shell and core of different materials were created using these rectangles. A composite solid (6”× 6”× 2”) with two different materials (recycled ABS shell and rubber as shown in Figure 8-1) was created and the material properties were defined as explained in the following section. Presence of any air voids and pockets were not considered in this model. A perfect bond was assumed between the polymer and rubber layers and respective boundary nodes were merged.

Define materials and properties

Different layers were created in the work plane to separate the entities (core and shell) of the model created in earlier steps. Solid model thus created was sliced into simple sections and distributed within different layers. Material properties, loads and constraints were then assigned to these entities in separate layers.

Material properties of recycled ABS known from previous research (Bargo, 2000) and GE plastics website (www.Geplastics.com) were assigned to the solid shell in the model. Properties of rubber were assigned to the solid core in the model. Thermal conductivities of ABS and rubber are 2.8895e-6 and 2.27238e-6 Btu/lbs-sec-in^2-F/in.

Table 0-1 Thermal properties of fiber reinforced polymers

Material	Specific heat C ($J\ kg^{-1}\ {}^{o}C^{-1}$)	Density ($kg\ m^{-3}$)	Heat capacity . C ($J\ m^{-3}\ {}^{o}C^{-1}$)	Thermal conductivity K ($W\ m^{-1}\ {}^{o}C^{-1}$)	Thermal diffusivity[a] δ ($m^2\ s^{-1}$)
CFRP[b] (_|_ fibers)	1200	1600	1.9×10^6	0.8	0.42×10^{-6}
CFRP[b] (|| fibers)	1200	1600	1.9×10^6	7	3.7×10^{-6}
GFRP[c] (_|_ fibers)	1200	1900	2.3×10^6	0.3	0.13×10^{-6}
GFRP[c] (|| fibers)	1200	1900	2.3×10^6	0.38	0.17×10^{-6}

Defined as = K/ C, where K is the thermal conductivity, is mass density is the specific heat, and C is the heat capacity.
[b] Carbon fiber reinforced polymer.
[c] Glass fiber reinforced polymer

After creating material and properties, meshing was done to generate nodes and elements. Loads and constraints were applied on the nodes of the solid elements created.
Meshing

Tetrahedral or hexagonal meshing can be done using FEMAP software. Hexagonal meshing was used so that nodes at the interface between the outer shell and inner core could be merged. Edges of these solids were divided into equal segments to obtain predetermined number of elements and nodes. Then, nodes at common edges were merged, allowing transfer of load from outer to inner solid.

The hollow ABS plastic shell prevents direct hexagonal meshing and hence it was sliced. The outer core was sliced into 4 parts. Each solid section was placed in a separate layer and sliced down to simple shapes. Curves forming the solid were divided into segments of particular length such that each division represented 0.25”. Then, the solid was meshed using specified mesh size, followed by addition of the solids. Curves on opposite surfaces as well as on outer and inner solids were subdivided such that they had matching element divisions and consistent mesh sizing. After meshing, all the parts were added to retain the original geometry of the outer shell.

Hexagonal meshing generates elements of “C3D8” type which were later changed in the ABAQUS input file as “C3D8T” type elements to allow imposing of thermal load (intended load pattern). All solid segments were then merged by checking for coincident nodes and the meshing process was completed.

Applying loads

Surface thermal load was applied to the guardrail offset block model in the form of temperature, which was later converted into nodal and elemental temperatures upon translation or expansion. Surface temperature load of 250° F was applied to the model for 60 minutes and analyzed in steps of 5-minute increments. The analysis was continued by changing surface load to room temperature (70° F) and analyzing the terms of response at every 5-minute increment for 60 minutes.

Applying constraints

In the experiment, test sample cut from the offset block was placed on the platen of the press heated to 250^{o} F. Only thermal load in the form of surface temperature and no mechanical load was imposed on the sample. To implement support conditions similar to field installed offset block in finite element analysis, 6”× 2” face of the block (bottom surface of the model) of the test sample modeled was fixed to avoid displacements, and surface temperature was applied on it. Fixed condition implies zero displacements and rotations when applied to a node, element and curve of a surface or solid.

Exporting the analysis model

Boundaries of the finite element model created were constrained and temperature (thermal load) was applied in FEMAP, and then exported to ABAQUS for solving. An input file was automatically created with the extension “inp” and necessary changes were made to modify the “C3D8” type elements to “C3D8T” type, thus completing the export process.

Solving the model and viewing the results

The input file generated after exporting the model created in FEMAP to ABAQUS through challenge server was opened in word file and necessary changes were made. Model was solved in ABAQUS using standard commands and output file with extension “fil” was imported and opened in the FEMAP active window. The “fil” file was imported back to FEMAP and opened to observe the temperature parameters as results of the analysis.

Results

Results from the finite element analysis were obtained in the form of temperature profiles in the test sample as seen from several snap shots in Figure 8-2. Temperature contours with respect to time at various distances from the heat source were obtained.

Temperature rise and fall during the heating and cooling phases within the test sample with respect to time at 0.25”, 0.5”, and 1” distances from heat source were plotted as graphs to observe heat conduction behavior of the block.

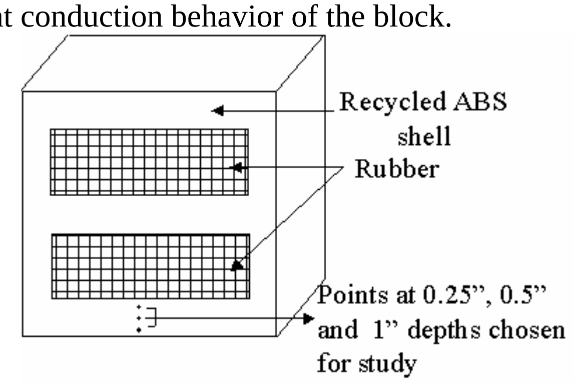
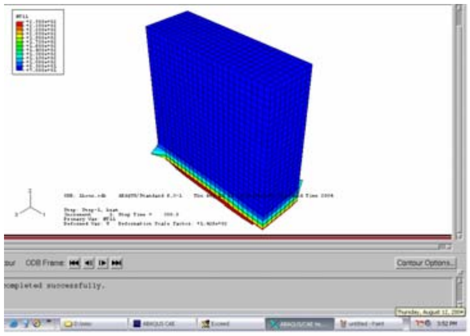
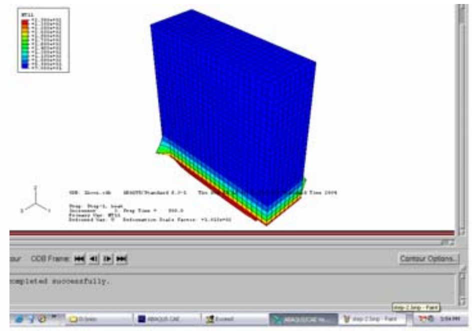
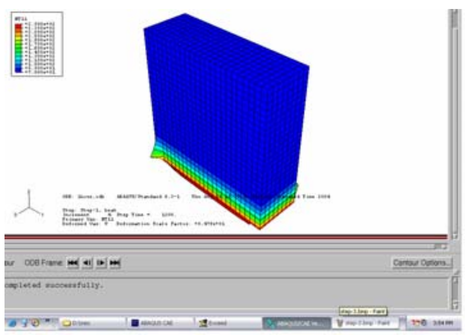


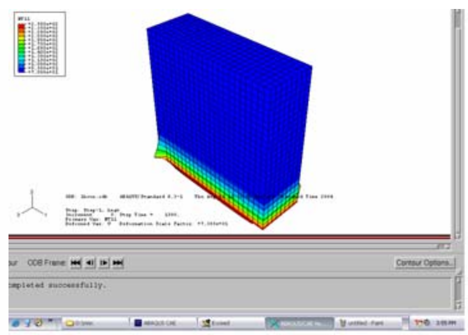
Figure 0-1 Test sample modeled using FEMAP for thermal analysis



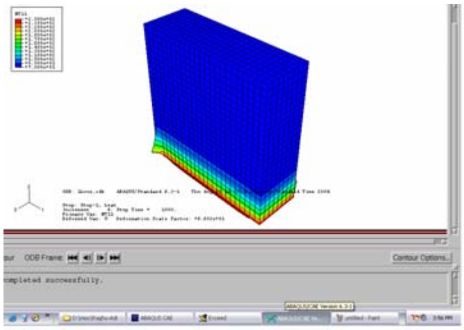


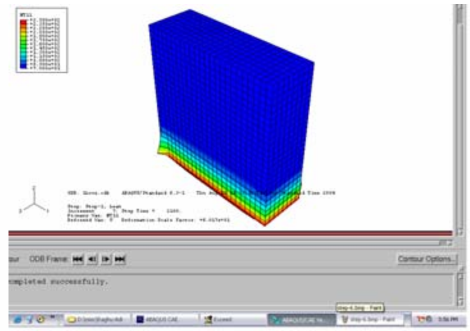
(a) End of 5 minutes (heating at 250^{o} F) **(b) End of 10 minutes (heating at 250^{o} F)**



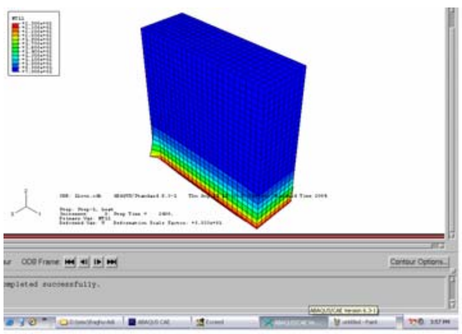


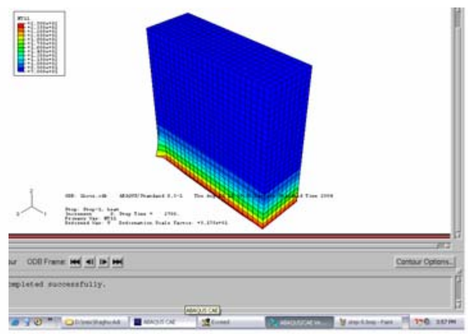
(c) End of 15 minutes (heating at 250^{o} F) **(d) End of 20 minutes (heating at 250^{o} F)**



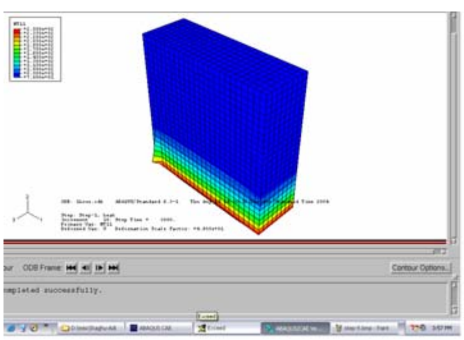


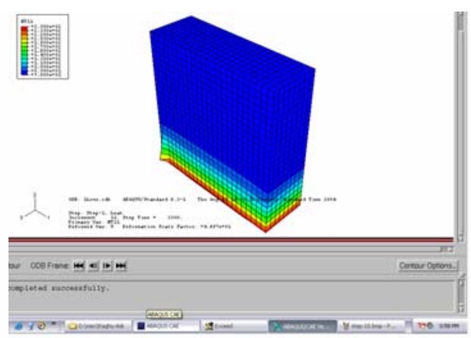
(e) End of 25 minutes (heating at 250^{o} F) (f) End of 30 minutes (heating at 250^{o} F)



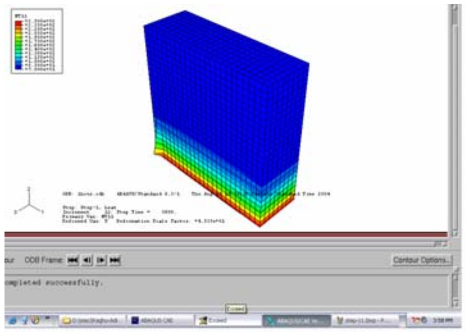


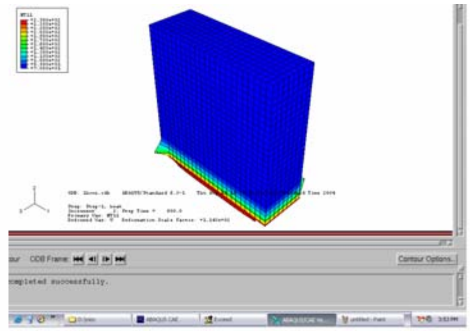
(g) End of 35 minutes (heating at 250^{o} F) (h) End of 40 minutes (heating at 250^{o} F)





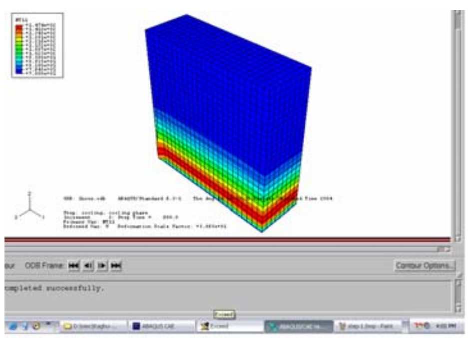
(i) End of 45 minutes (heating at 250^{o} F) (j) End of 50 minutes (heating at 250^{o} F)

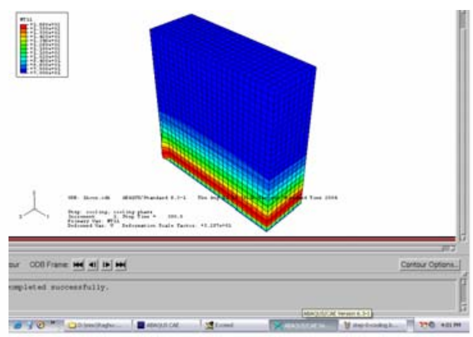




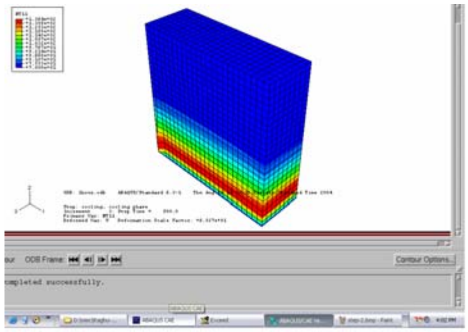
(k) End of 55 minutes (heating at 250^o F) **(l) End of 60 minutes (heating at 250^o F)**

Figure 0-2 Finite Element images of the offset-block sliced section during heating phase

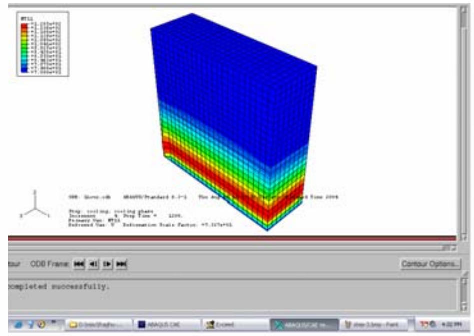




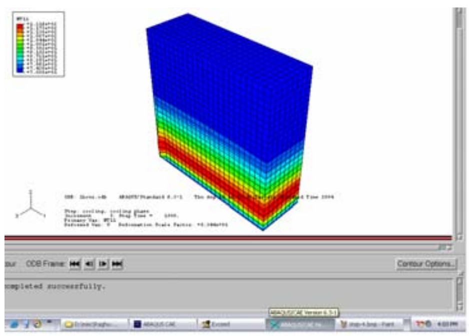
(a) End of 5 minutes (cooling at 70^o F) **(b) End of 10 minutes (cooling at 70^o F)**



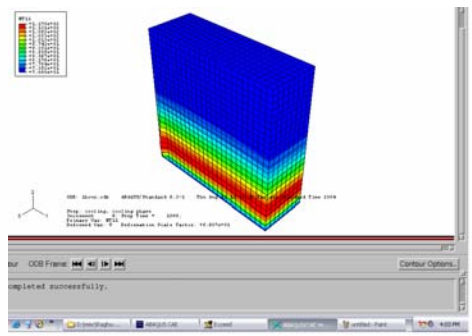
(c) End of 15 minutes (cooling at 70° F)



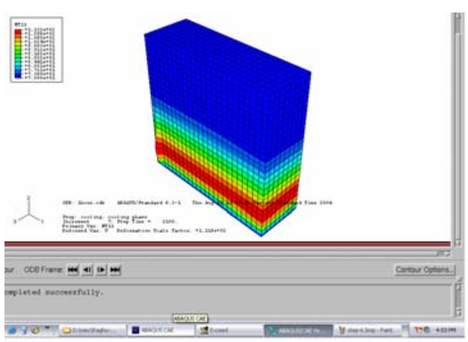
(d) End of 20 minutes (cooling at 70° F)



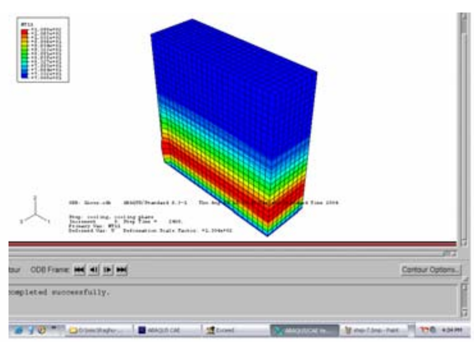
(e) End of 25 minutes (cooling at 70° F)



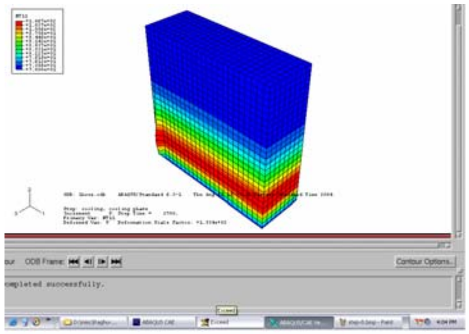
(f) End of 30 minutes (cooling at 70° F)

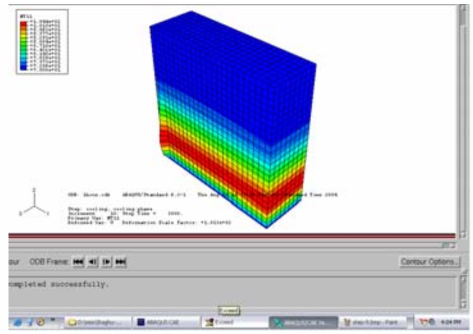


(g) End of 35 minutes (cooling at 70° F)

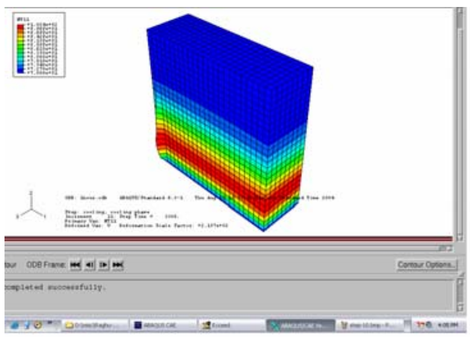


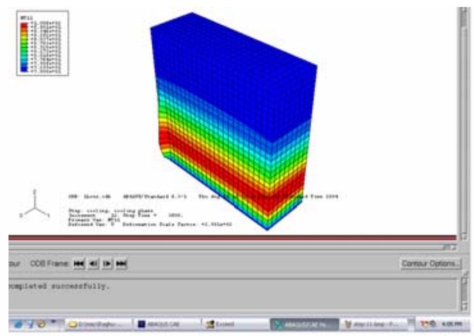
(h) End of 40 minutes (cooling at 70° F)





(i) End of 45 minutes (cooling at 70^o F)   (j) End of 50 minutes (cooling at 70^o F)





(k) End of 55 minutes (cooling at 70^o F)   (l) End of 60 minutes (cooling at 70^o F)

Figure 0-3 Finite element images of the offset-block sliced section during cooling phase

Figures 8-4 and 8-5 show changes in temperature at 0.25”, 0.5”, 1”, and 2.5” distance away from the heated surface of the offset block specimen with respect to time.

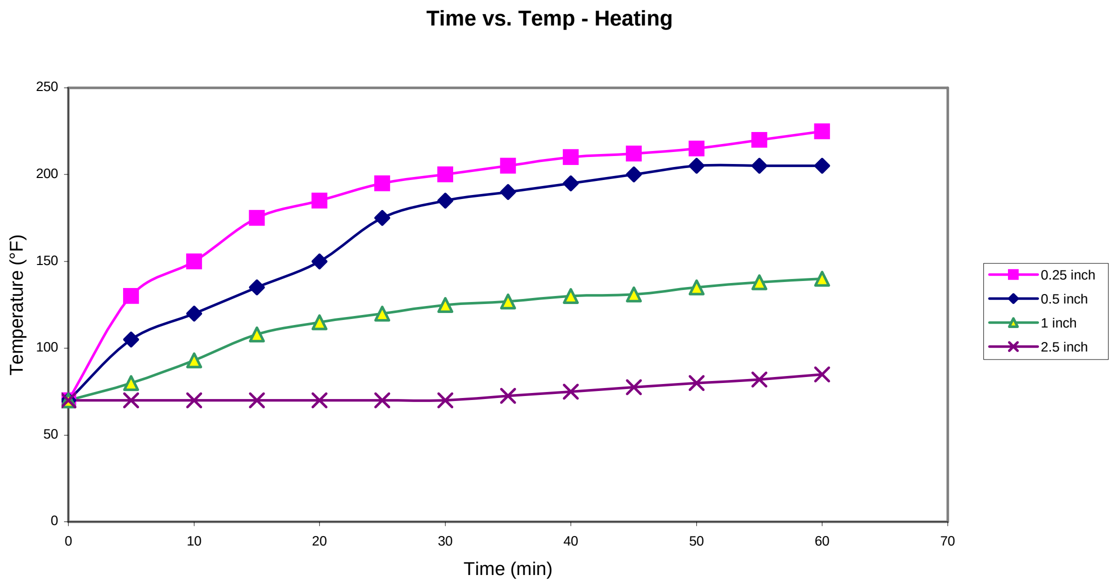


Figure 0-4 Temperature curves at different distances from heat source in the test sample vs. time (heating phase)

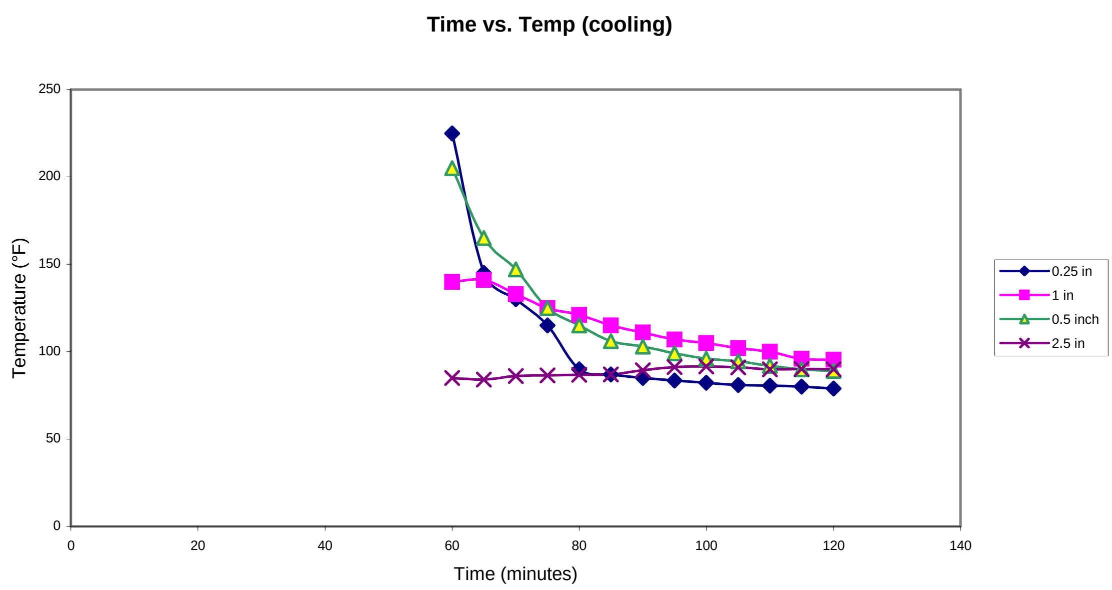


Figure 0-5 Temperature curves at different distances from heat source in the test sample vs. time (cooling phase)

The analysis was initially done with ABS thermoplastic resin and rubber core and the plots were obtained as shown in Figures 8-4 and 8-5. Then, as an approximation the thermal conductivity value of the outer shell was increased from that of pure ABS ($k = 2.27238\times10^{-6}$ Btu-in/(s-in^2-°F)) to glass fiber reinforced polymer (GFRP) ($k' = 4.015\times10^{-6}$ Btu-in/(s-in^2-°F)), to incorporate the effect of glass fabric within the offset block. Temperatures vs. time plots of the updated analysis are shown in Figures 8-6 and 8-7.

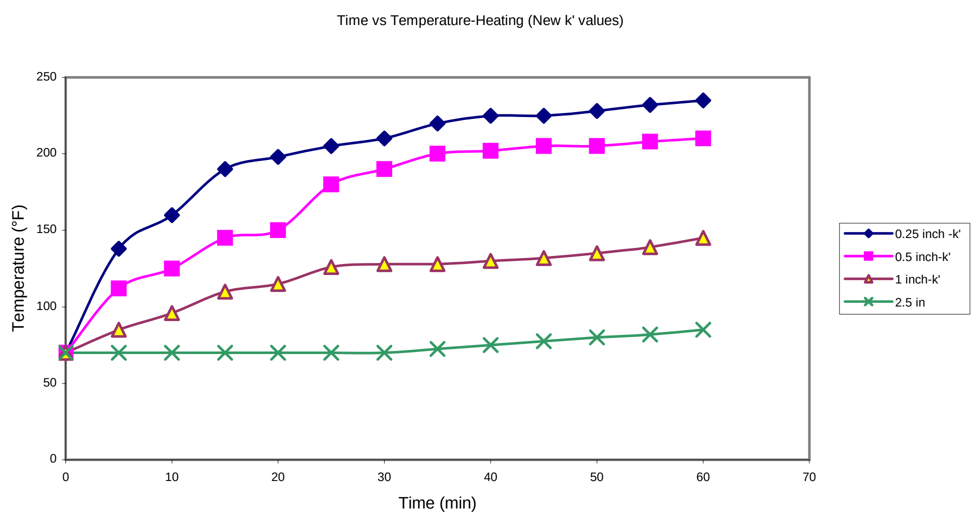


Figure 0-6 Temperature curves at different distances from heat source in the test sample with changed thermal conductivity (k') value vs. time (heating phase)

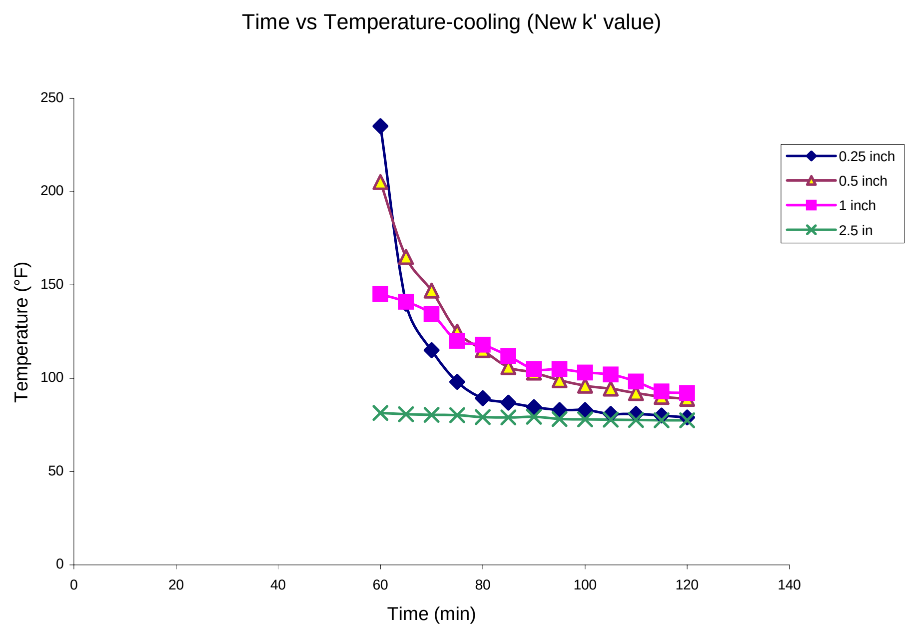


Figure 0-7 Temperature curves at different distances from heat source in the test sample with changed thermal conductivity (k') value vs. time (cooling phase)

Figures 8-8, and 8-9 were plotted by superimposing results from Figures 8-4, 8-5, 8-6 and 8-7 to represent the difference in temperature propagation due to change in thermal conductivity value (k).

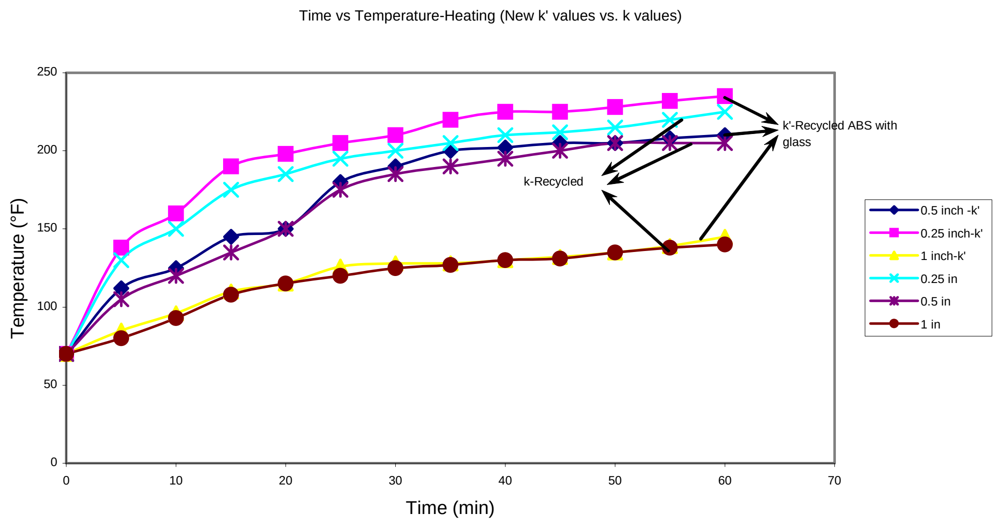


Figure 0-8 Variation in temperature progression due to change in thermal conductivity (k) values in heating phase

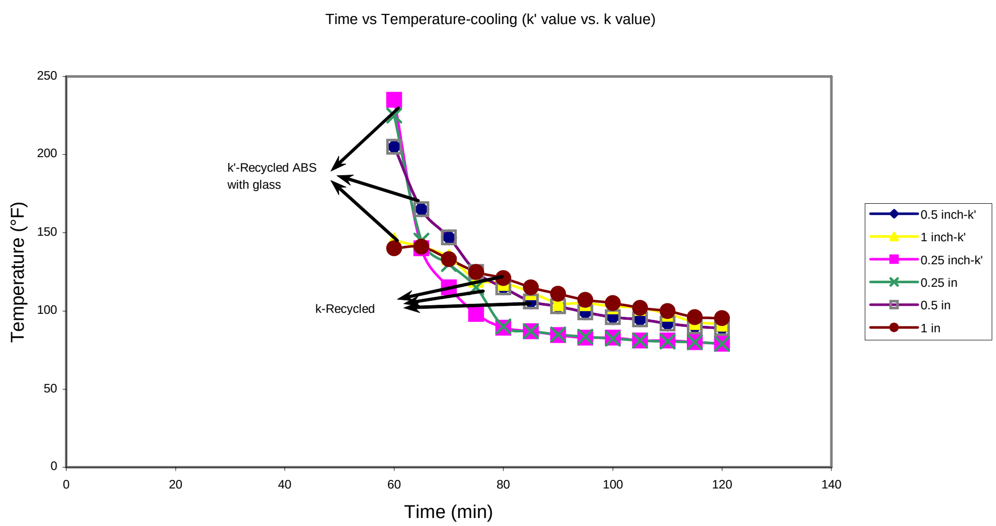


Figure 0-9 Variation in temperature progression due to change in thermal conductivity (k) values in cooling phase

Summary

Following summary is provided based on the finite element analysis results:

- Heat propagation within the composite with respect to time was studied using this analysis.
- At the end of 60 minutes of unidirectional 250° F heat application, the temperatures at 0.25”, 0.5” and 1” distances from heat source were 225° F, 205° F and 140° F respectively.
- The low final temperatures are due to the poor thermal conductivity values of the polymer and rubber constituents of the block as well as the type of heat source provided (unidirectional).
- The temperatures at 0.25”, 0.5” and 1” after the cooling phase due to applied 70° F heat were 79° F, 89° F and 95°F, respectively.
- Difference in temperature values at a given distance from heat source and at a given time due to changes in thermal conductivity between recycled ABS with glass fabric and plain recycled ABS were:
  - About 8° F more in heating phase, and about 2° F more during cooling phase at 0.25in for ABS with glass fabric.
  - About 5° F more in heating phase, and about 1° F more during cooling phase at 0.5in for ABS with glass fabric.
  - About 2° F more in heating phase, and about 1.5° F more during cooling phase at 1” for ABS with glass fabric.
- The heat transmission rates in this case are not linear. Thus, this model could be extended from a transient isotropic analysis to complex non-linear thermo-dynamic analysis.

Limitations of FE analysis

- The finite element model does not take into account the melt-flow and viscosity properties of the polymer, thus is not the exact representation of the original problem.
- Thermal properties of the polymer are temperature dependent and thus, a special software package may be used to arrive at a better solution.
- Study of heat flow properties of the constituents of polymer products would provide information that can be used in its manufacturing process. The time and temperature process parameters can be decided based upon their melt flow characteristics. Some of the expensive software packages that include such features and even predict the movement of the resin in the mold during the manufacturing phase are C-MOLD, MOLD-FLOW, and CADPRESS-THERMOPLASTIC etc.
- Experimental study of the heat propagation within a sliced portion of the manufactured guardrail offset block
- A sliced portion of the offset block was taken as test sample for the experiment.
- One face of the block was exposed to constant temperature source (platen of the press heated to 250° F), with rest of the heated platen insulated using rubber tires/wooden blocks/styrofoam. (Figure. 8-10)

- Temperature readings on the surface of the block were studied using infrared thermography at constant time intervals.
- The infrared images obtained enabled study of temperature (heat transfer) at various points on the surface of the block.

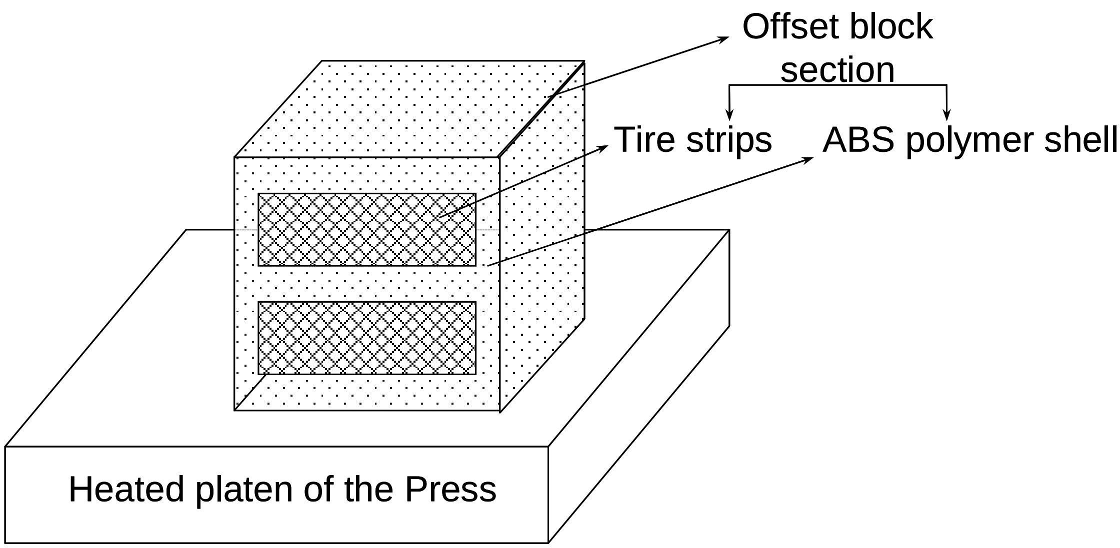


Figure 0-10 Sliced offset block on heated platen

The results from this experiment are represented in Figures 8-11 and 8-13 as follows:

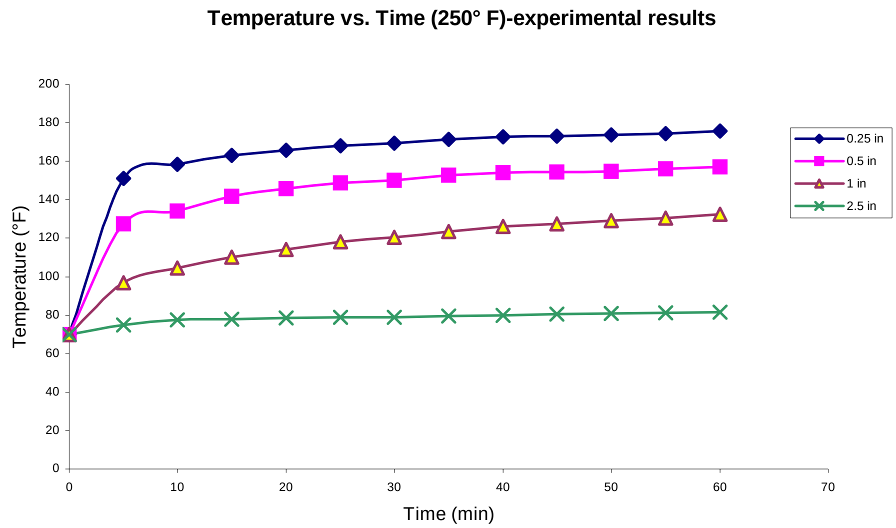


Figure 0-11 Time vs. Temperature curves from Infrared images for points at different distances from heat source during heating phase (250° F)

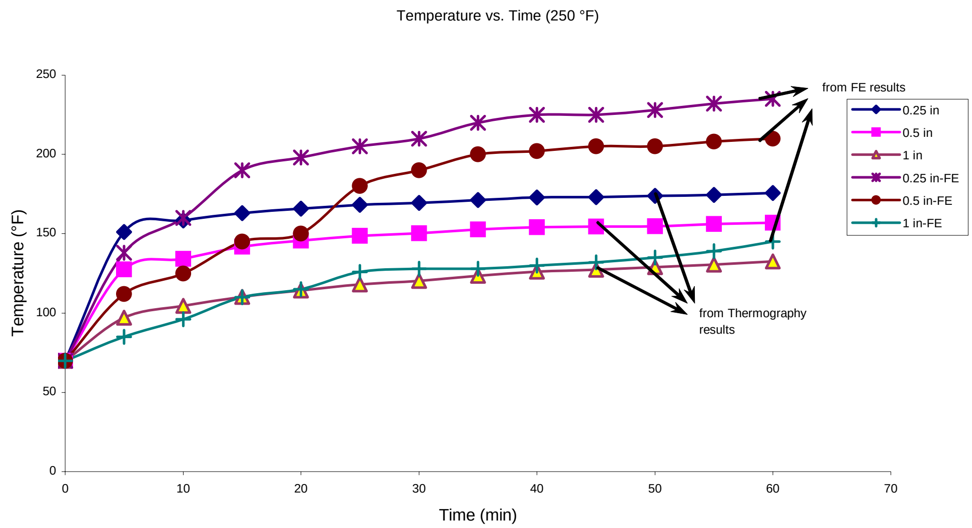


Figure 0-12 Time vs. Temperature curves from both Infrared images and FE analysis for points at different distances from heat source during heating phase (250°F)

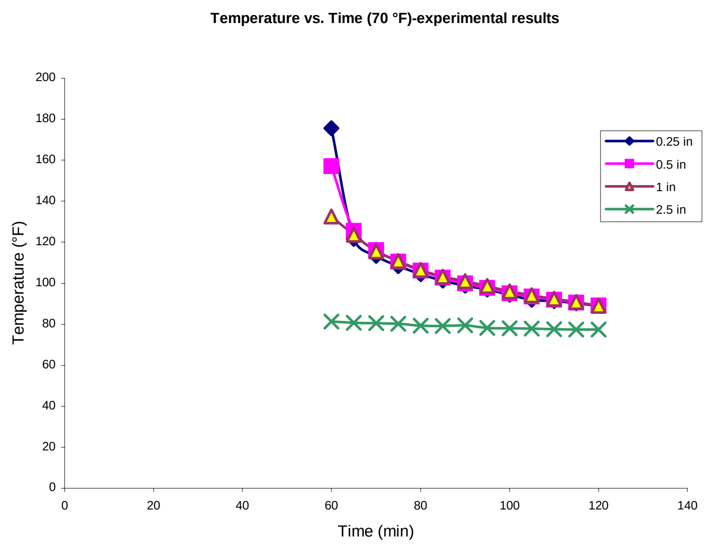


Figure 0-13 Time vs. Temperature curves for points at different distances from heat source from Infrared images during cooling phase (70^{o} F)

Temperature vs. Time (70 °F)-experimental results

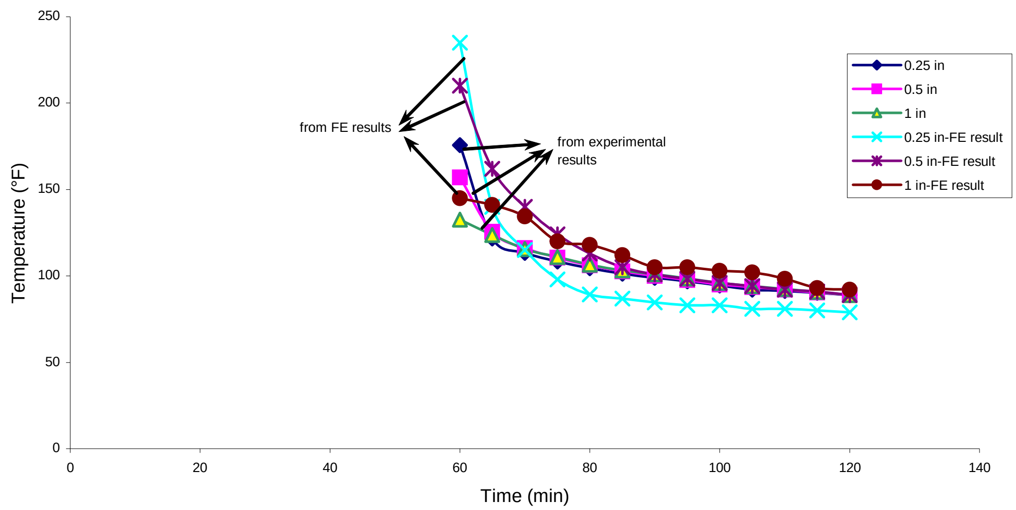


Figure 0-14 Time vs. Temperature curves for points at different distances from heat source from both Infrared images and FE analysis during cooling phase (70° F)

Summary

- Thermal images were automatically recorded at every 5-minute interval from the beginning of the experiment.
- Software used for viewing the thermal images enabled determination of temperatures at different distances from heat source, i.e., bottom of the test sample. Temperature data collected at 0.25", 0.5" and 1" for different time intervals during heating and cooling phases were plotted and analyzed.
- Slope of the curves decreased as the distance from heat source increased indicating non-linear heat transfer. Low heat transmission rates can be accounted due to low thermal conductivity of plastic, rubber tires and imperfections such as holes, gaps and voids in the specimen.
- The temperature values obtained from the experiment vary from those obtained from the finite element results due to the presence of air voids, gaps and heat losses in the specimen that were not considered.
- The final temperatures (after heating and cooling stages) at distances 0.25", 0.5", and 1" from heat sources were 89^{o} F, 89.2^{o} F, and 89^{o} F respectively.

Observing temperature effect on test sample by analyzing FE model at 0^{o} F, -20^{o} F and –40^{o} F

Further study was conducted on the temperature progression within the test sample (sliced from offset block) by analyzing the finite element model at low temperatures. Analysis was carried out for 0° F, -20° F and –40° F temperature application and temperature variation at 0.25”, 0.5” and 1” distances from heat source (from bottom of the sample) was plotted as a function of time. Figure 8-15 shows variation in temperature progression with respect to time at 0.25”, 0.5” and 1” distances from heat source (from bottom of the sample).

Analysis at 0° F

Results from our analysis of the model with a surface thermal load of 0° F is referred to as phase 1 (Figure 8-15). Continuation of the analysis with the sample maintained at 70° F is referred to as phase 2 and its results are shown in Figure 8-16.

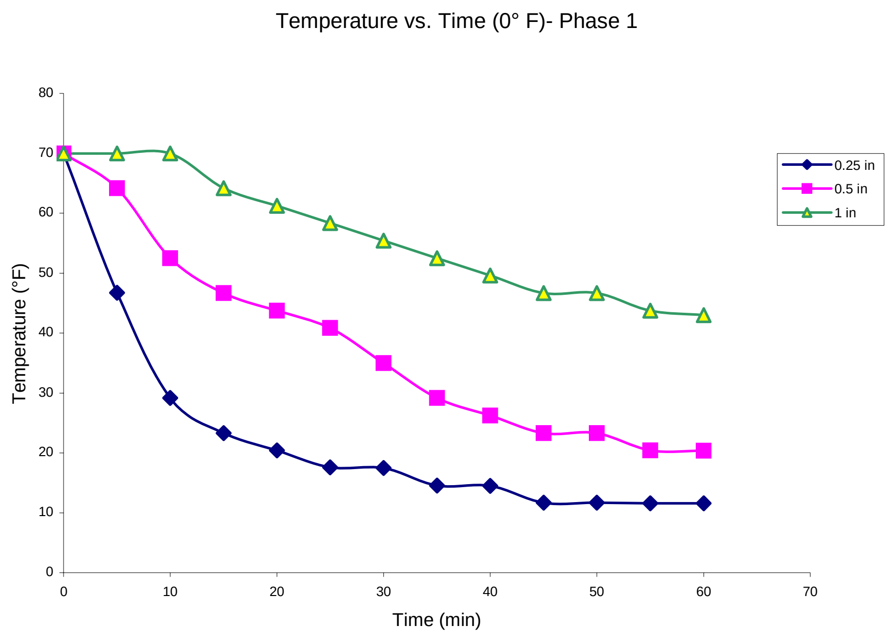


Figure 0-15 Temperature vs. Time (0° F) at different distances from heat source

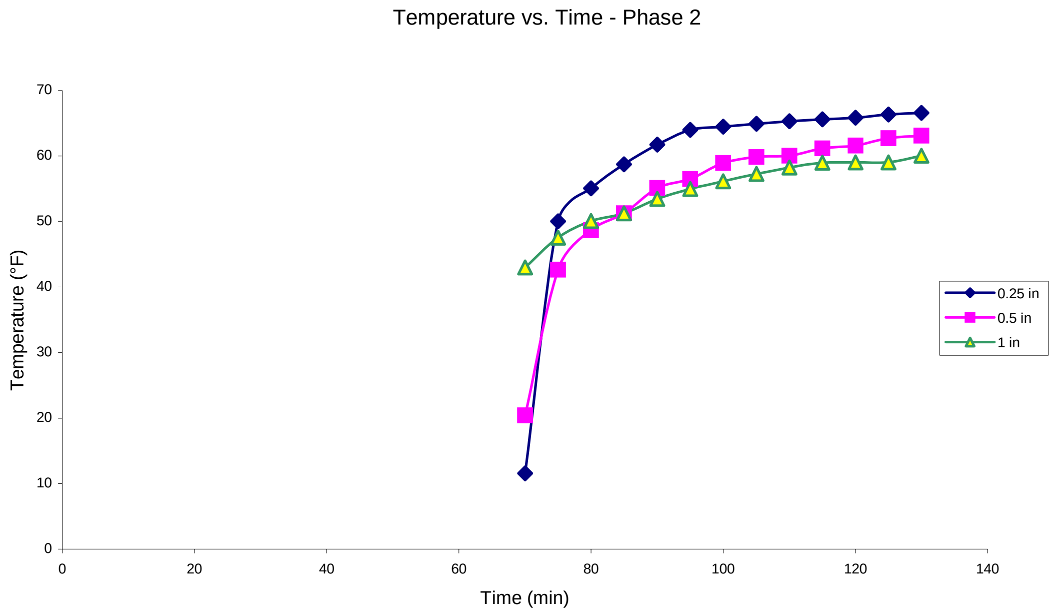


Figure 0-16 Temperature vs. Time (70° F) at different distances from heat source

Analysis at –20° F

Results of the analysis run with thermal load of –20° F in phase 1 (60 minute duration) are presented in Figure 8-17 and its continuation with sample maintained at 70° F in phase 2 (60 minute duration) is represented in Figure 8-18.

Analysis at -40° F

Results of the analysis run with thermal load of –40° F in phase 1 (60 minute duration) are presented in Figure 8-19 and its continuation with sample maintained at 70° F in phase 2 (60 minute duration) is represented in Figure 8-20.

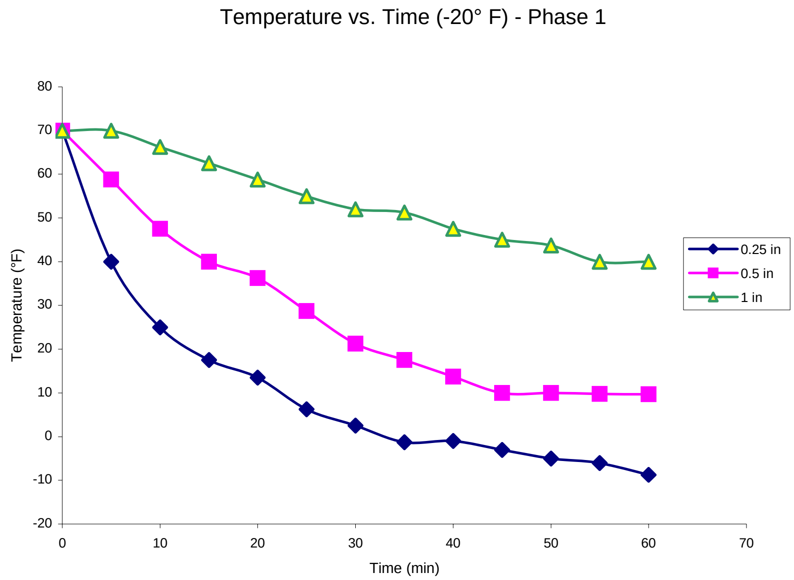


Figure 0-17 Temperature vs. Time (-20° F) at different distance from heat source

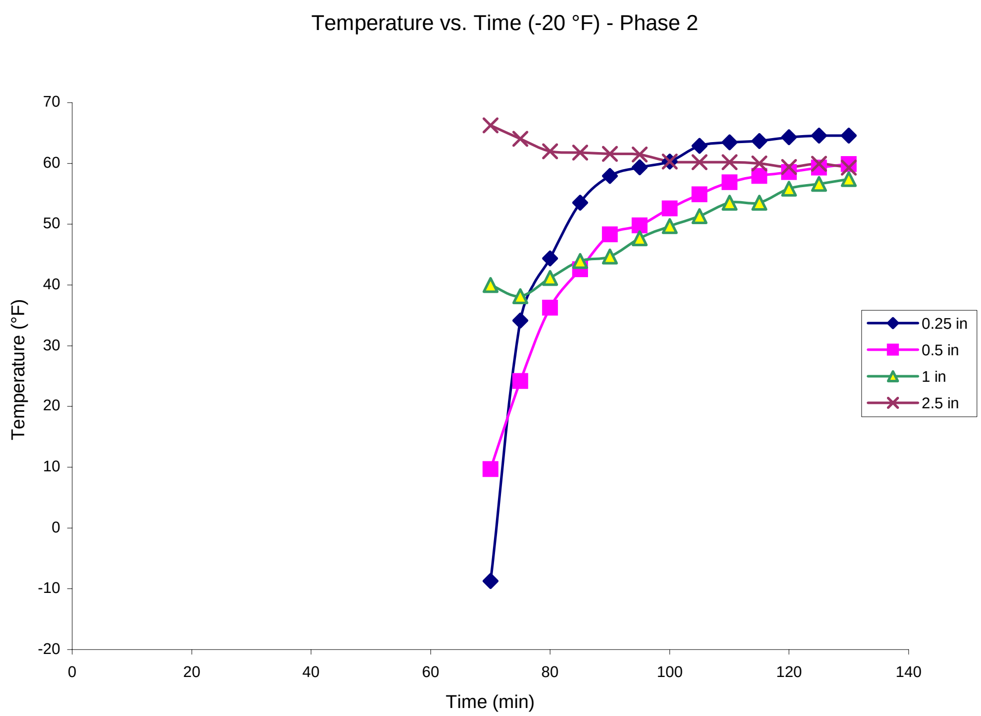


Figure 0-18 Temperature vs. Time (70° F) at different distances from heat source

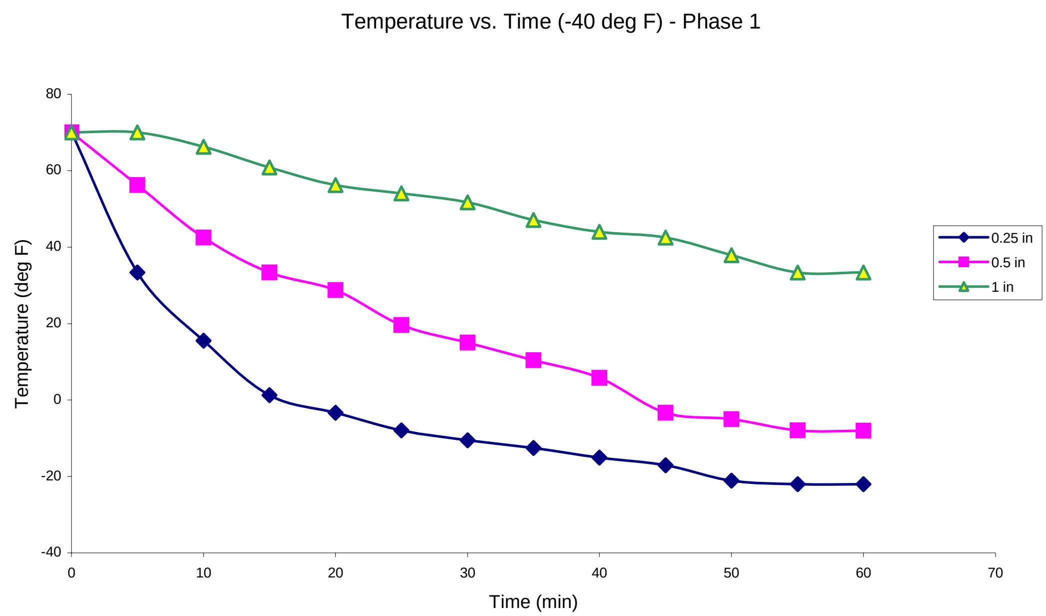


Figure 0-19 Temperature vs. Time (-40° F) at different distance from heat source

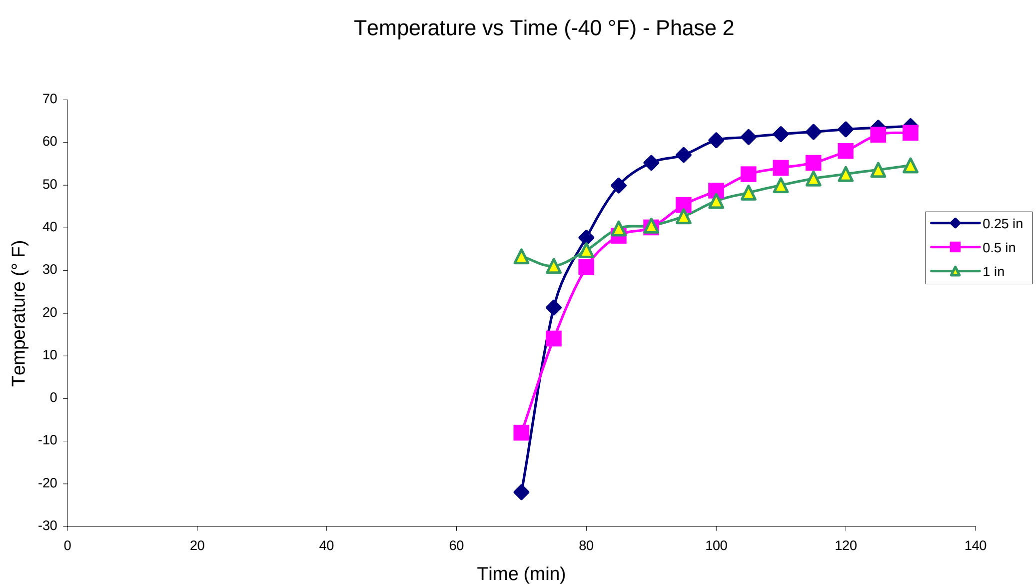


Figure 0-20 Temperature vs. Time (70° F) at different distances from heat source

Summary

Tables 8-1 to 8-3 represent time taken to attain different fractions of final temperature attained by the offset block for 60 minutes. Table 8-1 shows time taken to attain 60%, 75%, 85% and 90% of final temperature at 0.25” distance from the heat source. Phase 1 refers to exposing one surface of the sample to 0^o F/-20^o F/-40^o F for a duration of 60 minutes followed by phase 2, where the same surface was exposed to 70^o F for 60 minutes. Similarly, Tables 8-2 and 8-3 show the time taken to attain various fractions of final temperature at 0.5” and 1” distance from the heat source.

Table 0-2 Time taken to attain fraction of final temperature at 0.25” distance from heat source

Distance = 0.25”				
Applied temp. = 0^o F in phase 1 and 70^o F in phase 2				
	Phase 1 (^{o} F)	**Time (min)**	**Phase 2 (^{o} F)**	**Time (min)**
Final temperature attained	11.6	60	66.56	60
60% final	34.96	7	39.936	2
75% final	26.2	12.5	49.92	5
85% final	20.36	20	56.576	11
90% final	17.44	30	59.904	18
Applied temp. = -20^o F in phase 1 and 70^o F in phase 2				
	Phase 1 (^{o} F)	**Time (min)**	**Phase 2 (^{o} F)**	**Time (min)**
Final temperature attained	-8.75	60	64.59	60
60% final	22.75	7	38.754	8
75% final	10.9375	22	48.4425	12
85% final	3.0625	27	54.9015	16.5
90% final	-0.875	33	58.131	22
Applied temp. = -40^o F in phase 1 and 70^o F in phase 2				
	Phase 1 (^{o} F)	**Time (min)**	**Phase 2 (^{o} F)**	**Time (min)**
Final temperature attained	-22	60	63.84	60
60% final	14.8	8	38.304	11
75% final	1	14	47.88	14
85% final	-8.2	26	54.264	18.5
90% final	-12.8	36	57.456	26

Table 0-3 Time taken to attain different fractions of final temperature at 0.5" distance from heat source

Distance = 0.5"				
Applied temp. = 0° F in phase 1 and 70° F in phase 2				
	Phase 1 (° F)	**Time (min)**	**Phase 2 (° F)**	**Time (min)**
Final temperature attained	20.4	60	63.13	120
60% final	40.24	25	37.878	2.5
75% final	32.8	33	47.3475	8
85% final	27.84	38	53.6605	17
90% final	25.36	42	56.817	25
Applied temp. = -20° F in phase 1 and 70° F in phase 2				
	Phase 1 (° F)	**Time (min)**	**Phase 2 (° F)**	**Time (min)**
Final temperature Attained	9.7	60	59.91	120
60% final	33.82	22	35.946	9
75% final	24.775	28	44.9325	18
85% final	18.745	36.5	50.9235	26
90% final	15.73	38	53.919	23
Applied temp. = -40° F in phase 1 and 70° F in phase 2				
	Phase 1 (° F)	**Time (min)**	**Phase 2 (° F)**	**Time (min)**
Final temperature Attained	-8	60	62.29	120
60% final	23.2	22	37.374	16.5
75% final	11.5	33.5	46.7175	27
85% final	3.7	42	52.9465	36
90% final	-0.2	43	56.061	46

Table 0-4 Time taken to attain different fractions of final temperature at 1" distance from heat source

Distance = 1"				
Applied temp. = 0^o F in phase 1 and 70^o F in phase 2				
	Phase 1 (^{o} F)	**Time (min)**	**Phase 2 (^{o} F)**	**Time (min)**
Final temperature attained	43	60	60.019	120
60% final	53.8	33	36.0114	…
75% final	49.75	40	45.01425	3
85% final	47.05	44	51.01615	12
90% final	45.7	52	54.0171	25
Applied temp. = -20^o F in phase 1 and 70^o F in phase 2				
	Phase 1 (^{o} F)	**Time (min)**	**Phase 2 (^{o} F)**	**Time (min)**
Final temperature attained	40	60	57.39	120
60% final	52	30	34.434	3
75% final	47.5	40	43.0425	14
85% final	44.5	46	48.7815	28
90% final	43	49	51.651	35
Applied temp. = -40^o F in phase 1 and 70^o F in phase 2				
	Phase 1 (^{o} F)	**Time (min)**	**Phase 2 (^{o} F)**	**Time (min)**
Final temperature attained	33.33	60	54.59	120
60% final	47.998	34	32.754	4
75% final	42.4975	43	40.9425	20
85% final	38.8305	48	46.4015	30
90% final	36.997	52	49.131	37

Conclusions

- This analysis gives an idea about the time taken for material to conduct heat and attain different fractions (85%, 90%) of the final temperature.
- Time taken to attain 85% of final temperature at 0.25" distance from heat source was about 20 minutes for 0^o F, 27 minutes for -20^o F, 26 minutes for -40^o F and 30 minutes for 250^o F respectively.
- Time taken to attain certain temperature levels at specified distances away from heat source (250^o F) was successfully observed from infrared thermography and compared with FE results.

- Time taken to attain 165^o F (90% of maximum temperature attained) was 17 minutes at 0.25” distance away from heat source.
- Time taken to attain same temperature at same distance from heat source from FE results was 11 minutes.
- Time taken to attain 149^o F (90% of maximum temperature attained) at 0.5” distance away from heat source was 25 minutes from infrared thermography results.
- Time taken to attain same temperature at same distance from heat source was 18 minutes as known from FE results.
- Similarly, Time taken to attain 126^o F (90% of maximum temperature attained) at 1” distance away from heat source was 38 minutes from infrared thermography results.
- Time taken to attain same temperature at same distance from heat source was 26 minutes as known from FE results.

- Thermography results indicate increase in time to attain particular temperature value as compared to FE results. It should be noted that the specimen used in thermography possessed realistic gaps, voids and temperature leaks near the surface.
- By supplying heat in more than one direction, temperature gains at different interior points can be attained in lesser time.

Conclusions

Introduction

In this research, offset blocks for highway and bridge guardrail systems were developed using recycled polymer reinforced with glass fabric as shell and discarded tire strips/wood as core materials. Optimum compression molding process parameters for manufacturing guardrail-offset blocks using recycled polymers, glass fabric and rubber tire strips were determined as a part of this research. In order to evaluate mechanical properties of recycled polymers (ABS) used to manufacture these blocks, coupon specimens were manufactured with and without glass fabric and tested in compression, tension, bending, and impact. A limited comparison was made with vinyl ester (thermoset) specimens with and without glass fabric and specimens cut from a field-installed wooden offset block. A sliced section of guardrail-offset block manufactured was experimentally tested for its heat conduction properties using infrared thermography. A finite element model was created to represent the sample used in the experiment and analyzed under the effect of thermal loading. Additional composite products like angle plates, dowel bars were manufactured using recycled polymers (ABS) and their properties were evaluated. Dowel bars were also manufactured using another type of thermoplastic resin coated fibers (1" in length), commercially known as "Twintex."

Summary of offset block manufacturing

- Several refinements were made to manufacture prototype-offset block in the laboratory for highway and bridge guardrail system.
    - Using additional heaters on all the side plates of the mold to improve heat transfer from mold to offset block during manufacturing. Successful results in the form of products with better uniformity in blending and homogeneity were observed.
    - Using commercially available thermoplastic pipe (cut to a required height) as a premolded insert during the last stage of manufacturing to reduce insufficient heat transfer problems along block thickness.
    - In addition to discarded rubber tire strips, compressed wooden shavings were also successfully used as a core material.
- Optimum process parameters for recycled resins that were used for offset block manufacture were determined after several compression molding trials.
    - Optimum process parameters for manufacturing core block modules (12.5" × 4.5" × 2") were: 20 minutes of preheating followed by 15 tons of load application at 450° F for about 15 minutes.
    - Optimum process parameters for manufacturing prototype offset block were: preheating for about 30 minutes at 450° F followed by application of 30 tons load for about 30 minutes at the same temperature. (Thirty minutes of heating is also justified by infrared thermography and finite element modeling results)

- Final procedure for producing a good prototype offset block in the laboratory includes:
  - Molding two core block modules (12.5” × 4.5” × 2”) with discarded rubber tire strips/wood and recycled polymer shell.
  - Reinforcing those core block modules with glass fabric, and drilling holes at the center to create a hole in final product to accommodate field installation with the aid of bolting.
  - Compression molding the core modules placed one on top of the other with a pipe insert in the middle and additional resin all around placement under required heat and pressure application.
    - *Note*: Lower pressure or time resulted in insufficient compacting of the resins with the tire strips and product with unblended constituents was observed. Increase in processing time and temperature resulted in appearance of burn marks on the products, along with blisters and holes.
- Prototype offset blocks were successfully installed near Star City Bridge, Morgantown, WV. They were found to be in excellent shape after 8 months of installation based on visual inspection (Figure 9-1).

Figure 0-1 Guardrail offset blocks near Star city bridge, WV after 8 months of field installation

Summary of coupon specimens

Coupon specimens (with and without glass fabric) conforming to ASTM standards were made of recycled ABS (thermoplastic) and vinyl ester (thermoset), and tested in compression, tension, bending and impact. Fiber volume fraction of 3.68% was maintained in tension, bending and impact test specimens, while fiber volume fraction of compression test specimens was 1.84%.

Compressive strength

- Compressive strength increased by 28.16% (6616 psi to 8479 psi) and compressive stiffness increased by 28.98% (0.16×10^6 psi to 0.21×10^6 psi) on an average in ABS specimens due to glass fabric reinforcement.
- Compressive strength increased by 23.75% (10803 psi to 14423 psi) and compressive stiffness increased by 33.5% (0.23×10^6 psi to 0.29×10^6 psi) on an average in vinyl ester specimens due to glass fabric reinforcement.
- Average compressive strength of specimens cut from field installed wooden guardrail offset block was 5317.74 psi and average stiffness was 0.15×10^6 psi.
- Average compressive strength of ABS with glass fabric (8479.805 psi) was about 1.6 times higher than that of wood (5317.4 psi).
- Average compressive stiffness value of ABS with glass fabric specimens (0.21×10^6 psi) was about 1.4 times higher than that of wooden specimens (0.15×10^6 psi).
  - *Note*: It should be noted that wood with fiber being parallel to the loading axis and ABS with proper glass fiber/fabric configuration could exceed the strength and stiffness values than those obtained in this limited investigation.

Tensile strength

- Tensile strength increased by 5.21% (4413 psi to 4643 psi) and tensile stiffness increased by 18.49% (0.31×10^6 psi to 0.37×10^6 psi) on an average in ABS specimens due to glass fabric reinforcement. However, problems were noted in resin compatibility with fabric and some void formations. Hence, additional testing is necessary to draw further conclusions on test specimens.
- Tensile strength increased by 14.7% (5264 psi to 6038 psi) and tensile stiffness increased by 15.8% (0.37×10^6 psi to 0.43×10^6 psi) on an average in thermoset vinyl ester samples due to glass fabric reinforcement.
- Average stiffness value of wooden tension specimen cut from a field installed guardrail offset block was 0.579×10^6 psi.

Bending strength

- Bending strength increased by 45.12% (from 11865 psi to 17219 psi) and bending stiffness increased by 26.87% (from 0.38×10^6 psi to 0.48×10^6 psi) on an average in ABS specimens due to glass fabric reinforcement.
- Bending strength increased by 42.59% (16522 psi to 23561 psi) and bending stiffness increased by 20.29% (0.70×10^6 psi to 0.84×10^6 psi) on an average in vinyl ester specimens due to glass fabric reinforcement.
- Average bending stiffness value of specimen cut from a field installed wooden guardrail offset block was 0.665×10^6 psi.

Impact strength

- From previous study (Basto, 2002) decrease in impact strength (2.17 lbf/in to 0.96 lbf/in) was observed in recycled ABS specimens due to addition of chopped glass fibers.
- In this study, recycled ABS resin used with continuous fabric having bi-directional fibers resulted in an increase in impact strength (4.63lbf/in from 2.41lbf/in) due to better energy dissipation.
- Impact strength of recycled ABS specimens with continuous glass fabric (4.63lbf/in) was found to be 1.45 times more than specimens cut from field installed wood offset blocks (3.192lbf/in).
- In this study, vinyl ester samples used with continuous glass fabric having bi-directional fibers resulted in an increase in impact strength (0.66lbf/in from 0.34lbf/in) due to better energy dissipation.

Conclusions

- Use of continuous (particularly bi-directional) fabric instead of chopped fibers resulted in better impact resistance. ABS specimens with continuous fabric having bi-directional fibers also showed higher impact strength compared to specimens cut from a field installed wooden offset block (4.63lbf/in from 3.192lbf/in).
- Glass fabric used for molding the specimens was compatible with thermoplastic resins as verbally stated by the manufacturer. However, it does not provide increase in strength and stiffness during tension tests and resulted in premature failures along fiber/resin interface. Further tests have to be done with a fabric that is truly compatible with thermoplastics.

Recommendations

- Large scale manufacturing of offset blocks could be done easily and in a very short time with preheated, extruded and melted resin (charge).
- With the use of preheated resin (extruded mass of resin) as a charge, heat transfer problems during manufacturing could be eliminated (associated with direct pellet heating).
- Removing curvature of the tire strips will help reduce voids in the final offset blocks. The steel mesh in the rubber tires helps maintain undesirable tire curvature, which needs to be reduced to possible extent using techniques such as “Shear crimping”.
- A two-step procedure was followed using premolded side plates and core blocks during manufacturing of offset block. This could be reduced to one step manufacturing procedure by remodeling the mold, modifying resin-filling procedure, and introducing preheated and melted resins (charge).

Thermo-mechanical properties of the offset block

Infrared thermography

Thermal propagation from heated mold surface to its constituents during manufacturing process of offset blocks was studied using infrared thermography. Presence of core material like rubber, along with polymer pellets around it, reduces rate of heat transmission owing to their low thermal conductivities.

An experiment was conducted with a sliced section of offset block exposed to unidirectional heat transfer. One surface of the section was exposed to 250^{o} F (T_1) temperature in phase 1 (heating) and 70^{o}F (T_2) temperature in phase 2 (cooling). Progression of temperature with respect to time at various depths was observed using infrared thermography method and also modeled using finite element analysis.

- Surface temperature measurement of the guardrail-offset block was done using infrared thermography during manufacturing process at every 5-minute interval.
- Results from the infrared thermography conducted on sliced section of offset block were compared with those from finite element analysis.
- Time taken to attain certain temperature levels at specified distances away from heat source was successfully observed from infrared thermography.
  - Time taken to attain 165^{o} F (90% of maximum temperature attained) was 17 minutes at 0.25in distance away from heat source.
  - Time taken to attain same temperature at same distance from heat source from FE results was 11 minutes.
  - Time taken to attain 149^{o} F (90% of maximum temperature attained) at 0.5in distance away from heat source was 25 minutes from infrared thermography results.
  - Time taken to attain same temperature at same distance from heat source was 18 minutes as known from FE results.
  - Similarly, Time taken to attain 126^{o} F (90% of maximum temperature attained) at 1in distance away from heat source was 38 minutes from infrared thermography results.
  - Time taken to attain same temperature at same distance from heat source was 26 minutes as known from FE results.

Limitations

- Only surface imperfections can be studied using this technique.
- Measurement of the surface temperature profile by infrared camera is affected by environmental parameters such as solar radiation, air temperature, wind, rain, surface stains and patches and shadows.
- Infrared camera used to obtain pictures of the mold during manufacturing process has decreasing accuracy with increasing depths.

Finite element analysis

- Finite element model of the offset block was created similar to the experiment described in section 9.4.1, and temperature progression was studied at various distances from heat source with respect to time.
- Time taken to attain 85% of final temperature at 0.25” distance from heat source was about 20 minutes for 0^o F, 28 minutes for -20^o F and 26 minutes for -40^o F respectively.
- Similarly, time taken to attain 90% of final temperature at 0.25” distance from heat source was about 30 minutes for 0^o F, 33 minutes for -20^o F and 36 minutes for -40^o F respectively.
- Time taken to attain 85% of final temperature at 0.25” distance from heat source was about 30 minutes for 250^o F.
- Similarly, time taken to attain 90% of final temperature at 0.25” distance from heat source was about 34 minutes for 250^o F.
- Finite element analysis supports the optimum heating duration used in this study.
    - Core block with 2” thickness having ≈ 1.5” thick rubber block needed 20 minutes of preheating followed by 15 minutes of molding under 15 tons load at 450^o F. Melting temperature of ABS is ≈ 400^o F.
    - Final stage manufacturing of a block with 6” thickness having 3” thick rubber needed 30 minutes of preheating followed by 30 minutes of molding under 30 tons load at 450^o F.
- Considering time as an important criterion in large-scale manufacturing, these results provide useful data regarding heat progression or cooling rate with respect to time through the thickness. This can also be used to verify temperature progression in a finished product cooled at room temperature in an industry.

Recommendations

- Temperature values from the infrared images were obtained by spot measurement tool provided by the camera software. Collecting values through this method is approximate with a possible variation of $\pm 2^o$ C or ±2% of measured value in C. Hence, for accurate thermal evaluation refined thermal measurements have to be used.
- The finite element model does not take into account melt-flow and viscosity properties of the polymer, thus is not exact representation of the actual molding process. Also, properties of the melted polymer being heated and cooled is temperature dependent and thus a special software package must be used to arrive at a better solution.
- Defects in the specimen like voids, air gaps (heat losses also) etc were not considered in the finite element model and thus results deviate from the actual ones (infrared thermography test results).
- By using better software (e.g., CADPRESS, MOLDFLOW etc), heat propagation within mold contents, resin flow characteristics etc can be studied. That would be

a closer representation of practical scenario, and be helpful in suggesting changes for improving end-product quality.

Summary of additional composite products

Some additional recycled composite products like angle plates and dowel bars were manufactured using recycled ABS (thermoplastic) resins through compression molding process.

Dowel bars

- Dowel bar manufacturing process required three cycles of molding for each successful product in terms of blending and uniform melting of resins.
- Optimum process parameters for each cycle to manufacture dowel bars were: 10 minutes of preheating at 450^{o} F, followed by 35 minutes of load application. Heaters were used only on two sides of the mold and load application was just sufficient to close the mold.
- In addition, a dowel bar was also manufactured using commercial thermoplastic-coated 1" long fibers called "Twintex." Manufacturing trials to determine its process parameters indicated higher process temperature requirement than that is available with current set of heaters.

Recommendations

- Heaters if used on all sides, would increase heat transfer within the mold contents, thereby reducing number of cycles and duration of each cycle.
- Use of preheated resin would eliminate heat transfer problems and simplify mold setup by reducing number of heaters.
- Resin with chopped fiber and/or continuous fibers could be used to obtain products with higher strength/stiffness values suitable for field installation.

Angles

- Optimum process parameters for manufacturing angle plates with recycled ABS thermoplastic resins reinforced with glass fabric were found to be: preheating the mold with its contents (glass fabric and recycled ABS pellets) at 450^{o} F for 25 minutes and load (20 tons) application for about 30 minutes at same temperature.
- Manufacturing two right-angled legs of an angle plate through pressure application in compression molding process was successfully achieved by designing a V-mold. The V-mold was designed such that pressure was exerted on both legs of the angle plate, producing a good product with regards to uniformity in blending.

  Some of the problems encountered during the process were:
- Placing lead electrical wires coming out of the top portion of the mold away from hot mold/platen of the press surfaces.
- Placement and alignment of glass fabric.

Recommendations

- Use of resin with chopped fibers would eliminate problems in placing glass fabric in the mold.
- Use of preheated, melted and extruded resin (as charge) would eliminate heat transfer problems and reduce wastage of the material in the form of flash (excess resin oozing out of the mold).
- By using fibers/fabrics that are compatible with thermoplastic resins, angle plates with high stiffness and strength values can be manufactured and used for field installation.

Recommendations for future research work

- Use of preheated resin in manufacturing composite products with recycled resins will improve manufacturing efficiency. Offset block manufacturing process could be simplified with some modifications and can be used for large-scale manufacturing such as reinforced railroad ties.
- Offset blocks manufactured through compression molding process have to be evaluated through crash tests.
- Manufacturing procedures for additional composite products like angle plates and dowel bars should be further refined with respect to optimizing process parameters and dimensions including time.
- Resins with chopped fibers should be used to manufacture recycled composite products and tested for field installation purposes.
- Long-term properties (creep and aging) of recycled composite products have to be researched.
- Finite element analysis could be done with better software that predicts resin flow behavior during product manufacturing process. Continuous monitoring of manufacturing process can be achieved by this method and changes could be incorporated into processing to improve end-product quality.

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APPENDIX-A
EXPERIMENTAL ERROR

Experimental error in calculating stress/strength

If load = P, thickness = T and width = W

Error in load measurement = 1 % (Ref: Instron Series 8500 Two-Column Load Frame Operating Manual, 1999)

Error in thickness and width measurement = 0.004 units (Ref: Swiss Precision Instruments Manual, 1999)

Error in load = P ± 0.01 P

Error in area = (T±0.004) * (W±0.004) = TW ± 0.004(T+W)

Error in stress = Error in load /error in area

Minimum stress value = $\dfrac{(P-0.01P)}{(TW+0.004(T+W))}$ Eq-(A-1)

Maximum stress value = $\dfrac{(P+0.01P)}{(TW-0.004(T+W))}$ Eq-(A-2)

Error = $\pm\ \dfrac{(\text{Maximum stress value - Minimum stress value})}{2}$ Eq-(A-3)

An illustration of error in stress calculation for an average stress in compression test is as shown

Stress= load/ area = 6616.05psi

Specimen dimensions : T=0.5 inch and W=0.5 inch

From Eq-(1)

Minimum stress value = $\dfrac{(P-0.01P)}{(TW+0.004(T+W))}$

$$= \frac{P}{TW}\frac{(1-0.01)}{\left(1+0.004(\frac{1}{W}+\frac{1}{T})\right)}$$

$$= 6616.05\frac{(1-0.01)}{\left(1+0.004(\frac{1}{0.5}+\frac{1}{0.5})\right)}$$

$$= 6446.74 \text{ psi}$$

From Eq-(2)

Maximum stress value = $\dfrac{(P+0.01P)}{(TW-0.004(T+W))}$

$$= \frac{P}{TW}\frac{(1+0.01)}{\left(1-0.004(\frac{1}{W}+\frac{1}{T})\right)}$$

$$= 6616.05\frac{(1+0.01)}{\left(1-0.004(\frac{1}{0.5}+\frac{1}{0.5})\right)}$$

$$= \quad 6790.87 \text{ psi}$$

From Eq-(3)

$$\text{Error} \quad = \pm \frac{(\text{Maximum stress value - Minimum stress value})}{2}$$

$$= \pm \frac{(6790.87 - 6446.74)}{2}$$

$$= \pm 172.06 \text{ psi}$$

$$\text{Percentage error in stress} = \frac{172.06}{6616.05} \times 100 \quad = 2.6$$

The above explained error calculation procedure was repeated for compression, tension and bending tests. Errors in stress measurement are given in table

Table A-1 Error in stress calculation

Type of test/specimen	**Minimum stress (psi)**	**Maximum stress (psi)**	**Error (psi)**	**Percentage error**
Compression test T=0.5inch W= 0.5 inch				
ABS without fabric	6446.74	6790.87	±172.06	2.6
ABS with fabric	8262.89	8703.96	±220.53	2.6
Vinyl ester without fabric	10527.10	11089.03	±280.96	2.6
Vinyl ester with fabric	14054.42	148.4.63	±375.1	2.6
Wood	5181.65	5458.24	±138.29	2.6
Tension test T=0.25 inch W = 0.5 inch				
ABS without fabric	4267.06	4567.36	±150.14	3.4
ABS with fabric	4388.99	4697.87	±154.43	3.4
Vinyl ester without fabric	5089.46	5447.63	±179.08	3.4
Vinyl ester with fabric	5837.99	6248.84	±205.42	3.4
Wood	6050.45	6476.25	±212.9	3.4
Bending test T=0.25 inch W=0.5 inch				
ABS without fabric	11471.67	12278.99	±403.66	3.4
ABS with fabric	16647.51	17819.09	±585.79	3.4
Vinyl ester without fabric	15974.31	17098.52	±562.1	3.4
Vinyl ester with fabric	22778.98	24382.07	±801.54	3.4
Wood	14300.8	15307.2	±503.21	3.4

Experimental error in calculating stiffness/elastic modulus

Elastic modulus = slope = stress/strain

Error in strain measurement = ±1 (10^{-6} in/in)

$$\text{Maximum error in slope} = \frac{\text{maximum stress value}}{\text{minimum strain value}} \qquad \text{Eq-(A-4)}$$

Minimum error in slope = $\frac{\text{minimum stress value}}{\text{maximum strain value}}$ Eq-(A-5)

Error = ± $\frac{(\text{Maximum slope} - \text{Minimum slope})}{2}$ Eq-(A-6)

An illustration of error in stress calculation for an average stress in compression test is as shown

Stress = 6616.05 psi

Strain = 39634 x 10^{-6} in/in

Stiffness = slope =stress/strain = 0.1669 x 10^{6}psi

From Eq-(4)

$$\text{Maximum error slope} = \frac{\text{maximum stress value}}{\text{minimum strain value}} = \frac{6790.87}{39633} = 0.1713 \times 10^{6}\text{psi}$$

From Eq-(5)

$$\text{Minimum error slope} = \frac{\text{minimum stress value}}{\text{maximum strain value}} = \frac{6446.74}{39635} = 0.1626 \times 10^{6}\text{psi}$$

From Eq-(6)

$$\text{Error} = \pm \frac{(\text{Maximum slope} - \text{Minimum slope})}{2} = \pm \frac{(0.1713 - 0.1626)}{2} \times 10^{6}\text{psi} = \pm 0.0043 \times 10^{6}\text{psi}$$

$$\text{Percentage error} = \frac{0.0043}{0.1169} \times 100 = 2.6$$

The above explained error calculation procedure was repeated for compression, tension and bending tests. Errors in stress measurement are given in table

Table A-2 Error in stiffness calculation

Type of test/specimen	**Maximum stiffness (x 10^{6}psi)**	**Minimum stiffness (x 10^{6}psi)**	**Error (10^{6}psi)**	**Percentage error**
Compression test	T=0.5inch W= 0.5 inch			
ABS without fabric	0.1713	0.1626	±0.0043	2.6
ABS with fabric	0.221	0.2098	±0.0056	2.6
Vinyl ester without fabric	0.2423	0.23	±0.0061	2.6
Vinyl ester with fabric	0.2999	0.2847	±0.0076	2.6
Wood	0.1533	0.1455	±0.0038	2.59

Tension test	T=0.25 inch W = 0.5 inch			
ABS without fabric	0.3280	0.3064	±0.0108	3.9
ABS with fabric	0.3810	0.3559	±0.0125	3.5
Vinyl ester without fabric	0.3885	0.3629	±0.0128	3.4
Vinyl ester with fabric	0.4500	0.4203	±0.0148	3.4
Wood	0.6333	0.5916	±0.0208	3.4
Bending test	T=0.25 inch W=0.5 inch			
ABS without fabric	0.3954	0.3694	±0.0130	3.4
ABS with fabric	0.5017	0.4687	±0.0165	3.4
Vinyl ester without fabric	0.7247	0.6770	±0.0238	3.4
Vinyl ester with fabric	0.8718	0.8144	±0.0286	3.4
Wood	0.5553	0.5187	±0.0182	3.4

Appendix P: Task 3.4

Front Page Article, May 20, 2002

PLASTICS NEWS.com®

Electronic leftovers a mixed bag for recyclers

By Steve Toloken
PLASTICS NEWS STAFF

With steady production on more than one shift, annual MBA Polymers Inc. capacity with current equipment could exceed 25 million pounds

Leftover electronics present both a challenge and an opportunity for plastics recyclers.
Photo courtesy of MBA Polymers, Inc.

RIPLEY, W.VA. (May 20, 9:30 a.m. EDT) -- Buddy Graham wants to make his little piece of West Virginia into a Silicon Valley for electronics recycling.

Graham, president of the Polymer Alliance Zone in Ripley, is buying 148 acres and a vacant, 312,000-square-foot building so PAZ can create the first industrial park for recycling electronics. He envisions it as a place where recyclers can locate alongside companies using recycled resin to manufacture products, and they can all benefit from nearby research and development operations.

> **'There is absolutely a need for this. When you look at what is going on around the world, we haven't seen anyone who has combined the plastics and glass and metals in recycling, as far as electronics.'**
>
> **Buddy Graham**
> **Polymer Alliance Zone**

PAZ, a plastics-oriented economic development agency, also is trying to develop an online trading system for recycled resins, and it has helped to fund a Tufts University project that is developing standards to make it easier to recycle plastics from electronics.

Graham admits it is an unorthodox role for the economic development agency, which formed in 1996 to promote the industry in three counties that are heavy with plastics manufacturing.

Rather than just trying to bring in plastic processors, PAZ has latched on to the idea of being a catalyst in an area where it sees real need. It is doing that with $3.5 million in federal funds - some of it secured through a special congressional appropriation - and an anticipated $5 million in state funds and $15 million in private funding.

Right now, there is not much infrastructure in the United States to collect the mountain of computers and other electronics thrown out. But Graham thinks that could change.

A coalition of major electronics manufacturers, governments and environmental groups in the United States, called the National Electronics Product Stewardship Initiative, in March tentatively agreed to support fees to facilitate recycling and support any related federal legislation. The European Union and Japan are pursuing more aggressive plans, and shareholders at several electronics manufacturers are pressing the industry to take action.

> **'In North America we need more sourcing of material. It is a chicken-and-egg thing. A big computer manufacturer doesn't want to go into this big product development unless they know there are sources of material.'**
>
> **Mike Biddle**
> **MBA Polymers, Inc.**

So far, Graham has not brought any electronics recyclers to his corner of West Virginia, but he said he hopes to announce the first company within 60 days.

"There is absolutely a need for this," Graham said. "When you look at what is going on around the world, we haven't seen anyone who has combined the plastics and glass and metals in recycling, as far as electronics."

The group sees an opportunity because "as we looked at the picture of end-of-life electronics equipment, everybody points to the plastics as the issue," said Doug Ritchie, president of SDR Plastics Inc. in Ravenswood, W.Va., and chairman of PAZ´s industry steering committee.

Like PAZ's plans, though, much of recycling plastics from electronics remains a work in progress.

Some companies are investing in it. Flextronics International Ltd., for example, recently invested in MBA Polymers Inc., a state-of-the-art recycler of plastics from durable goods. Flextronics, one of the world's largest contract manufacturers and injection molders, wants to help MBA expand, he said.

"We're not waiting for legislation in the U.S.," said Jim Sacherman, chief marketing officer at Flextronics in San Jose, Calif. "We are seeing more interest in our customers in recycled content."

But others are taking a more cautious approach. Electronics recycler Butler-MacDonald Inc. in Indianapolis, for example, is beefing up its plastics-recycling capabilities but remains wary of the computer marketplace.

"We are not moving into processing computer electronics," said Ray Pomerleau, Butler-MacDonald plastics director.

Companies have approached the firm to do more with computers, but "we like to deal with feed streams that are predictable."

"Whenever you deal with computers, you have materials coming in from every manufacturer under the sun," Pomerleau said.

He said problems like the variety of resins used, many of which have similar densities but are incompatible with each other for recycling, and the presence of interior shielding, make it difficult to recycle economically. Recyclers also talk about problems getting consistent volumes of electronics to process, and undeveloped markets for the recycled resin.

He praised the NEPSI process, but said the industry may need to help fund the recycling of plastics.

"You can't count on small manufacturers to foot all of the upfront costs," he said.

For one plastics recycler that focuses on electronics, the problem is not being able to collect enough material.

Mike Biddle, president and chief executive officer of MBA, in Richmond, Calif., said his company can recycle plastics economically on a large scale. But North America does not have the collection and processing infrastructure to match Japan and Europe.

"In North America we need more sourcing of material," Biddle said. "It is a chicken-and-egg thing. A big computer manufacturer doesn't want to go into this big product development unless they know there are sources of material."

While there are many unknowns, quiet work also is happening behind the scenes.

The Environmental Protection Agency's Chicago office is spearheading a trial to collect more recycled resin for electronics markets, and the Gordon Institute at Tufts University in Medford, Mass., runs a forum giving manufacturers and others a chance to resolve some of the more technical challenges.

The institute, for example, has developed a rating system for identifying and communicating what type of recycled resin a company has. Too often buyers and sellers do not have a common language to describe what each has.

“A lot of people who generate the stuff don’t know what they have," said Patty Dillon, project manager for the Stakeholder Dialogues on Recycling Engineering Thermoplastics from Used Electronics Equipment. "Rather than a very generic term like saying, ‘I have electronic plastics,’ you would be better able to communicate with someone trying to buy and sell. … It improves the economics.”

The Gordon program also is starting to work with Underwriters Laboratories Inc. in Northbrook, Ill., to develop a new test method for recycled resins. The current tests used to validate virgin materials do not work as well with recycled material, even if the recycled material has the same overall performance, Dillon said.

“Certainly if more material were available with the UL certificate, it would be less costly for incorporating recycled content in the product,” Dillon said. “It will definitely broaden the market for recycled material, and not just in electronics products.”

Molders who work in electronics markets said it is tough to tell how the NEPSI push will affect them.

Bruce Ginder, president of Mack Design Inc. in West Henrietta, N.Y., said the electronics manufacturing industry is talking more about recycling, but it is not uppermost in conversations between the electronics industry and molders.

“Once they start to dive into these issues, they start to back away because they realize there are a lot more issues they have to deal with than meets the eye,” Ginder said.

For example, there are sometimes inconsistencies in batches of recycled resin because it is harder to trace the source of materials, he said. European countries are more demanding about flame retardants than the United States, which complicates both design and recycling, he said.

Flextronics´ investment in MBA is pushed more by Europe and Japanese regulations than by anything happening in the United States, Sacherman said. He said MBA´s technology lessens the importance of designing for product take-back, because it makes recycling easier.

In the United States, the NEPSI process will prove beneficial to plastics recycling because it will, over time, increase the amount of materials available and spur market development, according to Dillon. For electronics recycling, the challenges are getting adequate supply and being able to process it cost effectively, she said.

Right now, one problem is that while communities complain that they do not have anywhere to take plastics collected from electronics, manufacturers complain that they cannot source enough recycled material, said EPA program analyst Gordon Hui.

“That is still the big picture out there - trying to develop a high-value use for it … that you can resell on the market, especially when resin prices are down,” said Graham.

Articles printed in The State Journal, Dec. 3, 2004 issue:

Trash to Treasure

Company Seeks New Solutions For Old Electronic Equipment

By PAM KASEY
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Picture all the electronic gadgets you've used up your first calculator, your old laptops and desktops, the many cell phones, TVs and VCRs all piled together in your back yard.

Heave on a photocopier or fax machine, out of fairness.
Now think about the piles in your neighbors' yards and behind the small and large businesses all across the country: That's the American electronics waste problem.

End-of-life electronics are a relatively new waste stream, but an exploding one: More than 400 million personal computers have been sold in the United States since 1981, half of those since 2000.

About 150 million PCs are guessed to be in landfills by now. Already in 1997, more than 3 million tons of electronics were buried nationwide twice the volume of everything going into West Virginia landfills annually. And it grows each year.

The fact is, most of the glass, metals and plastics in those gadgets could be usefully recycled. And about 12 percent of retired PCs do undergo some recycling. Some "recyclers" broker the equipment to countries with low wages for demanufacturing and lax standards for disposal of toxics, such as lead. Others recover the glass or metals and shred the rest and put it in landfills.
But no one knows yet how to deal with the mixed plastics that make up between 20 and 40 percent of a typical computer.
An economically and environmentally sound strategy for this emerging national problem would transport end-of-life electronics to central locations. It would take them in the front door, disassemble them and sort the various substances, then resell those at the back door as raw materials for remanufacture plastics included.

This is what the **Mid-Atlantic Recycling Center for End-of-life Electronics** in Wood County proposes to do.

A project of the **Polymer Alliance Zone**, **West Virginia University** and **DN American**, the MARCEE project brings expertise in polymers and information technology to partnerships with government, manufacturing and the recycling industry. While making progress on all fronts, MARCEE has positioned itself at the center of a coming total national recycling solution that, as it evolves, will mean new industry and jobs for West Virginians

Project Seeks Solution to Plastics Recycling Problem

By PAM KASEY
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MORGANTOWN—Of all the challenges to recycling end-of-life electronics — collecting them to central locations, figuring out who should pay — the most intractable is how to recycle the plastics. The **Mid-Atlantic Recycling Center for End-of-life Electronics** is working on that very problem.

Richard Turton, a professor of chemical engineering at **West Virginia University**, has worked with the MARCEE project for the past three years, primarily in the area of separation technologies: how to economically sort a computer into usable piles of raw materials.

Of the main components—glass, metals and plastics—the glass is relatively easy. So are the metals, Turton explained: Once aluminum and steel are separated magnetically, "aluminum is pretty much aluminum." But when it comes to polymers, he said, a plastic is not a plastic. "When you get a computer case in, although it looks like it might all be made of one plastic, in reality it's made from several," he said. "For example, the buttons on the keyboard would be a different plastic probably from the main part of the keyboard." Typical plastics used are high-impact polystyrene, or HIPS; acrylonitrile butadiene styrene, or ABS; and polycarbonate.

"There are all sorts of grades of plastic that you can buy under the name of HIPS," Turton said. "So even when you get a stream that looks like all the same chemical, there's a whole variety of physical properties." **Rakesh Gupta**, also at WVU, has found that very small amounts of impurities degrade the properties of a recycled polymer. Re-use through separation, his work suggests, would require an economically unfeasible level of purity of better than 99 percent.

What makes more sense is to work with a mix, and that's easier said than done. "Different plastics don't want to mix with each other," Gupta explained. "A very heterogeneous mixture has very poor properties. It might break easily. Also, the different plastics melt at different temperatures so you don't know what temperature to set on your extruders to melt these and shape these into a new article."
But in his work researching blends of recycled and virgin polymers, Gupta has come up with a product that requires no separation and offers consistent and usable properties. His findings are currently in process for a patent through WVU's Technology Transfer office.

He "would like to think that this is the first time anyone has come up with a use for mixed plastics." Lawyers involved in the patent process are researching that now.
"If you look at mixed plastics, they have essentially zero value. You typically have to pay somebody to take the material away," Gupta said.

A patent would be a breakthrough for the MARCEE project in its mission to recycle and market the polymers in end-of-life electronics.

WVU researchers are seeking high-value applications, Gupta said, such as a wood-plastic composite decking material for homes that improves on the stiffness and mold resistance of products currently on the market.

This is good news for **Doug Ritchie**, president of **SDR Plastics** and **Star Plastics** in Jackson County. He has done some post-consumer electronics recycling—as opposed to post-industrial, which is a purer stream. "We definitely need some help on market demands for these materials so we can have a pull-through of the recycled raw materials coming through," Ritchie said.

Wood County to Provide Platform for Recycling Computers

By PAM KASEY
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Working with partners nationwide, the **Mid-Atlantic Recycling Center for End-of-life Electronics** in Wood County is at the forefront of a national solution to the growing problem of retired electronics.

The MARCEE project aims to be the first-ever total recycling solution for end-of-life electronics. A partnership that includes the **Polymer Alliance Zone**, **West Virginia University** and **DN American**, MARCEE is shaped by the constraining economics of electronics recycling. For example, a total recycling solution will depend on the ability to create consistent, marketable recycled outputs of glass, metals and plastics.

There are active markets now for the glass and metals, but the plastics are a problem. No one knows how to recycle the mixed stream of post-consumer plastics, as opposed to purer streams of post-industrial plastics.

That is what makes the PAZ region of Jackson, Wood and Mason counties along the Ohio River an ideal home for electronics recycling. As explained in MARCEE's 2002 business plan, "PAZ has the highest concentration of production of high-technology, specialty and engineering polymers in the world." PAZ now has 73 industrial and public sector members, according to President **R.V. "Buddy" Graham**.

Industrial and academic participants at PAZ and WVU are at work now, engineering mixed plastics inputs with varied properties into recycled polymers of consistent properties. They're also working to identify high-value uses for those recycled polymers.

A second factor shaping MARCEE is the economics of separation.
Unlike other recyclers that might take only the glass or the metals and discard the rest, MARCEE will capitalize on the efficiencies of separating the whole computer into its parts and selling those for remanufacture.

"The real secret to making this work is, how do you configure the different technologies through one process line?" Graham said.

"You want to touch it a minimum of times because labor is what drives the cost up." So MARCEE is not simply the polymer-recovery part of a larger solution to the nation's electronics recycling problem: It's a total recycling solution. Retired computers will come in the front door and be demanufactured. After glass is removed from monitors, the remaining materials then will be processed and separated for sale to metal smelters and to plastics processors. A third factor further shapes the project.

Although MARCEE is designed as a total recycling solution, it's not economical to transport whole computers from all over the country to Wood County, according to project manager **Walter Alcorn**. They are, after all, mostly air. What makes more sense is for MARCEE to accept whole computers from a relatively small radius; say, up to a couple hundred miles. At the same time, though, it's relatively inexpensive to transport the plastics once they're shredded. Organizers envision the MARCEE project as the nationwide polymer recycling center for the entire industry.

So the MARCEE project offers, on the one hand, a regional model for demanufacturing and recovery of glass and metals. And, on the other hand, it offers a nationwide solution to the plastics problem. Graham expects to announce the selection of a demanufacturer in January, with work to begin in April on a small scale at MARCEE's demonstration site in Wood County.

In estimates reviewed by the state **Development Office**, MARCEE projects creating around 100 jobs in demanufacturing and other demonstration aspects early on, with perhaps 1,000 or more in manufacturing during the coming decade as a polymer remanufacturing cluster develops in the PAZ region. The full-blown project will develop only as the national partners in government, manufacturing and the recycling industry resolve fundamental issues. Graham points out that an economical solution requires a coordinated national infrastructure for collection, transportation and disassembly. MARCEE is working with its partners to design that infrastructure.

<u>DN American Charts End-of-Life Electronics Collections</u>

By PAM KASEY
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What is the most efficient way to collect end-of-life electronics for recycling? Curbside? Return to manufacturer? Trade-in at retailer on replacement?

DN American of Fairmont, the information technology partner of the **Mid-Atlantic Recycling Center for End-of-life Electronics**, is helping to find the answer. Electronics manufacturers and recyclers can't seem to agree on the question. Some like a front-end, fee-based system in which consumers pay as part of the original purchase price, according to MARCEE project manager **Walter Alcorn**. Others like a producer-responsibility system in which manufacturers would handle equipment on retirement.

California and Maine already have legislated different systems and, if manufacturers and recyclers can't agree soon on one system to be used nationwide, they're going to face a national patchwork of requirements.
What is needed is good data collected from a series of pilot recycling projects. This is where DN American comes in.
DN American analyzed data gathered from 52 pilot electronics collection events held across the federal **Environmental Protection Agency**'s mid-Atlantic region in 2001 and 2002, according to **Jeff Tucker**, a senior software engineer at DN American.

Among the lessons learned at events ranging from one-time collections in **Wal-Mart** parking lots to ongoing take-backs at full-time centers, Tucker said, was this: You get a lot of stuff. "You don't get just computers and keyboards; you get TVs 30 years old in the wood consoles and IBM computers in the big metal cases from the 1980s," he said. So while electronics recyclers in business today simplify their waste stream by taking only **Dell** computers or **Verizon** cell phones, a truly comprehensive recycling program will have to face that challenge.

With the success of that early program, EPA established Plug-In To eCycling, a larger program going on now, and approached DN American once again to handle the data. The Plug-In program is gathering more detailed data on questions such as the age of equipment coming in, the composition of the waste stream and how consumers react to fees at varying levels.

Before collecting Plug-In data, DN American, with the MARCEE project, consulted with 45 industry stakeholders to create a set of standard data elements, Tucker said.
"One thing we saw (in the earlier eCycling program) was that programs collected data in different ways," he explained. "One collected total pounds while another collected the total number of monitors, so there wasn't a good way to look at data across all programs." Plug-In program participants submit their data on a nine-page, Web-based and printable form. The first data are flowing in now, Tucker said, and he expects to have a preliminary report by early March.

"It's probably going to be the best look at electronics recycling collection programs that we've ever had," he said. "It's going to give us insight into how you can set up an efficient take-back program in the U.S. That's what the stakeholders want to see: how to set this up as efficiently as possible."

With this centralized data repository, Tucker said, the industry is starting to look at MARCEE as the leader in data collection and analysis for sound decision-making in electronics recycling."

McDonough Takes Strategic View of 'Remaking Things'

By PAM KASEY
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In contracting with internationally renowned architect and designer **William McDonough**, founding principal of **William McDonough + Partners** of Virginia, the **Mid-Atlantic Center for Recycling End-of-life Electronics** is bringing innovative strategies to polymer recycling. One of the primary proponents of what some call "The Next Industrial Revolution," McDonough's designs range from the environmental optimization of product chemical compositions to community plans that restore native habitat and hydrology while spurring economic development.

McDonough is co-author of "Cradle-to-Cradle: Remaking the Way We Make Things," a book printed on plastic resins and inorganic fillers instead of paper. It has received the Presidential Award for Sustainability.

He distinguishes his approach of eliminating waste — cradle-to-cradle, rather than cradle-to-grave — from a "zero waste" approach that, in his mind, is insufficient.
"If you decide that you're going to reduce your fuel consumption, typically what happens is that you can reduce to a certain point," McDonough said in an interview. Beyond that, "the cost-benefit analysis is not working: You're spending so much money chasing such a small target that you can actually never get there."

Instead, he likes to use the phrase: "Waste equals food." "That doesn't say minimize waste. It says waste is food," McDonough said. "And if that's the case, then we eliminate the concept of waste."

He described, for example, a factory he worked with in Switzerland in which the water coming out of the pipe is now cleaner than the water going in. "At the beginning, we were saying this was an approach that appeared to have great promise.
Now we've shown that, not only does it have promise, it has immense social value and immense economic value, as well as environmental intelligence." McDonough spoke of another redesign his firm did of **Ford Motor Co**.'s famous Rouge manufacturing complex in Dearborn, Mich. The plant now has a 10-acre roof planted with water-absorbing plants and several manmade wetlands to filter potentially damaging runoff after storms.

"It's not efficiency. I'm not making the pipes smaller or reducing the chemicals in the treatment; I'm reconceiving the building as a nutrient system for making oxygen," he said. "It's just more fun," he added. "It's exciting. It doesn't bemoan the limits of human imagination; it celebrates its abundance."

McDonough's interest in the MARCEE project stems from his view of most recycling as "downcycling": The materials become less and less valuable until they have to be landfilled. "Since 1880, the human species has produced about 680 million tons of aluminum. We still know where 440 million tons of it is. That's recycling," he explained.

“We’re looking at polymers the same way. All the computer cases, all the plastics that are out there, can be intelligently tagged for reuse, come back to the place where they were originally formed, get reused, then return five years later when your computer is no longer advanced.” How can the electronics industry intelligently design products so they’re assets at the ends of their lives? he asked. But, he added, if it doesn’t make business sense, it won’t happen. “We work in the commercial world, and we produce immense profits for our clients,” he said. “We honor commerce as the engine of change.”

State Journal February 18, 2005

WVU Researchers Use Recycled Items in Bridge Material

By CATHY BONNSTETTER

MORGANTOWN — **Hota GangaRao**, **Constructed Facilities Center** director at **West Virginia University**, and other researchers at the center are formulating and making materials that just may replace steel as the material of choice for civil engineering. The process also eventually may help empty out landfills.

The materials, composites made of glass fibers and plastics and other materials, already are being used experimentally in bridges and roads across the state with great success.

“We’ve not had any complaints,” GangaRao, who has been the center’s director since 1988, said. “Let’s just leave it at that.”

The plastic/glass composite materials have been used on the deck systems of 10 bridges across the state, including the first one: Market Street Bridge in Wheeling. The CFC also has made composite reinforcement bars for parts of Corridor H near Elkins, University Avenue in Morgantown and six bridges around the state. The materials have been used for deck and superstructure projects on two bridges including the Laurel Lick Bridge near Weston.

“The reason we like to think it is going so well is that this composite material flexes in a way that is compatible with concrete,” GangaRao said. “Steel corrodes, and as it does it expands, cracking the concrete. This just does not corrode.”

The projects were made with virgin plastic and glass, but the CFC is working to replace the virgin materials with recycled ones. The CFC is moving toward a 50-50 ratio between recycled and virgin materials. The recycled materials are performing well under testing, and GangaRao hopes to move to a 20 to 80 percent ratio of virgin to recycled material.

The CFC gets its recycled plastic from **SDR Plastics** in Ravenswood. “Recycled materials are absolutely cheaper than virgin ones,” said GangaRao, who also is a civil and environmental engineering professor. “Plus, you are raising the plastic’s value and taking it out of the landfill. Our landfills are 35 percent plastic.”

The CFC also is experimenting with using the composites for the upper hulls of ships. "The material is about a quarter the weight of steel but about twice the strength," said **P.V. Vijay**, research assistant professor.

The use of composite materials in civil engineering has been around since the 19th century, according to the CFC Web site. "We just keep adapting," GangaRao said. "Our contribution has been the use of recyclables."

The CFC also has produced a granite-looking material from recycled plastics, glass fibers and a core made from rubber tires. It can be used for outside benches or window frames, among other things.

"There is no weathering — period," GangaRao said. Unless you need it to weather. "You can retain some weathering properties if you need the material to match a house or anything else," Vijay said. "We can make it look like anything." It's taken about four years to develop these materials.

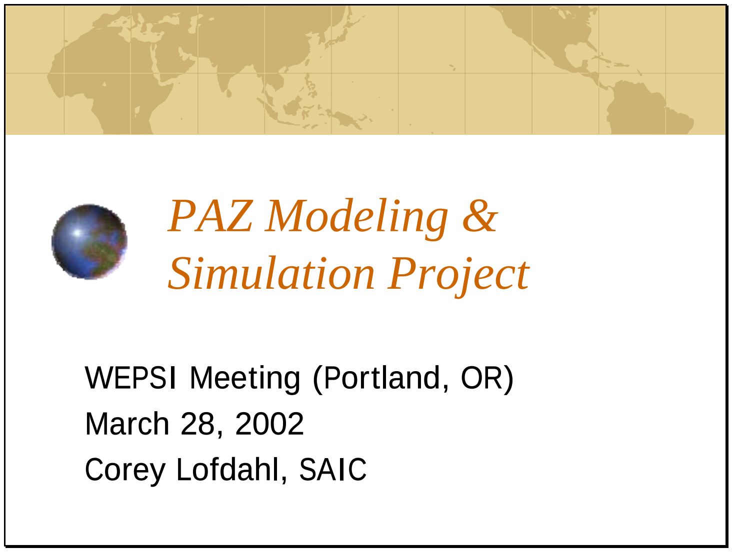
"Most of the work is to understand the properties of the materials," GangaRao said. "There is no application until we are sure of the properties."

The CFC researchers hope to find more uses for the material and even bring down the cost. Ultimately, they want to mass produce it.

"We have been discussing production with a local business," GangaRao said. "We could create 300, 400 jobs in mass production and use millions of tons of recycled plastic."

But research takes money — in this case $2 million a year — as well as expertise and time. "We have about 101 issues to think about," he said. "But this is like anything else — you just have to get it right."

Slide 1



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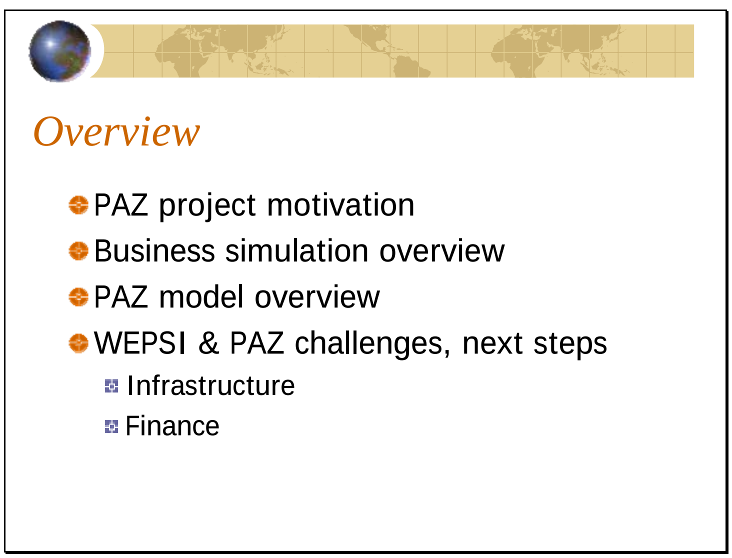


Slide 3

PAZ Model Motivation

- EOLE a growing problem
- Economic development of recycling industry presents an opportunity
- Plan out business logistics and finances to catch problems early
- How much material must be processed and transported? Economically feasible?

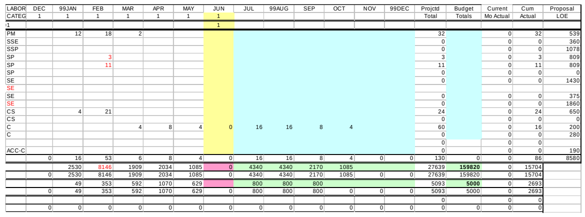
Slide 4

Business simulation overview

- There are lots of relationships and details to track
  - Let the computer do it
- Tests the system before it is built
- Incorporates relevant expertise from many people – “reconcile the diversity”
- Helps achieve consensus & good results

Slide 5

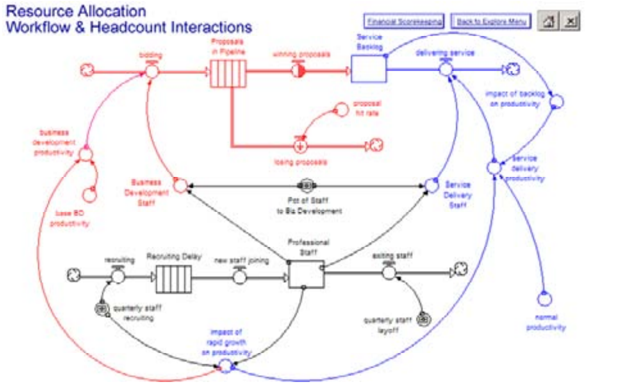
Spreadsheets



- Support financial analyses
  - Balance sheet, Cash flow, Income statement
- Operations & the business itself recede

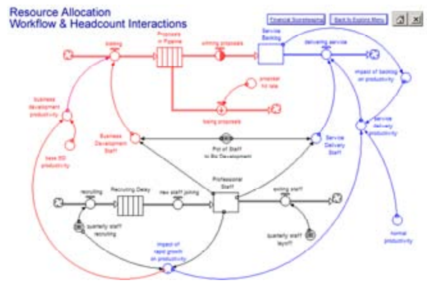
Slide 6

Business simulation -- more visual



Slide 7

Business simulation



- Operations drive the analysis
- The business drives the finances

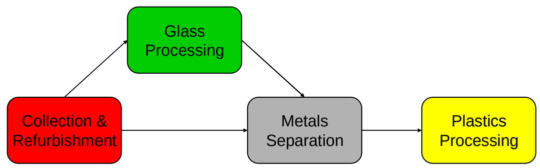
Slide 8

PAZ Model structure & data acquisition

- Currently at 90+ variables & assumptions
  - Operational representation
  - Financial representation
    - Revenues
    - Costs
- Variables are available for criticism & modification
  - Breakeven analysis possible – quantify subsidy
- Coordinating data acquisition efforts with industry leaders

Slide 9

Modeling EOLE operations & flow



- Key concerns
  - Inputs & interfaces -- quality & quantity
  - Internal processes & capacity
  - Outputs – flows, prices, & costs
- Flexible representation of tech. details

Slide 10

Modeling EOLE financials

- Operational concerns are connected to the financial through **capacity**
  - "How much do you have to spend to process so many tons of stuff a week?"
- Capacity leads to **revenues** through sales – easy, output * price
- Capacity leads to **costs** through processing operations -- hard

Slide 11

Modeling EOLE costs ($/week)

- Variable costs
  - Shipping & landfill
  - Transfer prices
- Fixed costs
  - Payments on initial capacity investment
  - Maintenance & utilities (% of investment)
  - Labor
  - Space

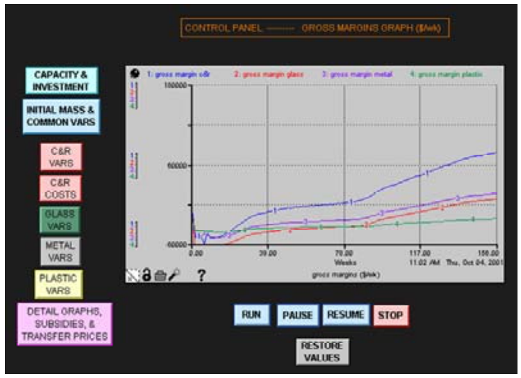
Slide 12

Financial scenario analysis

- Once revenues & costs are understood, then financial viability can be evaluated
  - Collection & refurbishment
  - Glass processing
  - Metals separation
  - Plastics processing
- Scenarios consist of varying price and cost structures & checking the changes

Slide 13

PAZ simulation control panel

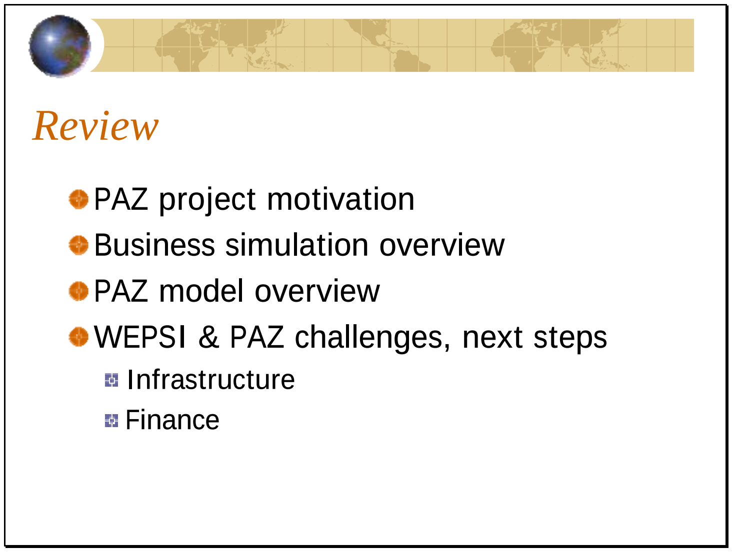


Slide 14

Next steps

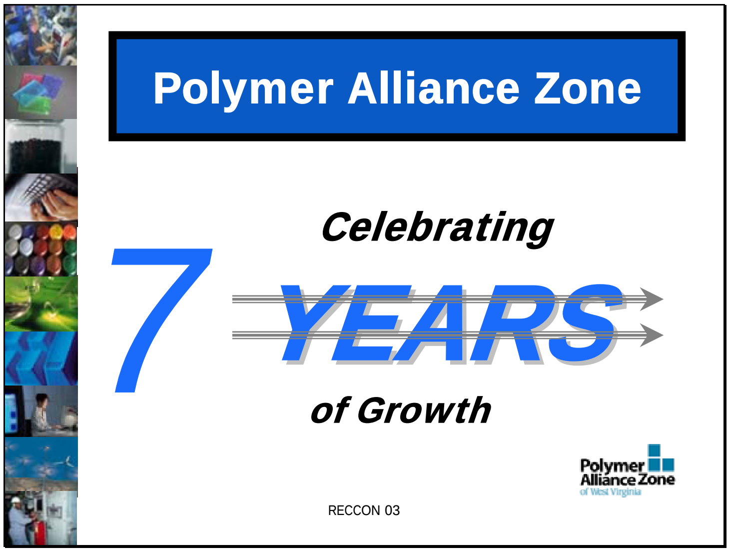
- Collection
- Sale of recycled materials
- Geography, distance, shipping
  - Regional vs national?
- Variable values used in current model
- Relationships portrayed in model

Slide 15


Review
PAZ project motivation
Business simulation overview
PAZ model overview
WEPSI & PAZ challenges, next steps
Infrastructure
Finance

Slide 1

Slide 2



Slide 3

Polymer Alliance Zone

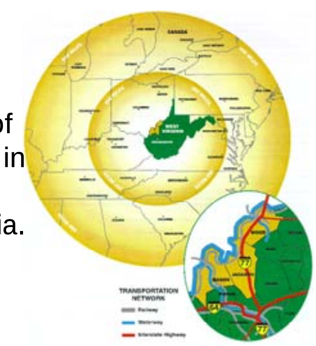
- The Polymer Alliance Zone was formulated in 1996 through an executive order of WV Governor Gaston Caperton to attract new industry and add-value to present industry.
- PAZ has one of the highest concentration of production of high-technology, specialty and engineering polymers in the world.
- PAZ is industry driven … currently there are eighty-four members of the Polymer Alliance Zone.
- Our funding comes from both the public and private sectors.

RECCON 03

Slide 4

Polymer Alliance Zone

The Polymer Alliance Zone is strategically located in the heart of the polymer industry in the Mid-Ohio Valley sector of West Virginia.



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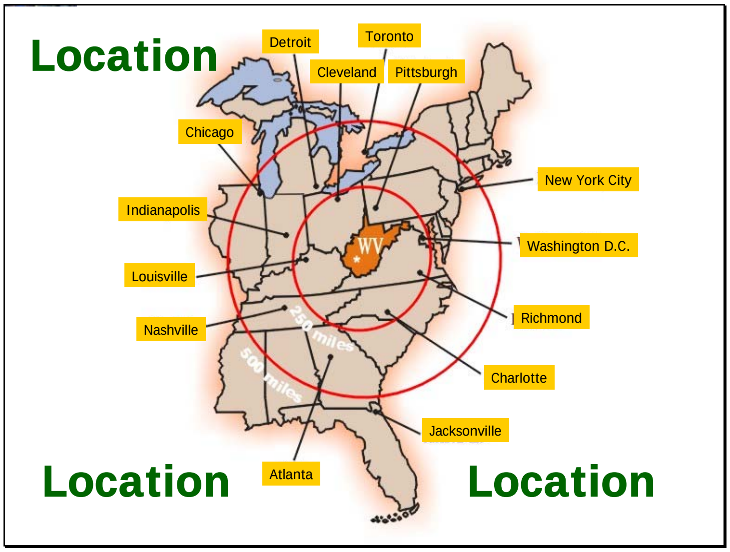

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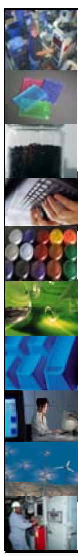


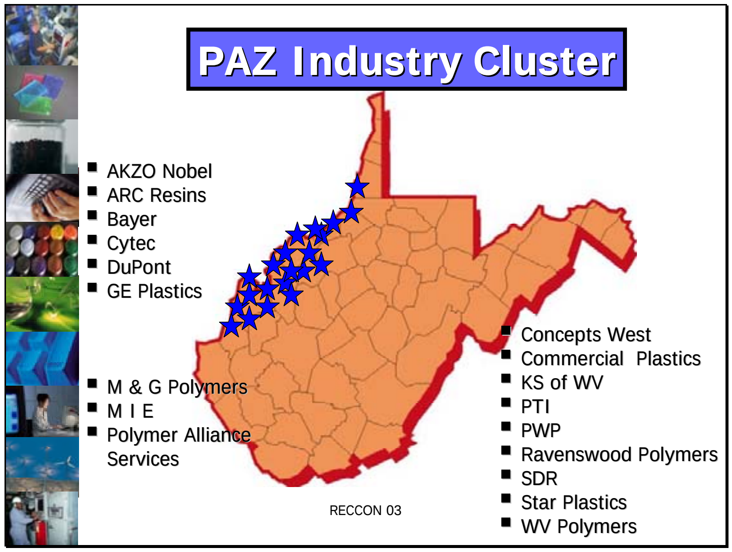
Polymer Alliance Zone

- The objective of Polymer Alliance Zone is to **recruit new companies** that will add jobs and investments to the Zone as well as maintain the stability of the polymer industry in West Virginia
- The overriding criteria of our development activities is that each project is designed to **add value** to each member company in the Zone.
- A spirit of **collaboration** and **cooperation** rather than **competition** will be maintained in all prospect development activities.

RECCON 03

Polymer Alliance Zone of West Virginia

Slide 7



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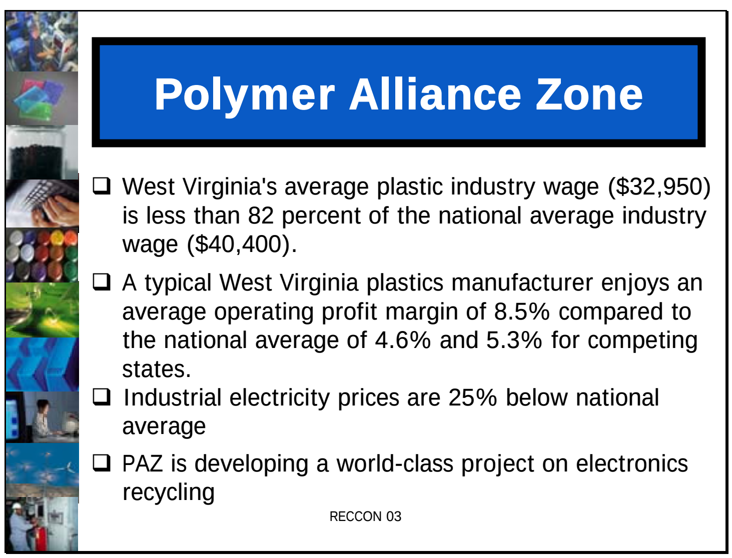

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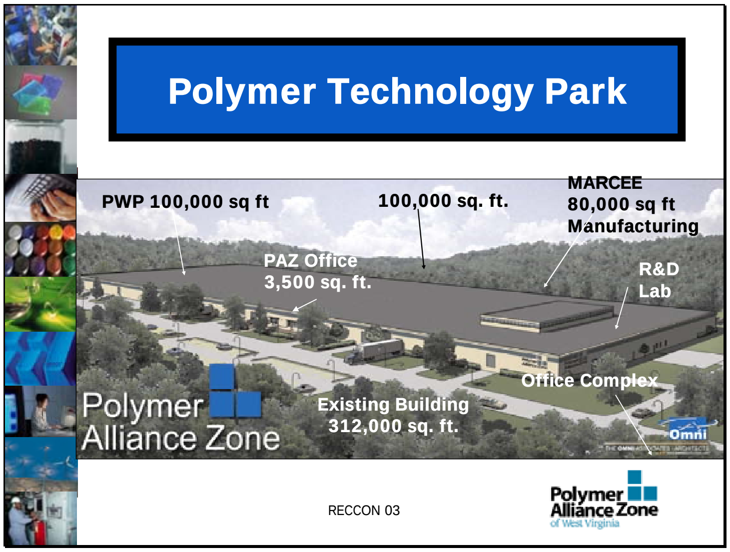

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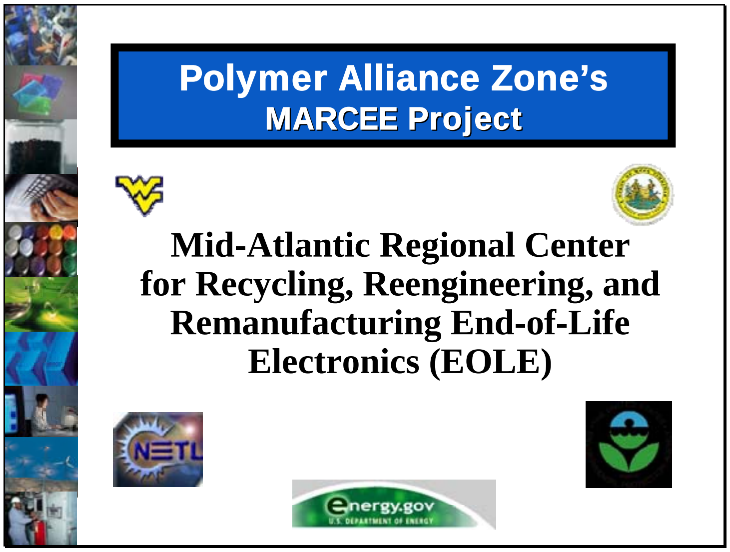
Slide 11



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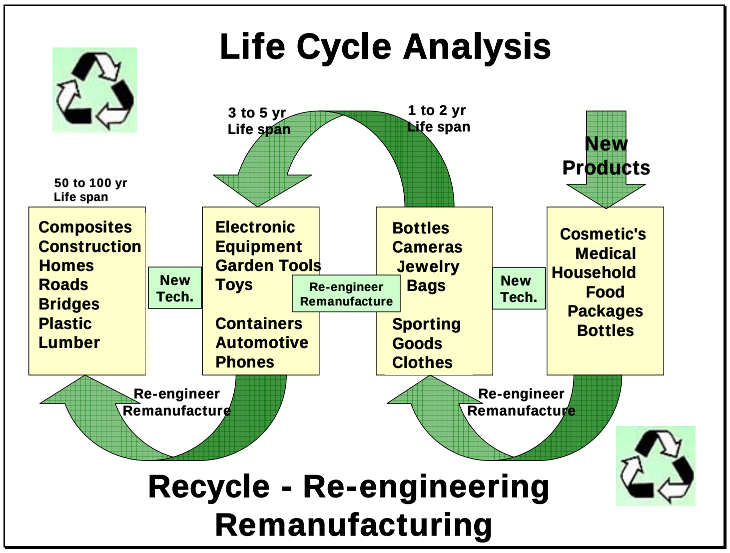

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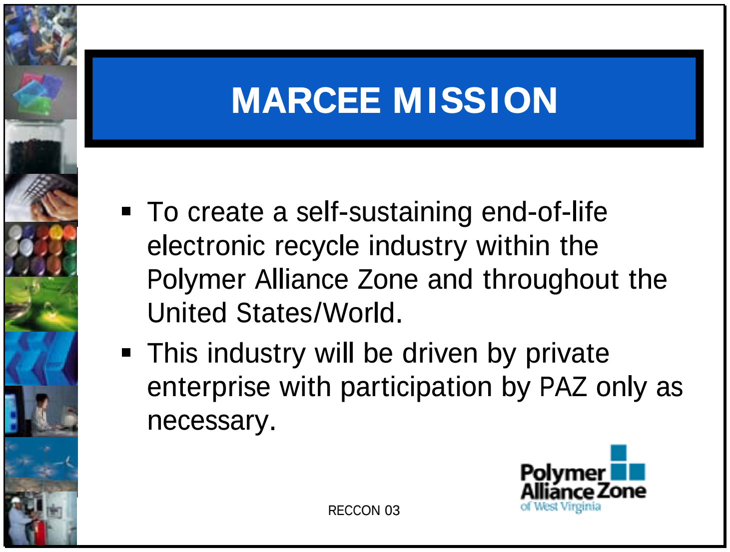

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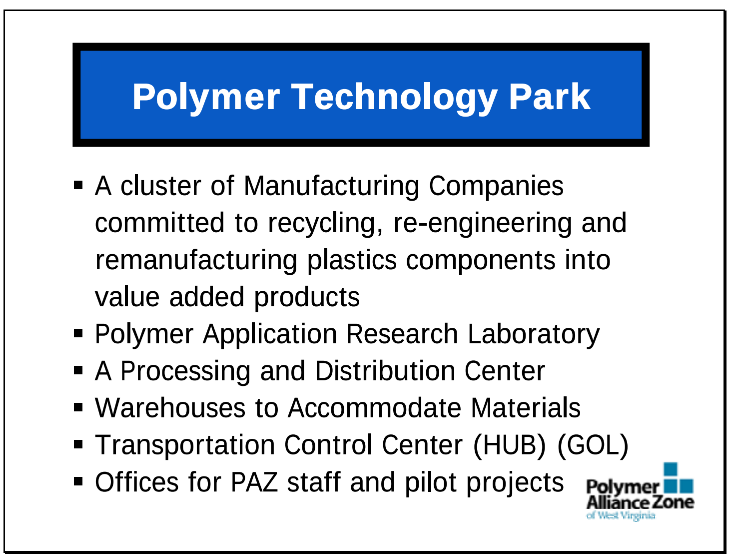

Slide 15

Polymer Technology Park

- The Park will be one of the most advanced "people oriented," industrially functional and "environmentally friendly" industrial sites in the world.
- The Park is being planned to take advantage of the natural beauty and will be a showplace to test new applications of "Green Products."

Polymer Alliance Zone of West Virginia

RECCON 03

Slide 16

Polymer Alliance Zone's MARCEE Project

Where are we now?

- **Plastics Separation**
  - All pieces to the puzzle
- **Glass**
- **Metals**
- **Down Stream Partners/Participants**

Polymer Alliance Zone of West Virginia

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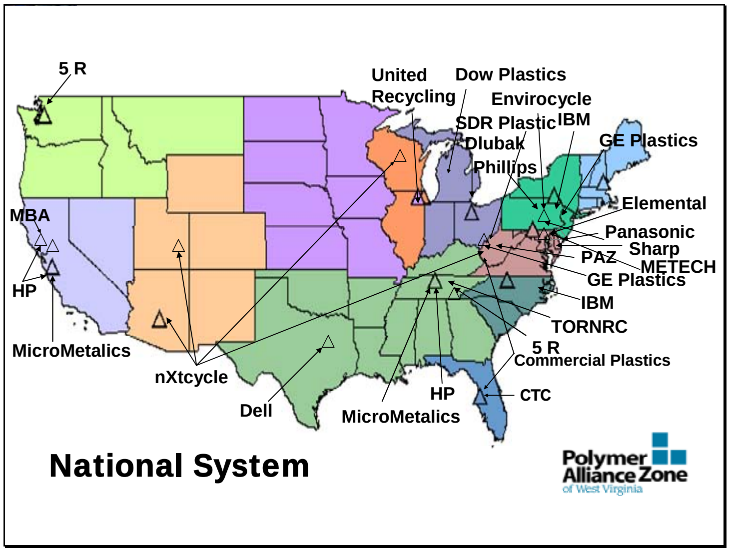
Slide 17



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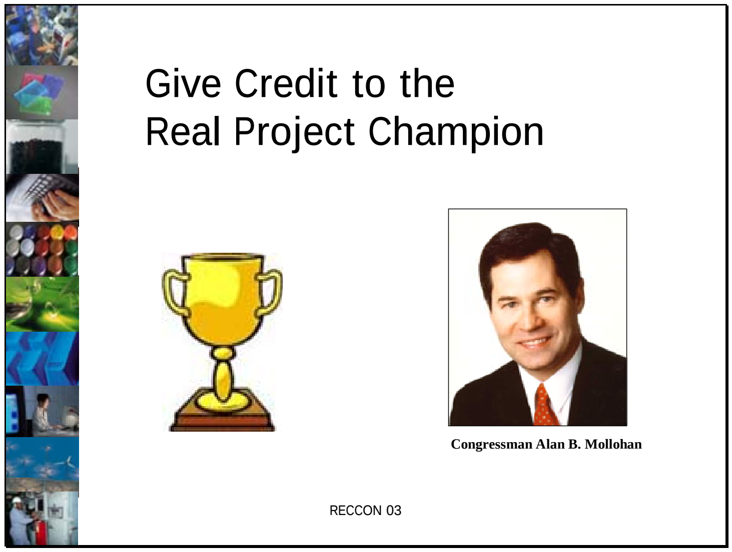
Slide 19



Slide 20

Slide 21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International Conference on
Recycling Information Exchange
and Industrial Practices
GAIKER
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West Virginia University.
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CENTER FOR ELECTRONICS
VERC
Polymer
Alliance Zone
of West Virginia
RECCON 03

Appendix Q: Task 3.6 for DN American

EPA REGION III – eCycling Pilot Project Overview

The Mid-Atlantic States and the EPA Regional office in Philadelphia launched the Region 3 eCycling Project in 2001 and the Pilot culminated in December 2002. This pilot was the first, and remains the only multi-State electronics collection and recycling effort to receive widespread support from the major players within the electronics industry, and from state and local government. The pilot was very successful in leveraging approximately $1.1 million in funding primarily from State and local government, and resulted in the following accomplishments:

- 58 residential collection events held throughout Region 3;
- 9 permanent collection programs started;
- Over 2,700 tons of end-of-life electronics diverted from the municipal waste stream and recycled; and
- More than 26,000 cathode ray tubes (CRTs) collected and recycled.

Although the collection numbers are impressive, the best results of the pilot are that it demonstrated that:

- Six states can collaborate effectively to provide regulatory flexibility across a large, multi-jurisdictional area;
- Recycling markets will develop to manage the increasing supply of materials in an environmentally sound manner;
- Permanent collections sites have proven to be the most cost effective method to collect materials;
- EPA, State governments, electronic manufacturers/retailers, and recyclers can develop partnerships to address challenging environmental issues;
- Third party organizations are very important in helping to deploy funds from the private sector; and
- An effort grounded on shared responsibility, and robust outreach to local government and consumers can work very well.

The eCycling Pilot would not have been possible without our State partners and without the involvement of the Mid-Atlantic counties, cities, and organizations who hosted eCycling events and covered recycling costs.

The Region 3 pilot also benefitted from strong support from the both the EPA Office of Solid Waste, and the Climate Change Office within the Office of Air and Radiation.

Please find the eCycling Report on the EPA Region 3 website at http://www.epa.gov/reg3wcmd/eCycling.htm

EPA Plug-In To eCycling Overview

Plug-In To eCycling is a consumer electronics campaign working to increase the number of electronic devices collected and safely recycled in the United States. Launched in January 2003, Plug-In To eCycling is one component of EPA's Resource Conservation Challenge (RCC), a national effort to find flexible, yet more protective ways to conserve our valuable resources. It is also part of EPA's Product Stewardship Program.

Plug-In To eCycling focuses on three major areas:

- Providing the public with information about electronics recycling and increasing opportunities to safely recycle old electronics.
- Facilitating partnerships with communities, electronics manufacturers, and retailers to promote shared responsibility for safe electronics recycling.
- Establishing pilot projects to test innovative approaches to safe electronics recycling.

EPA developed the shared responsibility pilots under the Plug-In To eCycling campaign to help demonstrate the kinds of voluntary partnerships that can significantly increase recycling of used electronics in the United States. Currently, no national infrastructure exists for collecting, reusing, and recycling electronics. The participating groups identified the importance of using these pilots to find the most efficient and practical electronics collection method and to obtain more information about end-of-life electronics.

Through Plug-In, private and public sector partners are hosting ongoing and one-time collection programs. They are also testing innovative approaches to implementing and paying for electronics recycling, with costs shared by OEMs, retailers, governments, and consumers. Plug-In also is creating a common XML framework which Plug-In partners and numerous other entities engaged in electronics recycling can track and analyze results. To these results we can add those gleaned from the Region III eCycling project as well as those generated by numerous other local and regional efforts. Through the creation of this common framework, these entities, as well as all other interested parties will have the opportunity to assess the results of a robust sampling of electronics recycling efforts across the USA. In partnership with the Plug-In program, the results of this analysis will be presented at a national electronics recycling summit planned by EPA for the late fall or early winter of 2004. The analysis of data as well as the subsequent conversation at this summit will facilitate the development of thoughtful next steps for electronics recycling nationwide. The availability of this information will also encourage market development in a much-needed area.

Plug-in To eCycling Website: http://www.epa.gov/epaoswer/osw/conserve/plugin/

EPA Supported EPEAT Program Overview

EPEAT is a multi-stakeholder process to design and implement a tool for evaluating the environmental performance of electronic products. After development of the initial set of EPEAT program requirements, the EPEAT tool is being implemented by an Implementation Team of expert stakeholders. Their mission is to finalize development and implement an assessment tool for use during the procurement of electronic products and services. The EPEAT tool is intended to:

- Promote continuous improvement in the environmental performance without stifling, and while encouraging, innovation;
- Address the lifecycle of electronic products including, but not limited to, design, procurement, use, and end-of-life implications;
- Inform purchasing decisions by institutional purchasers regarding the environmental attributes of electronic products;
- Provides market advantage for companies that provide products and services that achieve improved environmental performance;
- Is low cost, user friendly, and causes minimal delay in time to market;
- Produces credible, verifiable outcomes that are accepted by relevant stakeholders and
- Provides sufficient value in the marketplace to sustain itself.

The management of electronic equipment at the end-of-life (EOL) is becoming a problem of increasing urgency. Developing solutions to this challenge is being addressed through multi-stakeholder dialogues, whose goal is to create a shared responsibility framework to greatly expand the reuse and recycling of discarded electronic devices.

One of the dialogues, the Western Electronic Product Stewardship Initiative (WEPSI), proposed that methods be explored to provide a marketplace reward for product designs that embody superior environmental attributes. Product design makes a great difference in the cost efficiency and environmental effectiveness of EOL management. Some products retain substantial value at EOL, while others can be costly to manage.

Public agencies are concerned about the total cost of ownership of their purchases, and they benefit from lower EOL costs. These agencies, through their purchasing, can send a strong market signal. But purchasing officials need a clear and easy-to-use method to evaluate products. Recognizing the maxim that “what gets measured, gets managed”, the focus of this project is to develop an assessment tool that will advise procurement officials regarding the environmental attributes of personal computing devices.

Overall EPEAT Project Goals

In short, the goal of the EPEAT development project is to develop an assessment tool that:

- Is simple and clear to a purchasing agent,
- Is voluntary but inviting for manufacturers,

- Is transparent and flexible to a product designer, and rewards innovation,
- Is low cost and causes no delay in time-to-market,
- Addresses the significant EOL issues faced by the reuse and recycling community, and
- Effectively measures preferred environmental design.

The EPEAT project has successfully called on dedicated stakeholders to help examine and come to consensus on potential assessment methods. The EPEAT Implementation team is now identifying the appropriate organizational structures to implement and operate an assessment tool, and is producing a plan for development and funding.

DN American Charts End-of-Life Electronics Collections

By PAM KASEY
pkasey@statejournal.com

What is the most efficient way to collect end-of-life electronics for recycling? Curbside? Return to manufacturer? Trade-in at retailer on replacement?

DN American of Fairmont, the information technology partner of the **Mid-Atlantic Recycling Center for End-of-life Electronics**, is helping to find the answer.
Electronics manufacturers and recyclers can't seem to agree on the question. Some like a front-end, fee-based system in which consumers pay as part of the original purchase price, according to MARCEE project manager **Walter Alcorn**. Others like a producer-responsibility system in which manufacturers would handle equipment on retirement.
California and Maine already have legislated different systems and, if manufacturers and recyclers can't agree soon on one system to be used nationwide, they're going to face a national patchwork of requirements.

What is needed is good data collected from a series of pilot recycling projects. This is where DN American comes in.

DN American analyzed data gathered from 52 pilot electronics collection events held across the federal **Environmental Protection Agency**'s mid-Atlantic region in 2001 and 2002, according to **Jeff Tucker**, a senior software engineer at DN American.
Among the lessons learned at events ranging from one-time collections in **Wal-Mart** parking lots to ongoing take-backs at full-time centers, Tucker said, was this: You get a lot of stuff.

"You don't get just computers and keyboards; you get TVs 30 years old in the wood consoles and IBM computers in the big metal cases from the 1980s," he said.
So while electronics recyclers in business today simplify their waste stream by taking only **Dell** computers or **Verizon** cell phones, a truly comprehensive recycling program will have to face that challenge.

With the success of that early program, EPA established Plug-In To eCycling, a larger program going on now, and approached DN American once again to handle the data.
The Plug-In program is gathering more detailed data on questions such as the age of equipment coming in, the composition of the waste stream and how consumers react to fees at varying levels.

Before collecting Plug-In data, DN American, with the MARCEE project, consulted with 45 industry stakeholders to create a set of standard data elements, Tucker said.
"One thing we saw (in the earlier eCycling program) was that programs collected data in different ways," he explained. "One collected total pounds while another collected the

total number of monitors, so there wasn't a good way to look at data across all programs."

Plug-In program participants submit their data on a nine-page, Web-based and printable form. The first data are flowing in now, Tucker said, and he expects to have a preliminary report by early March.

"It's probably going to be the best look at electronics recycling collection programs that we've ever had," he said. "It's going to give us insight into how you can set up an efficient take-back program in the U.S. That's what the stakeholders want to see: how to set this up as efficiently as possible."

With this centralized data repository, Tucker said, the industry is starting to look at MARCEE as the leader in data collection and analysis for sound decision-making in electronics recycling."

National Electronics Manufacturing Initiative – NEMI Workshop Overview

DN American continues its information technology support for the electronics recycling industry by participating in the development of industry data exchange standards.
On behalf of the MARCEE Project, Terri Linger attended the Material Declaration Data Exchange Workshop in Santa Clara, California at the end of August. The data exchange workshop was sponsored by the National Electronics Manufacturing Initiative (NEMI) - an industry-led consortium whose mission is to assure leadership of the global electronics manufacturing supply chain.

The workshop provided a forum for industry participants to discuss the challenges and solutions for information exchange in support of global environmental initiatives that impact the electronics industry. A special emphasis was placed on understanding the reporting requirements for the European Union's RoHS and WEEE directives.

Although the work is not yet complete, the participants of the workshop made much progress toward identifying requirements for a data exchange standard and a summary report along with recommendations will be produced by the end of 2004.

Workshop Goals:

- to understand current and proposed solutions and the role of data exchange standards, including IPC PDX and RosettaNet;
- help participating companies and organizations understand the data interchange landscape, and current best practices and future directions, from both a process and IT perspective; and
- to reach consensus on a matrix of data exchange requirements for compliance to materials declaration regulations.

DEVELOPMENT OF XML INDUSTRY STANDARDS FOR INFORMATION EXCHANGE AND COMMERCE

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Abstract

Information sharing via a common language is the basis upon which successful industries and supply chains are built. The rapid changes now underway in the electronics recycling industry require concurrent changes in the common language of industry commerce. Today's economy and business climate also depends on cross-border industry collaboration – yet another challenge to developing and implementing common industry terminology -- brought about in large measure through the increased use of Information Technology tools. A set of common document interfaces that would allow industry partners the ability to not only view data but also integrate the data with backend ERP or database systems is a compelling vision. The problem to be addressed is how to use the Internet and a flexible XML schema to reduce costs and ultimately help generate new market opportunities for today's businesses.

I. Introduction

The use of information technology and the Internet are changing the way business is done in today's global environment. Consistent with the evolution of these business processes, the use of data for decision-making is also increasing at a rapid pace. This increased demand for better information faster has led to the use of several types of Markup Languages. The term Markup is generally applied to any set of codes or tags added to the contents of a document in order to indicate its meaning or presentation.[1] The best example of this is the use of Hypertext Markup Language (HTML) on web pages. Through the use of a software program called a web browser users are able to view pages of information that are presented using a series of tags. The tags tell the software (web browser) how to interpret the data and display the information to the screen. The use of HTML has changed the way most companies do business and how information is accessed via the Internet. An extension of this concept is the eXtensible Markup Language (XML) that originated in September 1998 by the World Wide Web Consortium (W3C).[2] XML by design was created with the concept of transferring data embedded into its definition. It is an independent, global way to express any kind of information using constructs that can be accommodated to fit particular needs.[3] Figure 1 shows an example of XML tags and document structure.

```
<?xml version="1.0" standalone="yes"?>
<MarketListing>
    <Listing xmlns="GreenOnlineMarketListing">
        <Title>ABS white pellets</Title>
        <TradeTypeID>1</TradeTypeID>
        <PostDate>2004-02-17T00:00:00</PostDate>
        <EndDate>2004-06-17T00:00:00</EndDate>
        <MarketCategoryID>26</MarketCategoryID>
        <QualityID>0</QualityID>
        <Quantity>9867</Quantity>
        <UnitOfMeasure>tons</UnitOfMeasure>
        <City>Parkersburg</City>
        <State>WV</State>
        <Price>11.33</Price>
```

Figure 1. Sample of XML syntax and document structure.

Typically, XML standards are developed through industry collaboration. Entities such as industry groups, major industry participants, non-profit organizations or neutral web services firms. Examples include industry alliances in fields such as Steel, Automotive, and Aerospace.[4] The purpose of these industry groups is focused on developing XML guidelines, standards, and terminology that can be applied throughout the industry. As described in this paper, one such project underway in the area of electronics recycling is an initiative sponsored by the Mid Atlantic Recycling Center for End-of-life Electronics (MARCEE) project.

The concept of a lightweight and flexible data definition that can be used in a global environment and accommodated to fit the needs of the electronics recycling industry has led the MARCEE project to introduce XML into the supply chain management infrastructure for the electronics recycling industry. Industry leading software companies such as Software AG [5] have identified several benefits derived from a common framework developed utilizing XML and include:

- Simplicity – Information coded in XML can be easily read and processed by various computer formats.
- Open Standard – XML is a W3C standard and recognized by the software industry.
- Extensibility – There are no fixed tags. New tags can be added as necessary.
- Multilingual Document Support – important feature for integration with international applications.
- Multiple Data Type Support – XML documents can contain multimedia data such as images, videos, and sound.

In many industries not unlike the electronics recycling industry, information is stored in various formats including paper documents, electronic documents, spreadsheets, and relational databases. The one major hurdle to this type of information storage is that it is not the most efficient way to share information between industry partners. Therefore, by utilizing a common data framework the individual partners do not need to invest heavily in new computer systems or databases, they just need to format information in a common structure. This is also becoming easier as major word processors and spreadsheet programs allow for the creation of XML documents. The MARCEE project feels that this is a key discriminator in the area of information exchange and the impact information technology can play in supporting an industry such as electronics recycling.

II. Data Transformation and the Supply Chain

In order to reduce complexity and gain economies of scale within a supply chain, stakeholders in other industries are looking again at the benefits of information technology. By developing a common language or framework in which industry partners can communicate the quality and flow of information can be increased dramatically. A common framework will also require less specialized implementation efforts for industry partners to share data and allow for a quick-to-deploy solution that maximizes investment in data not in software costs. The use of proprietary data systems are quickly disappearing and are being replaced by more open architecture-based systems which allows for easier data integration. There are several efforts currently being funded or otherwise supported by pilot projects through the Department of Energy [6] and the Environmental Protection Agency [7] in the area of data transformation within the field of electronics recycling. Many of these efforts are in coordination with the previously mentioned MARCEE project. To demonstrate how reducing the complexity of the supply stream can ultimately increase the ability to recycle electronics more efficiently, the MARCEE project has divided the supply stream up into 3 distinct modules with 2 feedback / information sharing channels as illustrated in Figure 2.

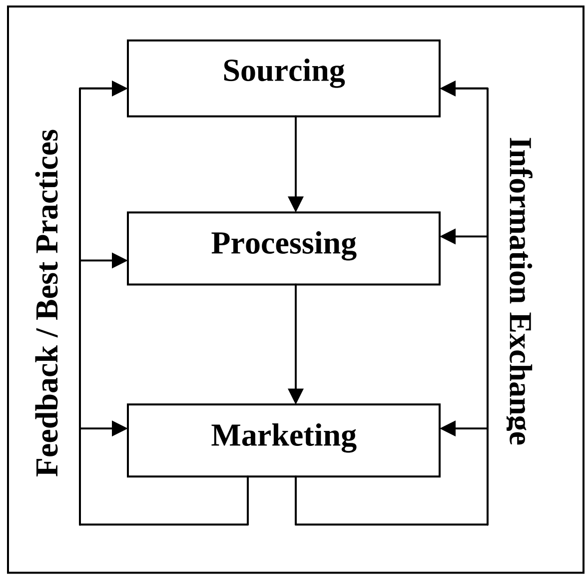

Figure 2. Individual Modules of MARCEE Electronics Recycling Supply Chain

By using the modular approach, the MARCEE project has been able to identify specific areas where the use of information technology and specifically XML can be utilized. The need to demonstrate how XML can be integrated within the supply chain led the MARCEE project to use a digital services platform of the Polymer Alliance Zone of West Virginia (PAZ) called GreenOnline.com, which serves as the XML-enabled platform for several supply chain integration pilot demonstrations.

III. Overview of XML and Electronics Recycling Industry

To understand how XML standards can integrate within an industry we first must look at the three types of standards that currently exist within the area of XML.

- Infrastructure Standards for the Web
- Interoperability Standards

- Industry / Business Specific Standards

The first area primarily deals with the development of standards that impact how the Internet functions and is currently being handled by the W3C. The W3C has several working groups that concentrate on infrastructure, Internet resources, and software development. The second area is focused on how XML standards can be used to aid in interoperability between systems. The OASIS [8] group is one example of a standards body working on topics such as a replacement for EDI transactions between electronic systems. The third area is the one that relates to the electronics recycling industry and leads to the development of XML standards for a specific industry. In order for the electronics recycling industry to utilize information technology tools efficiently such as online marketplaces or supply chain management tools, a commonly accepted terminology must be developed. This common terminology will ease the integration of data with existing systems and help increase the use of electronic tools, E-business platforms and other applications of evolving information technology solutions.

The electronics recycling industry is a prime example of an industry that could benefit from the use of information technology and an integrated supply chain management approach. Given the industry's historically low margins and developing status, the opportunity for cost reduction is attractive.

To demonstrate the need for a common terminology the MARCEE effort has supported several pilot or demonstration projects that have required multiple stakeholders or industry partners to communicate through the use of electronic systems. The following sections include a description of the pilot project along with a discussion as to how a common terminology or XML standards could aid in the development of additional information technology tools that support electronic commerce.

IV. XML Integration – Sourcing

Both the electronics recycling industry and the modules of the MARCEE Electronics Recycling Supply Chain contain three primary steps, the first of which is sourcing. Sourcing in the electronics recycling industry is usually described as either post-consumer or post-industrial. The example we outline here will focus on the more complex and less developed of the two, post–consumer sourcing.

The MARCEE project initiated this activity by identifying a sourcing project in the Mid-Atlantic region where information flow was critical and needed to be handled in a timely fashion. The EPA Region III eCycling pilot project provided this opportunity. In support of the eCycling pilot, five individual states that make up Region III participated in over 45 electronics recycling collection events. The MARCEE project provided an electronic data collection system that was web-based and linked to an online data warehouse. This system tracked multiple data points including elements like tons of material collected, product breakdowns, costs associated with collection, and many others. During this data collection process several instances occurred where the development of XML standards would have provided a common data transformation framework and made sharing of pilot project results easier. During the pilot, several stakeholders such as OEM's, recyclers, and collection sponsors expressed interest in obtaining quick access to the data on an ongoing basis. This prompted several discussions on the creation of a standard set of data elements that could be represented through the use of XML.

Like efforts in the Mid-Atlantic, national electronics recycling efforts would benefit tremendously from a common data transformation framework. Currently numerous government, non-profit, and private sector organizations are striving to build or enhance the infrastructure for electronics recycling nationwide. Many of these entities are testing ways of best serving their customers and doing so within budget. There is currently no national system for tracking results of these programs, including volume of material collected, types of materials, and costs associated with collecting, transporting, and processing these materials. Without these data points, it is difficult to evaluate needed systems or approaches for managing these products at end of life. This lack of data stymies the development of markets for the materials generated and the ultimate roll-out of a national system.

A common XML framework will enhance data collection and provide a forum for sharing needed data, allowing for the analysis of results of an array of collection programs and the identification of opportunities for recycling business development. Partnering with a number of programs, all of which agree to common XML standards, will allow for the initiation of a national system for collecting and analyzing data key to electronics recycling nationwide. The U.S. EPA's Plug-In To eCycling effort is one such program.

As with any supply chain model the efficiency can only be derived from the information that flows throughout the chain. Given that efforts like the EPA programs are working hard at providing quality data, platforms similar to GreenOnline.com provide the data foundation for more robust simulation and modeling tools in order to anticipate market shifts and answer "What If?" type questions regarding supply and demand, pricing, volumes, etc. Two simulation tools are currently being used by the Polymer Alliance Zone of West Virginia (PAZ) [9] to analyze the interface between material flows, economics, and geographic optimization across the sourcing and processing modules.

Plug-In To eCycling

Through Plug-In, private and public sector partners are hosting ongoing and one-time collection programs. They are also testing innovative approaches to implementing and paying for electronics recycling, with costs shared by OEMs, retailers, governments, and consumers. Plug-In also is creating a common XML framework which Plug-In partners and numerous other entities engaged in electronics recycling can track and analyze results. To these results we can add those gleaned from the Region III eCycling project as well as those generated by numerous other local and regional efforts. Through the creation of this common framework, these entities, as well as all other interested parties will have the opportunity to assess the results of a robust sampling of electronics recycling efforts across the USA. In partnership with the Plug-In program, the results of this analysis will be presented at a national electronics recycling summit planned by EPA for the late fall or early winter of 2004. The analysis of data as well as the subsequent conversation at this summit, will facilitate the development of thoughtful next steps for electronics recycling nationwide. The availability of this information will also encourage market development in a much needed area.

Several other areas relating to product sourcing have been identified and working groups created to help determine the information needed, thus forming the basis of a common XML schema for the post-consumer collection process. An example of this type of industry participation leads us to the second step in the supply chain: processing.

V. XML Integration – Processing

The process of recycling electronics can take on many different flavors. There are several companies working in the field of recycling that use different processes and procedures in order to separate, process, and recycle the plastics, metals, and glass found in most consumer electronics. To make this a more efficient process and adaptable to electronic commerce a need for a better way to classify or characterize a challenging set of recycled materials was identified.

With financial support from the MARCEE project, industry participated in this effort in cooperation with the Gordon Institute at Tuft's University Stakeholder Dialogues on Recycling Engineering Thermoplastics from Used Electronic Equipment. The Dialogue process has actively engaged companies throughout the supply chain, including major resin suppliers and original equipment manufacturers, along with plastics processors, molders, electronics recyclers, federal, state and regional government officials, and other industry experts. Over 60 organizations have participated in the Dialogue process since its inception. An industry-led Materials Characterization task force was created in order to help focus efforts on the problem of complex material attributes. The Materials Characterization task force activities included:

- Development of standard terminology for recovered / reprocessed electronic engineering Thermoplastics (ETPs)
- Development of a classification / grading system to enhance buying / selling of recovered ETPs
- Establish / specify a set of standardized test protocols for the characterization of recovered ETPs
- Integration of classification system into plastics trading platform

As a result the EETP Recycled Material Characterization Matrix was developed. This matrix provides the necessary terminology to facilitate characterization and communication of complex recycled/recyclable plastic materials by several different attributes.[10] The matrix was ultimately adopted as an industry standard by the Institue of Scrap Recycling Industries (ISRI) in 2003 [11] and converted into an XML schema that is currently being utilized by GreenOnline.com for marketplace characterization.

To demonstrate how this matrix could provide assistance we can look at a typical partner scenario. Two trading partners each have a different back-end computer system such as an ERP system or a proprietary engineering system. Trading partner 1 has some loose mixed plastic that needs additional processing. Trading partner 2 has the ability to process, sort, and shred the material. A typical negotiation process may include several phone calls, batch sampling, and final product acceptance. Since both partners are using a common messaging framework utilizing XML they can participate and share information in a quick and efficient manner utilizing a web-based system. A process that might normally take several days potentially can be reduced to several hours. Currently work being performed under the MARCEE project will allow for an online demonstration system to be created in order to capture a similar industry scenario. As this example focused more on the processing functions it will ultimately lead to the marketing of such semi- or non-commoditized materials.

VI. XML Integration – Marketing

The use of the Internet for electronic commerce has drastically changed the way we look at marketing and selling of products in today's marketplace. However, some products are much more complex than selling books or CD's online. Industrial materials such as plastic, metals, and glass have numerous product characteristics and forms that drive a material's potential value to successfully market material online. In order to market complex materials via an online marketplace a trusted method of characterization is required. To demonstrate this concept a series of XML schemas were developed. The schemas, collectively named erXML, include a “Plastic Material” schema, which defines the basic set of information needed to describe plastic material. Other schemas go one step further and define acceptable values for certain attributes of this material. These schemas include “Loose Mixed Plastic”, “Shredded Sorted Plastic”, “Granulated TV Plastic”, and several other schemas representing various grades of recyclable plastic material.

erXML Schemas are currently used for the GreenOnline marketplace to support an online “Material Characterization Wizard” which helps users specify exactly what type of plastic material they are posting. The wizard is made up of a series of web-based forms, which guide the user through a set of questions to determine the material type and ultimately ensure that the material specification conforms to the recycled material schema.

A software application called “Green Market Listing” makes use of the erXML “Market Listing” schema which defines the data necessary for posting a market listing on GreenOnline. Also, the “Plastic Material” schema, mentioned earlier, defines the structure of the XML data being gathered and validates this data, which is then transferred via a web service to the GreenOnline marketplace. Once the XML document is received by the GreenOnline system, it is validated against a specific erXML schema and posted on the marketplace under the corresponding market category (e.g. “Loose Mixed Plastic”).

VII. XML Integration – Information Exchange / Feedback / Best Practices

The increased use of web sites and web portals for sharing information has created a need for tools that allow for data to be updated dynamically. Static web pages that get updated once or twice a year are a thing of the past. Now web sites pull content from multiple data points including databases, HTML web pages, and XML documents. An example of this technology can be found on the ElectronicsRecycling.org web portal. This informational web site for the electronics recycling industry uses XML to pull content from other web sites. The site works cooperatively with the GreenOnline.com system in order to share information and content material. This same concept can be used in sharing information to a global marketplace. Via the Internet and electronic web-based platforms it is now possible to share information with a whole new set of industry stakeholders. There are several electronics recycling initiatives under way in the European Union,[12] Japan,[13] and the United States. Currently discussions are under way in developing a Worldwide Information Exchange developed around the use of XML in order to share information and expand marketing opportunities to a global perspective. One such example of this industry cooperation is between the MARCEE project and the Virtual European Recycling Center (VERC). These two entities recently presented a combined information technology session at the RECONN ’03 conference [14] on the topic of information exchange opportunities in the area of recycling technologies.

Information exchange is a cornerstone for any industry and by utilizing electronic tools combined with the global connectivity of the Internet we can drastically impact the productivity of companies in today’s business environment. As mentioned earlier there are two information or feedback channels as part of the MARCEE supply chain model. These channels allow for additional information to flow throughout the supply stream to help increase the effectiveness of online tools as well as share best practices. In order to maximize efficiencies industry needs to eliminate redundancies and streamline processes. By utilizing tools such as information web portals, electronic information repositories, and online best practice libraries, organizations can provide a value-added component to an industrial supply stream. Companies can now collaboratively share ideas and concerns in a rapid and electronic format that allows for almost real-time collaboration from anywhere in the world. For example, companies in the United States can now share information with European firms on issues impacting material flow via the Internet. Electronics Recycling is a global concern as seen by the number of countries that have now enacted legislation regarding end-of-life electronics. XML has the potential to become the technology enabler that allows for a dynamic information-sharing network to develop, however industry participation is vital to make this a reality.

VIII. Web Services and XML Integration

As previously mentioned XML is just the document structure that allows us to share data efficiently. In order to really maximize its potential we need to look at the development of applications and services that utilize the data or information being shared. As the Internet develops into more than just a series of static web pages, developers are beginning to see how applications or “services” could be offered via the Internet. The term “web services” is a relatively new concept and refers to a new breed of web application. A self-contained, self-describing, modular application that can be published, located, and invoked across the web. Web services perform functions, which can be simple requests to complicated business processes. Once a web service is deployed, other applications can discover and invoke the deployed service.[15]

Web services technologies are designed from the ground up to work with XML data. The potential lies in developing some very unique supply chain applications that can handle everything from simple product requests to a complex material characterization and specification negotiation. Once developed these web services can then be utilized by numerous industry partners and provide a common framework or architecture for information exchange. Web services have the potential to greatly impact the economies of scale within a supply chain by helping reduce the cost of developing individual proprietary supply chain applications.

Both the financial and insurance industries have been early adopters in the development of industry specific XML standards for sharing of information and have invested millions of dollars in order to create XML industry standards that provide better intra-industry communications. XML and web services have potential but it will ultimately depend on how industries such as the electronics recycling industry will adopt and utilize the technology.

VIV. XML Platforms – Industrial Exchange

To complete the discussion on integration of XML into the supply chain we will look at an electronic platform currently being utilized to support the electronics recycling industry. The Polymer Alliance Zone's GreenOnline.com has become a digital services platform for information technology tools to support environmental e-commerce.[16] This platform is currently supporting several information technology initiatives including the MARCEE project, EPA Region III ecycling project, EPA Plug-In To eCycling program, and the EIA consumer education initiative.[17] The platform also serves many other regional and or local efforts interested in the development of a national infrastructure for electronics recycling. GreenOnline has adopted XML in several demonstration or pilot projects and is currently working on additional efforts with international XML standards to help reduce the barriers of information exchange with international partners. GreenOnline.com is implementing several technologies in order to showcase how XML and web services can provide a strong platform for application development. However, the main focus for GreenOnline.com has always been the ability to create online marketplaces for buyers and sellers to meet and provide e-commerce opportunities. As a result of initial pilot project activities in the area of electronics recycling, GreenOnline.com created a demonstration marketplace that integrates with the ISRI characterization standards and showcases how supply chain integration could benefit from a more detailed set of XML standards. GreenOnline.com is just one of a number of e-business platforms that are currently adopting XML and web services, others include Amazon.com,[18] Ebay.com,[19] and Google.com.[20]

X. Conclusion

This brief discussion of XML and Supply Chain information technology support by no way covers all of the various components that exist throughout the industry. However, by focusing on several pilot and demonstration projects currently underway we hope this paper provides a basic understanding of how information technology can support a complex and dynamic industry. Once industry requirements are identified and accepted, the development of a set of XML specifications can provide the initial catalyst for information sharing and E-Business among industry partners, non-profits and public sector entities.

XI. Acknowledgments

The authors greatly acknowledge the support provided by the Polymer Alliance Zone of West Virginia (PAZ), Department of Energy – National Energy Technology Laboratory (NETL), Environmental Protection Agency – Office of Solid Waste, West Virginia University, US EPA Region III (particularly Claudette Reed), Patty Dillon of the Gordon Institute at Tuft's University Stakeholder Dialogues on Recycling Engineering Thermoplastics from Used Electronic Equipment, Terri Linger and Dr. Michael Fotta from GreenOnline.com and Dr. Craig Miller.

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INFORMATION ARCHITECTURE FOR AN ELECTRONICS RECYCLING NATIONAL COORDINATING ENTITY

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Abstract

A central recommendation of the National Electronic Product Stewardship Initiative (NEPSI) process is the creation of an organization to facilitate development of the nation's electronics recycling infrastructure prior to enactment of federal legislation. This organization was tentatively called the National Coordinating Entity, or NCE. As currently envisioned, a major function of this new organization is that of an information clearinghouse of electronics recycling data and knowledge. Given this emphasis on information exchange, this paper explores the recommended design option for the overall information architecture of the NCE.

I. Introduction

During the National Electronic Product Stewardship Initiative[1] (NEPSI), a multi-stakeholder subcommittee was tasked with identifying actions that could take place in the "interim" period. The interim period was defined as the time after the NEPSI agreement is signed, but before any new front-end financing system would be enacted by the federal government. During this interim period, NEPSI recommended the creation of a new National Coordinating Entity (NCE) which would be a predecessor to a national Third Party Organization and would play a central role in coordinating the activities during the interim period. The subcommittee identified potential tasks for the NCE during the interim period, such as:

- Set goals and measure progress for volumes of end-of-life electronics collected and recycled during the Interim Period
- Gather and analyze data from collection activities from all parties who collected/recycled products
- Identify and make readily available environmentally sound management (ESM) recycling guidance to help prevent sham recycling, using Organization for Economic Co-operation and Development (OECD) and industry standards as guides in addition to the NEPSI ESM recommendations
- The NCE may also adopt, endorse or implement a system for qualifying reuse/recycling vendors
- Develop and provide national messaging materials
- Provide clearinghouse of "how-to" documents, such as example contracts, collection models, etc.

Although a final, comprehensive NEPSI agreement has not yet been reached as of this writing, discussions with the majority of NEPSI stakeholders and leadership suggested there is much interest among all stakeholders to move forward on the ideas included in the NEPSI Interim Period document.

Building upon the NCE concept, a new organization – the National Center for Electronics Recycling (NCER) – was recently formed using this NEPSI guidance as a starting point to initiate collaborative actions to improve the electronics recycling infrastructure across the country.

II. Overview of NCER

Using grant funds dedicated to the MARCEE project (Mid-Atlantic Recycling Center for End-of-Life Electronics)[2], a team of veteran industry support staff and consultants initiated the new National Center for Electronics Recycling (NCER) in February, 2005. Consistent with the NCE concept from NEPSI, the primary purpose of this Center is to coordinate the plethora of initiatives targeting the recycling of end-of-life electronics in the United States prior to the passage of any national product take-back legislation, and initiate new activities when necessary. Under the leadership of an Advisory Committee of electronics manufacturers, the Center serves to promote the enhancement of the national infrastructure for recycling used electronics.

At its inception one overall goal of the NCER is to provide leadership as coordinator of specific initiatives and as an information clearinghouse for states, communities, manufacturers, retailers and other businesses that are implementing electronics collection and recycling programs. Other NCER goals are also being explored, and the NCER may eventually assume more broad-based functions such as a financing and contracting role to help build out the national electronics recycling infrastructure. The NCER is not an advocacy organization, and as a recipient of federal grant funding is prohibited from engaging in lobbying activities.

Like any start-up, the focus and list of NCER initiatives is expected to evolve over time. Given the complexities of this industry, a key factor for the success of the NCER will be the efficiency of a coherent information architecture for the collection, analysis and distribution of information. To illustrate the NCER information architecture, this paper explores the role of data and information in 4 potential NCER activities:

1. **Orphan Products**. Identification of the share of returned electronics for which a responsible manufacturer no longer exists or cannot be identified ("orphan" products).
2. **Multi-State Third Party Organization**. In cooperation with the ongoing Pacific Northwest Third Party Organization (TPO) pilot project, coordinate development of a privately-managed multi-state TPO (MSTPO) to administer state-developed front-end financing systems for electronics recycling. As a first step this joint project will explore how an MSTPO could be formed and could function to assume one or more recycling system responsibilities – ranging from a data clearing house to contracting for recycling services – across state lines. A private TPO is a critical element of the range of potential system scenarios, including the NEPSI-style advance recycling fee (ARF) proposal and jointly managed compliance efforts working under a manufacturer responsibility scheme. Although the Pacific Northwest TPO pilot project is proceeding without a presumption of any form of system funding, the implications of different system funding strategies will be actively explored. The importance of this project is that many stakeholders strongly believe in the principal of industry participation, together with other stakeholders, in management of the end-of-life system

[1] NEPSI - http://eerc.ra.utk.edu/clean/nepsi/

[2] MARCEE – Jointly funded project project through the U.S. Department of Energy and the U.S. EPA.

for their products. This multi-state effort will serve to create efficiencies in electronics recycling collection and recycling across state lines, harmonize compliance with multiple state and local electronics recycling programs, model and demonstrate a pricing structure for a TPO that minimizes costs while ensuring sound environmental management, and create a means of sharing management responsibility for implementing recycling programs with industry.

3. **National Baseline**. Establishment of a national baseline for electronics collection/recycling data and measure progress for volumes of end-of-life electronics collected and recycled prior to enactment of any federal legislation.
4. **Administration of a National Grant Program**. A national recycling technology and market development grant program would serve to develop better recycling technologies and processes, and to develop better markets for recycled materials. Improvements to recycling technologies will reduce costs, potentially increase recycler revenues and make recycling a more economically attractive alternative to landfilling and other forms of disposal. There is clearly a need for improved markets for recycled materials from electronic products. Although there are initiatives in progress targeting this – such as MARCEE's work on plastics recycling and EPEAT's[3] implementation of the Federal Electronics Challenge (FEC) recommendations – there remains a significant gap between actual prices of recovered materials (low to negative value) and the environmental benefits (high value due to resource recovery). For example, this grant program could work to identify alternative uses for materials like leaded glass in the marketplace where existing markets have virtually collapsed in the United States. Plastics remain an orphan material wanted only by recyclers abroad, many of whom employ questionable practices. A targeted national recycling grant fund could promote and finance innovate ways to internalize environmental benefits into material prices. The FEC and EPEAT initiatives are examples of the incorporation of previously non-monetary environmental considerations into the electronics procurement process. A grant funding source dedicated to supporting these types of initiatives would help create the technical infrastructure and market demand for a sustainable electronics recycling system.

Although the NCER may or may not pursue all of these initiatives during the coming months and years, they all share a common requirement to collect, analyze and distribute specialized electronics recycling-related information.

[3] Electronic Product's Environmental Assessment Tool - http://www.epeat.net/

III. The Need for an Information Architecture

The electronics recycling industry and national infrastructure is in an early stage, it is a highly fragmented industry with mostly localized suppliers, service providers, and serviced customers. According to Jerry Powell of *E-Scrap News*, there are more than 500 independent electronics recyclers currently operating around the United States[4]. Information flows are primarily between service providers and their customers (e.g., a local government and its recycling contractor). Common information channels also include recycling collectors, state/local/federal agencies, transporters, retailers, and manufacturers.

Data collected and transmitted may include a wide variety of electronics recycling collection elements. Key attributes that are necessary for accurate measurement and analysis of electronics recycling activities include the weight or number of units of electronics collected or recycled. Additional factors such as product brands, product types, program financing costs, regulatory or legislative context, event promotional costs, transportation costs, etc. complicate the management of these data and analysis of electronics recycling collection activities.

These data are currently being supplied by numerous sources involved in thousands of different collection activities; whether they be private programs sponsored by retailers or manufacturers, or government sponsored programs such as those highlighted in EPA's Plug-in to ECycling program[5]. The information flows are very fragmented, making if difficult to get high-quality information to develop or administer electronics recycling systems.

When looking at the electronics recycling industry as a whole it is very easy to see where deriving information from raw data can be a complex and time consuming problem. There are a number of groups and organizations collecting data but the lack of universal data standards industry-wide makes analysis extremely difficult and time consuming. However, once normalized and aggregated these data can provide a wealth of knowledge and insight into collection, recycling, and take-back projects and programs. With this in mind the need for a more comprehensive blueprint for handling data collection, data analysis, data sharing, and information exchange has led the NCER to develop an Information Architecture to provide a cohesive vision of the collection of data, management of data, and sharing of data to improve the overall measurement and analysis of industry specific information.

[4] Jerry Powell, Presentation at E-Scrap 2004, Minneapolis, MN, October 20, 2004

[5] EPA Plug-in to eCycling - http://www.epa.gov/epaoswer/osw/conserve/plugin/index.htm

IV. NCER Information Architecture Overview

Information Architecture is a term that can be used to define a number of activities relating to information technology. The NCER defines Information Architecture as a logical organization of information relating to the following areas:

- Data Collection and Management
- Information Exchange
- Industry Information Standards

The information architecture provides the ability for an organization to:

- Enable strategic information to be derived from operational data
- Improve productivity through better data organization
- Promote data sharing
- Reduce costs by eliminating data redundancies
- Reduce time spent on future data collection projects
- Provide a data standardization mechanism to allow for cross-project analysis

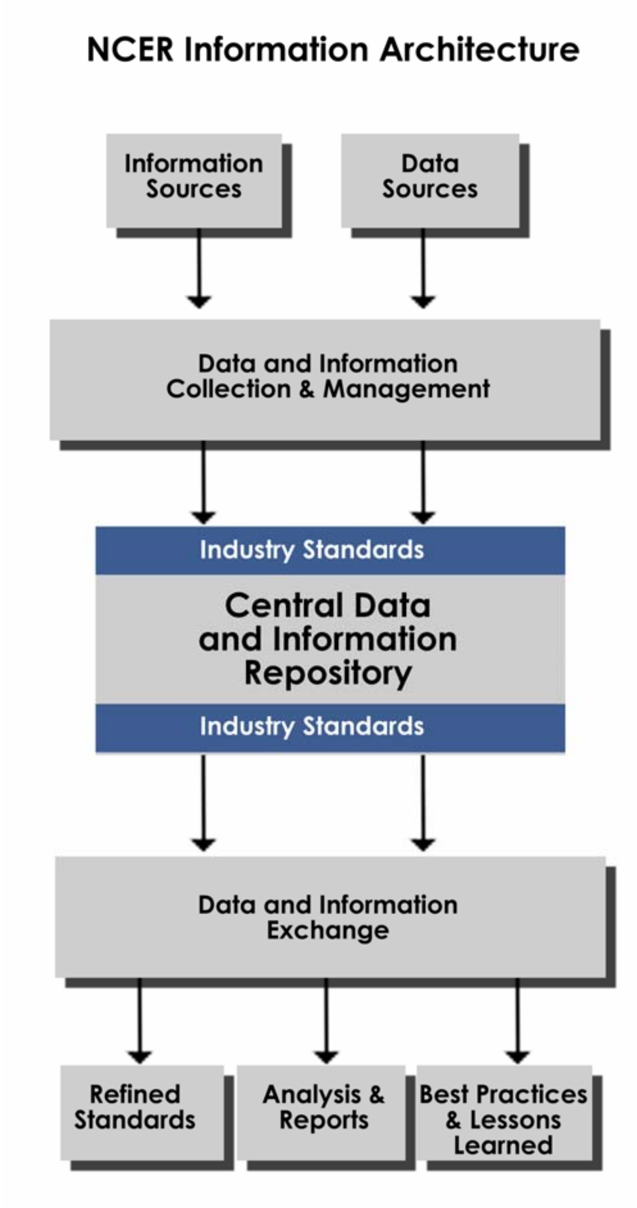

Figure 1.0 NCER Information Architecture

Operating without an Information Architecture limits an organization's ability to effectively evaluate disparate data across industry segments. This inefficiency often results in increased costs and inadequate analysis of the data. A recent survey of nearly 300 companies conducted by the Society of Information Management showed that Information Architecture was one of the top 10 management concerns.[6] Primarily this concern is derived from the costs associated with not only collecting data but also searching and retrieving data. A 2004 survey conducted by IT consulting company Delphi Group shows that 68% of users say finding information is difficult and time consuming.[7]

[6] "*Trendlines – Top 10 Information Management Concerns*", CIO Magazine 2/1/2005 (http://www.cio.com)

[7] J. Surmacz, "*Searching for Answers*", CIO Magazine, 10/15/2004.

The survey also showed that over 30% of respondents reported spending more than 8 hours per week searching for information and another 40% reported spending over 7 hours. [8] There are a number of inferences that can be derived from these studies but the most compelling is the need for a more robust information architecture to make collecting, managing, analyzing, and sharing information more efficient.

V. Information Architecture – Data Collection & Management

The first component of the NCER Information Architecture is based around the area of data collection and management. This is one of the primary tasks associated with any organization that collects and analyzes data. In order to work within the fragmented electronics recycling industry the use of web-based data collection tools have become essential. A recent pilot program in EPA Region III utilized the ability to collect pilot program results via a web-based system.[9] A similar nationally-based EPA program entitled "Plug-in to eCycling" is also utilizing the web-based approach for collecting data. Given the ease of use and reduced costs associated with web-based data collection, the focus of the NCER information architecture is based around the use of online databases and data collection systems. This paper will outline 4 key data areas that the NCER will potentially work on to illustrate the need for a more cohesive approach for collecting and sharing information.

- **Orphan identification initiative.** This would involve compilation of results from existing brand return share studies like the ones ongoing in Florida[10] and Hennepin County, Minnesota[11] to create an estimate of orphan share by product category. This would also require development of orphan definition(s) and a methodology for applying that definition to specific brands associated with returned electronic products.
- **Multi-State TPO development.** The information needs for this task cover a range of data types. For example, a first step is to define the critical functions of an MSTPO and estimate the cost of performing those functions (e.g., contracting, accounts collection, participant recruitment, auditing, education, etc.). Scope and cost estimates for the MSTPO will also derive from data produced by similar systems in the US and abroad (Hennepin County/Delaware data for volumes collected, European data of volumes/cost per lb., etc.).
- **National baseline of electronics recycling data.** This baseline would be established by gathering data from all parties who collected/recycled products and analyze data working with other stakeholders to verify accuracy of assumptions (such as quantity recycled, recycling processes employed, % of orphans, etc.). These data collection and analysis activities will cut across different public and private sector collection/recycling programs and provide the base data for the transition process by providing answers to questions such as "how much volume is out there to be collected?" "how much is this really costing?" and "how much variation is there across regions?" as well as for monitoring progress towards achievement of any goals set by the NCER.
- **National recycling/market development grant program**. This activity will require current and accurate information on technologies and markets, including firms active in those areas. It would also require economic analysis of the grants that are likely to have the most benefit in terms of market enhancement and/or technological advancement. In this way, the data obtained for other project areas such as the national baseline will be key to grant program prioritization and decision making.

VI. Information Architecture – Information Exchange

The second component of the NCER Information Architecture is the area of Information Exchange. One of the primary goals of any information architecture approach is to facilitate the exchange of information between the broadest set of suppliers, recyclers and buyers and then to subsequently integrate the use of such information into critical path business processes within the organization. In order to develop a cost-effective medium for sharing information within the electronics recycling industry, the NCER is maximizing the capabilities of the Internet. This information sharing and collaboration component integrates a number of technologies including industry web portals, web-based information reporting tools, dynamic web sites, and XML-based Web Services[12]. Leveraging off of the information infrastructure developed by the MARCEE project, the NCER has adopted a web-centric approach to information exchange. The primary interface is through the

[8] "*Delphi Research Asks: Does Search Contribute to Productivity*", 5/5/2004 (http://www.delphiweb.com)

[9] http://www.electronicsrecycling.org/ecycling/EPALogin/index.aspx

[10] Florida Electronic Product Brand Distribution Project, http://www.dep.state.fl.us/waste/categories/electronics/pages/FloridaElectronicProductBrandDistributionProject.htm

[11] Consumer Electronics Brand Tally, January 2005, http://www.hennepin.us/vgn/portal/internet/hcdetailmaster/0,2300,1273_83222_121543214,00.html

[12] Microsoft MSDN Web Services Center http://msdn.microsoft.com/webservices/

Electronics Recycling Industry web portal located at http://www.electronicsrecycling.org.[13]

The Electronics Recycling portal was designed to promote this coordination among various industry stakeholders including public agencies and organizations around the world involved in electronics recycling.
By utilizing web-enabled information technology as a means of data facilitation and information exchange, the NCER can now provide a dynamic and open industry architecture and framework. This comprehensive information network will provide the infrastructure for the exchange of information that represents the current knowledgebase of the industry.

This information portal has garnered national attention in newspapers and trade magazines and at present time over 75 individual sites link back to the electronics recycling web portal. The primary objective is to make available to potential industry participants key industry information through technology tools that are simple to use, interactive, and cost-effective to develop and maintain.

VII. Information Architecture – Industry Information Standards

The third component of the NCER Information Architecture revolves around the increased need for common data formats and information standards. To address this need, the MARCEE project in cooperation with many public and private sector entities interested in electronics recycling, has developed a set of data standards for electronics recycling collection[14]. As part of this data standards project, a centralized data repository for electronics recycling related information was created.[15] This data repository is an open, collaborative public/private data sharing project built around the creation of several eXtensible Markup Language (XML) standards to aid in the sharing of data and results from electronics recycling efforts. This project has laid the groundwork for creating a national baseline of electronics recycling data.

Other industry standards work is being done by the International Electronics Manufacturing Initiative (iNEMI)[16] which addresses the Restriction on Hazardous Substances (RoHS) directive[17]. The directive has been called the largest data collection challenge ever to face the electronics industry. In an effort to learn from relevant industry data standards achievements, the MARCEE project was represented at the last iNEMI data exchange workshop which provided some insight into the data needs and/or requirements of the electronics manufacturers and recyclers in the United States and internationally. The awareness of the development and use of data exchange standards by this and other groups is critical for the NCER because these standards will be part of the backbone of the NCER Information Architecture.

VIII. Conclusion

In order to support several activities surrounding information exchange, data collection, and industry collaboration the National Center for Electronics Recycling has created an Information Architecture. This architecture will be the framework by which future information activities will be built upon. This paper has provided a high level view of the three primary components of the NCER Information Architecture and how it will be used to support industry-specific interest areas. By building upon infrastructure already being developed by the MARCEE project and collaboration with industry projects such as NEPSI, EPA's Plug-In to E-Cycling and others, the NCER Information Architecture has already started to mature. The Information Architecture will continue to evolve and develop over the coming years and will provide the necessary flexibility to support data initiatives that may not be in existence today. The initial framework is in place and through the help of the NCER and various industry stakeholders will provide the much needed stability to the area of information sharing and collaboration.

IX. Acknowledgments

The authors greatly acknowledge the support provided by the Department of Energy – National Energy Technology Laboratory (NETL), Environmental Protection Agency – Office of Solid Waste, West Virginia University, Clare Lindsey US EPA, Claudette Reed US EPA, Kathy Osdoba US EPA, Verena Radulovic US EPA, and Polymer Alliance Zone of West Virginia (PAZ).

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[13] MARCEE Project Industry Web Portal http://www.electronicsrecycling.org

[14] Electronics Recycling Industry Data Standards - http://www.electronicsrecycling.org/Pages/DataStandards.aspx

[15] Centralized Data Repository - http://www.electronicsrecycling.org/cdr/

[16] International Electronics Manufacturing Initiative - http://www.nemi.org/cms/

[17] RoHS Directive – European Parliament -http://europa.eu.int/eur-lex/pri/en/oj/dat/2003/l_037/l_03720030213en00190023.pdf

Appendix R: Task 3.6 for Polymer Alliance Zone

CENTRALIZED ELECTRONICS RECYCLING DATA STANDARDS

DATA ELEMENTS AND DEFINITIONS

During the past decade, dozens of public and private organizations have created programs and pilot projects to collect and recycle end-of-life (EOL) consumer electronics.

Although these programs and pilots have yielded good data and provided insight into the volumes, long-term costs and challenges associated with collecting and recycling EOL electronics, analyzing these results across independent electronics recycling efforts has proven difficult.

As a first step towards solving this problem, through the MARCEE (Mid-Atlantic Recycling Center for End-of-Life Electronics) Project, EPA's Plug-In to eCycling in cooperation with the Plug-In Partners and the Polymer Alliance Zone of West Virginia (PAZ) have compiled a set of standard data elements to be used during the Plug-In pilot activities planned for 2004. These data standards have been incorporated in the National Electronics Recycling Data Collection forms. These forms may be used to capture data about your program or pilot for eventual inclusion in the National Electronics Recycling Data Repository or for your own data tracking purposes.

Comments or Questions?

Email: xml@GreenOnline.com

Sign up at http://www.ElectronicsRecycling.com/DataStandards and you will be notified when the web-based data collection forms are available for use.

Polymer Alliance Zone of West Virginia

marcee
MID ATLANTIC RECYCLING CENTER FOR END OF LIFE ELECTRONICS

Provided by: Green Online DATA SERVICES

U.S. Environmental Protection Agency

Post-Consumer Electronics Recycling Data Elements and Definitions

April 13, 2004

The tables below provide a list of data elements and definitions commonly used in the collection phase of post-consumer electronics recycling. These elements are intended to provide a common baseline of data across programs and pilots involved in electronics recycling across geographic regions, program sponsors and pilot types.

The data elements and definitions below were developed during March-April, 2004 through a series of conference calls, emails and discussion forum postings involving representatives of more than 45 public, private and non-profit organizations located around the United States. This effort was led by the Polymer Alliance Zone of West Virginia's MARCEE project in cooperation with US EPA's Plug-In to eCycling. Additional background on this effort is available at www.GreenOnline.com (see the link to "Recycling Data Standards"). Feedback on these elements and definitions is welcome by sending an email to XML@GreenOnline.com.

Some elements are presented as "core" and others as "non-standard." Core elements are those that are more appropriate to standardization – usually they are quantified and are articulated in specific units such as dollars or pounds. Non-standard data elements are those that are more difficult to standardize because either their definition is unclear, or because the size or format for data reported might vary considerably from respondent to respondent, or from program to program.

It should be noted that this document focuses on the data elements and their definitions. The specific elements used on any form at a collection event to gather data or in a database structure being developed to create a centralized data repository is still to be designed. Also, not every data element would be asked of every audience -- some data elements would only be included on a data entry form for recyclers, other data elements would only be included on a sponsor form, while a few data elements would be asked only of transporters. **This document is not intended to suggest that any core data element should be a required element for any data collection activity, public or private.**

Electronics Recycling Program/Pilot Sponsor Information

Data Element Name	Data Element Definition	Core/Non-standard
Program Sponsor Name	Name of program or pilot sponsor – the name of a government unit, coalition, company, non-profit, or other institution managing the program or pilot	Core
Sponsor Organization Type	Sponsor's organization type. Valid values include Retailer, Manufacturer, Local/County Government, State Government, Federal Government, Recycler, Coalition, Non-Profit or School	Core
Sponsor POC First Name	First name of program point of contact	Core
Sponsor POC Last Name	Last name of program point of contact	Core
Sponsor POC Email	Email address for the program point of contact	Core
Mailing Address	The exact address where a mail piece is intended to be delivered, including urban-style street address, rural route, and PO Box.	Core
Mailing Address City Name	The name of the city, town, or village where the mail is delivered.	Core
Mailing Address State Code	The alphabetic code that represents the name of a principal administrative subdivision of the United States.	Core
Mailing Address Zip Code	The combination of the five-digit Zone Improvement Plan (ZIP) code and the four-digit extension code (if available) that represents the geographic segment that is a subunit of the ZIP code, assigned by the U.S. Postal Service to a geographic location to facilitate mail delivery; or the postal zone specific to the country, other than the U.S., where the mail is delivered.	Core
Telephone Number	The number that identifies a particular telephone connection.	Core
Telephone Extension Number	The number assigned within an organization to an individual telephone that extends the external telephone number.	Core
Partner Organization Name	Name of company, organization or government agency that is not the sponsor but contributes financially or in-kind to the program/pilot.	Core
Partner Organization Type	Partner organization type. Valid values include Retailer, Manufacturer, Local/County Government, State Government, Federal Government, Recycler, Coalition, Non-Profit or School	Core

Partner Contribution Type	Type of contribution partner has given. Valid values include Financial/Monetary and In-kind. In-kind contributions include advertising, equipment, labor, space, transportation and other. Multiple values are allowed.	Core
Partner Contribution Amount	Total dollar value of partner's contribution.	Non-standard
Partner POC First Name	First name of Partner Organization point of contact.	Core
Partner POC Last Name	Last name of Partner Organization point of contact.	Core
Partner POC Email	Email address of Partner Organization point of contact.	Core
Partner Mailing Address	The exact address where a mail piece is intended to be delivered, including urban-style street address, rural route, and PO Box.	Core
Partner Mailing Address City Name	The name of the city, town, or village where the mail is delivered.	Core
Partner Mailing Address State Code	The alphabetic code that represents the name of a principal administrative subdivision of the United States, Canada, or Mexico.	Core
Partner Mailing Address Zip Code	The combination of the five-digit Zone Improvement Plan (ZIP) code and the four-digit extension code (if available) that represents the geographic segment that is a subunit of the ZIP code, assigned by the U.S. Postal Service to a geographic location to facilitate mail delivery; or the postal zone specific to the country, other than the U.S., where the mail is delivered.	Core
Partner Mailing Address Country Code	The alphabetic code that represents the name of a country where mail is delivered to an individual or organization.	Core
Partner Telephone Number	The number that identifies a particular telephone connection.	Core
Partner Telephone Extension Number	The number assigned within an organization to an individual telephone that extends the external telephone number.	Core

Electronics Recycling Program/Pilot Implementation Information

Data Element Name	Data Element Definition	Core/Non-standard
Program Reporting Period Start Date	Calendar date for starting of a program/pilot reporting period.	Core
Program Reporting Period End Date	Calendar date for ending of a program/pilot reporting period.	Core
Financing	How is the program financed: grants, government funds, manufacturer, retailer, point of purchase, or end-of-life fee. Allow multiple selections.	Core
Promotional Technique	Technique used to promote a recycling program/pilot. Valid values include flier, brochure, TV, radio, movie theater, newspaper, internet, government newsletter, recycler bill, other print, and other. Allow multiple selections.	Core
Total Promotional Cost	The cost of promoting a program/pilot.	Core
Program Set Up Cost	One-time cost that applies to ongoing programs/pilots and one-time events.	Core
Other Recurring Program Cost Type	Type of recurring program/pilot costs for ongoing programs that are not specified anywhere else.	Non standard
Other Recurring Program Cost	Dollar value of total other recurring program/pilot cost.	Core
Regulatory or Legislative Context	Regulatory or legislative context in which the pilot/prograrm is being implemented. Valid values include "Disposal Ban in Place", "Advance Recycling Fee Mandated", "Mandated Producer Responsibility".	Core
Unique Program/Pilot Features	Description of unique attributes of a program/pilot which sets it apart from others.	Non Standard

Collection Location Information

Data Element Name	Data Element Definition	Core/Non-standard
Collection Location POC First Name	Collection Location point of contact's first name.	Core
Collection Location POC Last Name	Collection Location point of contact's last name.	Core

Collection Location Email	Collection Location point of contact’s email address.	Core
Mailing Address	The exact address where a mail piece is intended to be delivered, including urban-style street address, rural route, and PO Box.	Core
Mailing Address City Name	The name of the city, town, or village where the mail is delivered.	Core
Mailing Address State Code	The alphabetic code that represents the name of a principal administrative subdivision of the United States, Canada, or Mexico.	Core
Mailing Address Country Code	The alphabetic code that represents the name of a country where mail is delivered to an individual or organization.	Core
Mailing Address Zip Code	The combination of the five-digit Zone Improvement Plan (ZIP) code and the four-digit extension code (if available) that represents the geographic segment that is a subunit of the ZIP code, assigned by the U.S. Postal Service to a geographic location to facilitate mail delivery; or the postal zone specific to the country, other than the U.S., where the mail is delivered.	Core
Collection Location Name	Name of the drop off location. For curbside note geographic area - curbside (e.g., Hennepin County – curbside)	Core
Collection Location Street Address	Street address where the collection takes place.	Core
Collection Location City	City in which the collection is taking place	Core
Collection Location State	State in which the collection is taking place.	Core
Collection Location Zip Code	Zip Code for the collection location.	Core
Collection Location GIS Information	The geographic position (latitude/longitude) of the collection location.	Non-standard
Consolidation Point	A yes or no indicating whether this collection location is a consolidation point.	Core
Consolidation Point GIS Information	The geographic position (latitude/longitude) of the consolidation point.	Non-standard
Frequency	The frequency of the collection activity (e.g., ongoing or single event)	Core
Start Date	The calendar date for which the collection activity starts.	Core
End Date	The calendar date for which the collection activity ends.	Core
Days of	Days of the week operated. Valid values include Sunday,	Non-

Operation	Monday, Tuesday, Wednesday, Thursday, Friday, and Saturday.	standard
Hours of Operation	Hours of operation.	Non-standard
Number of Participants Units	The name describing the logical grouping of participants such as vehicles, individuals, households, businesses, government entities or other for which data will be collected.	Core
Total Number of Participants	The number of participants between the start and end date for a collection program or activity.	Core
Backhauling	A yes or no indicating whether backhauling (using empty delivery truck to take recyclable electronics to the consolidation point and/or Collection Location) is used from this collection location.	Core
Materials Accepted	Materials deemed acceptable at this collection location. (Valid values derived from the products collected list)	Core
Materials Specifically Excluded	Specific materials not acceptable at a collection location.	Non-standard
Access to Service	Description of who is invited to take advantage of this service (e.g. residents of X jurisdiction). No limit could be a choice.	Core
Brand Sorting	A yes or no: is brand sorting taking place at this collection location?	Core
Quantities by brand by Unit or by Weight	Quantities of electronic brands by unit or by weight	Non-standard
Staffing Type	Type of staff working in preparation for and/or during the program activity. Valid values: Paid, volunteer, work release, and community service.	Core
Staffing Breakdown	The number of each type of Staffing.	Non-standard
Political Jurisdiction	Political Jurisdiction served by this program/activity (Municipality, County/Parish or State).	Non-standard

Recycler Information

Data Element Name	Data Element Definition	Core/Non-standard
Recycler Organization Name	Recycling company name.	Core
Recycler POC First Name	Recycler point of contact’s first name.	Core

Recycler POC Last Name	Recycler point of contact's last name.	Core
Recycler Email	Recycler point of contact's email address.	Core
Mailing Address	The exact address where a mail piece is intended to be delivered, including urban-style street address, rural route, and PO Box.	Core
Mailing Address City Name	The name of the city, town, or village where the mail is delivered.	Core
Mailing Address State Code	The alphabetic code that represents the name of a principal administrative subdivision of the United States, Canada, or Mexico.	Core
Mailing Address Country Code	The alphabetic code that represents the name of a country where mail is delivered to an individual or organization.	Core
Mailing Address Zip Code	The combination of the five-digit Zone Improvement Plan (ZIP) code and the four-digit extension code (if available) that represents the geographic segment that is a subunit of the ZIP code, assigned by the U.S. Postal Service to a geographic location to facilitate mail delivery; or the postal zone specific to the country, other than the U.S., where the mail is delivered.	Core
GIS Information	The geographic position (latitude/longitude) of the location in question.	Non-standard
Telephone Number	The number that identifies a particular telephone connection.	Core
Telephone Extension Number	The number assigned within an organization to an individual telephone that extends the external telephone number.	Core
Facility City Where Material Will be Processed	City where material will be processed if different than mailing address	Core
Facility State Where Material Will be Processed	State where material will be processed if different from mailing address	Core
Total Units Reused	Total units of products reused as original product use intended	Core
Total Pounds Recycled	Pounds of product collected destined for recycling.	Core
Total Pounds Disposed	Pounds of product collected destined for disposal.	Core
Total Pounds Processed for Waste-to-Energy	Pounds of product collected destined for waste to energy.	Core

Brokering	A yes or no indicating that some or all collected material is being brokered (i.e. sent to a third party without any processing).	Core
Recycling Processes Employed	Process employed by the recycler. Valid values include manual demanufacturing, automated shredding with material separation, automated shredding without material separation. Allow multiple selections.	Core

Recycler Cost Information

Data Element Name	Data Element Definition	Core/Non-standard
Recycling Contractor Fee per Pound of Material	Recycler's fee per pound of material. This fee applies to all product types collected.	Core
Recycling Contractor Fee Per Pound TVs	The per pound recycler fee paid by the Sponsor or Partner to recycle collected TVs.	Core
Recycling Contractor Fee Per Unit TVs	The per unit recycler fee paid by the Sponsor or Partner to recycle collected TVs.	Core
Recycling Contractor Fee Per Pound Computer Monitors	The per pound recycler fee paid by the Sponsor or Partner to recycle collected computer monitors.	Core
Recycling Contractor Fee Per Unit Computer Monitors	The per unit recycler fee paid by the Sponsor or Partner to recycle collected computer monitors.	Core
Recycling Contractor Fee Per Pound Computers	The per pound recycler fee paid by the Sponsor or Partner to recycle collected computers. "Computers" include CPU, PC, desktops, and servers but not laptops or notebooks.	Core
Recycling Contractor Fee Per Unit Computers	The per unit recycler fee paid by the Sponsor or Partner to recycle collected computers. "Computers" include CPU, PC, desktops, and servers but not laptops or notebooks.	Core
Recycling Contractor Fee Per Pound Laptops	The per pound recycler fee paid by the Sponsor or Partner to recycle collected laptops.	Core

Recycling Contractor Fee Per Unit Laptops	The per unit recycler fee paid by the Sponsor or Partner to recycle collected laptops.	Core
Recycling Contractor Fee Per Pound Printers/MFD/ Fax,/Desktop Copiers/Scanners	The per pound recycler fee paid by the Sponsor or Partner to recycle collected printers, MFDs, faxes, desktop copiers/scanners.	Core
Recycling Contractor Fee Per Unit Printers/MFD/ Fax,/Desktop Copiers/Scanners	The per unit recycler fee paid by the Sponsor or Partner to recycle collected printers, MFDs, faxes, desktop copiers and scanners.	Core
Recycling Contractor Fee Per Pound Audio/Visual Equipment	The per pound recycler fee paid by the Sponsor or Partner to recycle collected VCR, DVD, stereo, tape and CD players.	Core
Recycling Contractor Fee Per Unit Audio/Visual Equipment	The per unit recycler fee paid by the Sponsor or Partner to recycle collected VCR, DVD, stereo, tape and CD players.	Core
Recycling Contractor Fee Per Pound Small Peripherals	The per pound recycler fee paid by the Sponsor or Partner to recycle collected mice, keyboards, cables, and speakers.	Core
Recycling Contractor Fee Per Unit Small Peripherals	The per unit recycler fee paid by the Sponsor or Partner to recycle collected mice, keyboards, cables, and speakers.	Core
Recycling Contractor Fee Per Pound Cell Phones, PDAs and Accessories	The per pound recycler fee paid by the Sponsor or Partner to recycle collected cell phones, PDAs and accessories.	Core
Recycling Contractor Fee Per Unit Cell Phones, PDAs and Accessories	The per unit recycler fee paid by the Sponsor or Partner to recycle collected cell phones, PDAs and accessories.	Core

Recycling Contractor Fee Per Pound Batteries	The per pound recycler fee paid by the Sponsor or Partner to recycle collected batteries.	Core
Recycling Contractor Fee Per Unit Batteries	The per unit recycler fee paid by the Sponsor or Partner to recycle collected batteries.	Core
Recycling Contractor Fee Per Pound Toner Cartridges	The per pound recycler fee paid by the Sponsor or Partner to recycle collected toner cartridges.	Core
Recycling Contractor Fee Per Unit Toner Cartridges	The per unit recycler fee paid by the Sponsor or Partner to recycle collected toner cartridges.	Core
Recycling Contractor Fee Per Pound Ink Jet Cartridges	The per pound recycler fee paid by the Sponsor or Partner to recycle collected ink jet cartridges.	Core
Recycling Contractor Fee Per Unit Ink Jet Cartridges	The per unit recycler fee paid by the Sponsor or Partner to recycle collected ink jet cartridges.	Core
Recycling Contractor Cost Include Shipping?	A yes or no indication of whether the recycler's stated cost includes shipping or not.	Core
Additional Fees	Additional fees to the recycler including gaylord boxes, battery removal, shrink wrap, toner cartridges, on-site labor, reporting, information destruction/management and trailer rental.	Non-standard

Bulk Transporter Information

Data Element Name	Data Element Definition	Core/Non-standard
Transporter Organization Name	Transporter company name.	Core
Transporter POC First Name	First name of the transporter point of contact.	Core
Transporter POC Last Name	Last name of the transporter point of contact.	Core
Transporter POC Email	Email address for the transporter point of contact.	Core

Mailing Address	The exact address where a mail piece is intended to be delivered, including urban-style street address, rural route, and PO Box.	Core
Mailing Address City Name	The name of the city, town, or village where the mail is delivered.	Core
Mailing Address State Code	The alphabetic code that represents the name of a principal administrative subdivision of the United States, Canada, or Mexico.	Core
Mailing Address Zip Code	The combination of the five-digit Zone Improvement Plan (ZIP) code and the four-digit extension code (if available) that represents the geographic segment that is a subunit of the ZIP code, assigned by the U.S. Postal Service to a geographic location to facilitate mail delivery; or the postal zone specific to the country, other than the U.S., where the mail is delivered.	Core
Mailing Address Country Code	The alphabetic code that represents the name of a country where mail is delivered to an individual or organization.	Core
Telephone Number	The number that identifies a particular telephone connection.	Core
Telephone Extension Number	The number assigned within an organization to an individual telephone that extends the external telephone number.	Core

Bulk Transport Cost Information

Data Element Name	Data Element Definition	Core/Non-standard
Total Shipping Cost	Total cost in dollars to ship all material from a collection location.	Core
Number of Trips	Number of trips required to transport all material from a collection location to a recycler.	Core
Average Load Per Trip	Average pounds of material shipped per trip (i.e., per shipment) from a collection location to a recycler.	Core
Number of Miles Shipped	Total number of miles traveled to transport all material from a collection location to a recycler.	Core

Products Collected Information

Data Element Name	Data Element Definition	Core/Non-standard
Total Pounds Collected	Total pounds collected.	Core
Total Units Collected	Total units collected.	Core

TVs Pounds	The total pounds of TVs collected including plasma, console, TV/VCR combination, TV/DVD combination, analog direct view, analog projection, digital and monochrome TVs.	Core
TVs Actual Units	The total number of TVs collected as actually counted.	Core
TVs Calculated Units	The calculated number of TV units collected based on the average weight for this product type.	Core
TVs Average Weight	The average TV weight used to calculate the number of TV units collected.	Core
TVs User Fees	Dollar amount charged to the consumer for each TV dropped off.	Core
Computer Monitors Pounds	The total pounds of computer monitors collected including video displays, CRTs and flat screens of any size.	Core
Computer Monitors Actual Units	The total number of computer monitors collected as actually counted.	Core
Computer Monitors Calculated Units	The calculated number of computer monitor units collected based on the average weight for this product type.	Core
Computer Monitors Average Weight	The average computer monitor weight used to calculate the number of computer monitor units collected.	Core
Computer Monitors User Fees	Dollar amount charged to the consumer for each computer monitor dropped off.	Core
Computers Pounds	The total pounds of computers collected. "Computers" include CPU, PC, desktops, and servers but not laptops or notebooks.	Core
Computers Actual Units	The total number of computers collected as actually counted.	Core
Computers Calculated Units	The calculated number of computer units collected based on the average weight for this product type.	Core
Computers Average Weight	The average computer weight used to calculate the number of computer units collected.	Core
Computers User Fees	Dollar amount charged to the user for each computer dropped off.	Core
Laptops Pounds	The total pounds of portable computing devices such as laptops and notebooks collected.	Core
Laptops Actual Units	The total number of laptops collected as actually counted.	Core
Laptops Calculated Units	The calculated number of laptop units collected based on the average weight for this product type.	Core

Laptops Average Weight	The average laptop weight used to calculate the number of laptop units collected.	Core
Laptops User Fees	Dollar amount charged to the consumer for each laptop dropped off.	Core
Printers/MFD, Fax/Desktop Copiers/Scanners Pounds	The total pounds of printers, faxes, copy machines, scanners and similar multi-function devices (MFD) collected.	Core
Printers/MFD, Fax/Desktop Copiers/Scanners Actual Units	The total number of printers, faxes, copy machines, scanners and similar multi-function devices (MFD) collected as actually counted.	Core
Printers/MFD Fax/Desktop Copiers/Scanners Calculated Units	The calculated number of printers, MFD, fax, desktop copier and scanner units collected based on the average weight for this product type.	Core
Printers/MFD Fax/Desktop Copiers/Scanners Average Weight	The average printer, MFD, fax, desktop copier, and scanner weight used to calculate the number of printer, MFD, fax, desktop copier, and scanner units collected.	Core
Printers/MFDs Fax/Desktop Copiers/Scanners User Fees	Dollar amount charged to the consumer for each printer, fax/copy machines/scanners or MFD dropped off.	Core
Audio/Visual Equipment Pounds	The total pounds of VCR/DVDs, stereo/tape/CD player collected.	Core
Audio/Visual Equipment Actual Units	The total number of VCR/DVDs, stereo/tape/CD player collected as actually counted.	Core
Audio/Visual Equipment Calculated Units	The calculated number of audio/visual units collected based on the average weight for this product type.	Core
Audio/Visual Equipment Average Weight	The average audio/visual weight used to calculate the number of audio/visual units collected.	Core
Audio/Visual Equipment User Fees	Dollar amount charged to the consumer for each VCR or DVD, stereo/tape/CD player dropped off.	Core
Small Peripherals Pounds	The total pounds of small peripherals collected including mice, keyboards, cables, and speakers.	Core

Small Peripherals Actual Units	The total number of small peripherals collected including mice, keyboards, cables, and speakers as actually counted.	Core
Small Peripherals Calculated Units	The calculated number of small peripheral units collected based on the average weight for this product type.	Core
Small Peripherals Average Weight	The average small peripheral weight used to calculate the number of small peripheral units collected.	Core
Small Peripherals User Fees	Dollar amount charged to the consumer for each small peripheral dropped off.	Core
Cell Phones, PDAs and Accessories Pounds	The total pounds of cell phones, PDAs and accessory products collected including land-line phones, cordless phones, pagers, others.	Core
Cell Phones, PDAs and Accessories Actual Units	The total number of cell phones, PDAs and accessories products collected including land-line phones, cordless phones, pagers, others as actually counted.	Core
Cell Phones, PDAs and Accessories Calculated Units	The calculated number of cell phone, PDA, and accessory units collected based on the average weight for this product type.	Core
Cell Phones, PDAs and Accessories Average Weight	The average cell phone, PDA, and accesory weight used to calculate the number of cell phone, PDA and accessory units collected.	Core
Cell Phones, PDAs and Accessories User Fees	Dollar amount charged to the consumer for each cell phone, PDA and accessory dropped off.	Core
Batteries Pounds	The total pounds of batteries collected.	Core
Batteries Actual Units	The total number of batteries collected as actually counted.	Core
Batteries Calculated Units	The calculated number of battery units collected based on the average weight for this product type.	Core
Batteries Average Weight	The average battery weight used to calculate the number of battery units collected.	Core
Batteries User Fees	Dollar amount charged to the consumer for each battery dropped off.	Core
Toner Cartridges Pounds	The total pounds of toner cartridges collected.	Core

Toner Cartridges Actual Units	The total number of toner cartridges collected as actually counted.	Core
Toner Cartridges Calculated Units	The calculated number of toner cartridge units collected based on the average weight for this product type.	Core
Toner Cartridges Average Weight	The average toner cartridge weight used to calculate the number of toner cartridge units collected.	Core
Toner Cartridges User Fees	Dollar amount charged to the consumer for each toner cartridge dropped off.	Core
Ink Jet Cartridges Pounds	The total pounds of ink jet cartridges collected.	Core
Ink Jet Cartridges Actual Units	The total number of ink jet cartridges collected as actually counted.	Core
Ink Jet Cartridges Calculated Units	The calculated number of ink jet cartridge units collected based on the average weight for this product type.	Core
Ink Jet Cartridges Average Weight	The average ink jet weight used to calculate the number of ink jet units collected.	Core
Ink Jet Cartridges User Fees	Dollar amount charged to the consumer for each ink jet cartridge dropped off.	Core
Other Pounds	The total pounds of “other” products collected including land-line phones, cordless phones, pagers, others.	Core
Other Units	The total number of “other” products collected including land-line phones, cordless phones, pagers, others.	Core
Other User Fees	Dollar amount charged to the user for each product not in a predefined category dropped off.	Core

CENTRALIZED ELECTRONICS RECYCLING DATA STANDARDS

INDUSTRY MODEL DATA FORM

During the past decade, dozens of public and private organizations have created programs and pilot projects to collect and recycle end-of-life (EOL) consumer electronics.

Although these programs and pilots have yielded good data and provided insight into the volumes, long-term costs and challenges associated with collecting and recycling EOL electronics, analyzing these results across independent electronics recycling efforts has proven difficult.

As a first step towards solving this problem, through the MARCEE (Mid-Atlantic Recycling Center for End-of-Life Electronics) Project, EPA's Plug-In to eCycling in cooperation with the Plug-In Partners and the Polymer Alliance Zone of West Virginia (PAZ) have compiled a set of standard data elements to be used during the Plug-In pilot activities planned for 2004. These data standards have been incorporated in the National Electronics Recycling Data Collection forms. These forms may be used to capture data about your program or pilot for eventual inclusion in the National Electronics Recycling Data Repository or for your own data tracking purposes.

The following are included in the set of data collection forms:

* Sponsor Form
* Collection Activity Form
* Recycling Data Form
* Transporter Data Form
* Partner Information Form

Comments or Questions?

Email: xml@GreenOnline.com

Sign up at http://www.ElectronicsRecycling.com/DataStandards and you will be notified when the web-based data collection forms are available for use.

Polymer Alliance Zone of West Virginia

marcee
MID ATLANTIC RECYCLING CENTER FOR END OF LIFE ELECTRONICS

Provided by: Green Online DATA SERVICES

U.S. Environmental Protection Agency

Sponsor Form
(Page 1 of 1)

PROGRAM/PILOT NAME:			
COLLECTION LOCATION NAME:			
COLLECTION START DATE (m/d/yyyy):		END DATE:	

Program/Pilot Information

Program/Pilot Sponsor Name:					
City:		State:		Zip:	
Sponsor Organization Type:	☐ Coalition ☐ Non-Profit ☐ State Government ☐ Federal Government ☐ Recycler ☐ Regional Authority	☐ Retailer ☐ Manufacturer ☐ School ☐ Transporter ☐ Local/County Government			

Sponsor Point of Contact

First Name:		Last Name:			
Email:					
Address:					
City:		State:		Zip:	
Country:					
Phone:		Extension:			

Program/Pilot Implementation

Program Start and End Date refer to the starting and ending dates of the overall program/pilot and not any specific collection activity.

Program/Pilot Start Date:	(m/d/yyyy)	
Program/Pilot End Date:	(m/d/yyyy)	
Where does the financing for this program come from (how was it paid for)? (select all that apply):	☐ Drop Off Fee ☐ Government Funds ☐ Grants	☐ Manufacturer ☐ Point of Purchase ☐ Retailer
What are the promotional techniques used to promote this program/pilot? (select all that apply):	☐ Brochures ☐ Fliers ☐ Government Newsletter ☐ Internet ☐ Movie Theater ☐ Newspaper	☐ Other Print ☐ Radio ☐ Recycler Bill ☐ TV ☐ Other (specify)
Total Promotional Cost for this Program/Pilot:		
Program Setup Cost:	(One-time cost that applies to ongoing programs/pilots and on-going events.)	
Other Recurring Program Cost:		
Regulatory or legislative context in which pilot/program is being implemented:	☐ Advance Recycling Fee Mandated ☐ Disposal Ban in Place ☐ Mandated Producer Responsibility ☐ None	
Unique Program/Pilot Features:		

Collection Location Form

(Page 1 of 2)

PROGRAM/PILOT NAME:			
COLLECTION LOCATION NAME:			
COLLECTION START DATE:		**END DATE:**	

Collection Location Point of Contact

First Name:		**Last Name:**			
Email:					
Address:					
City:		**State:**		**Zip:**	
Country:					
Phone + Extension:					

Location Information

Collection Location Name:					
Address:					
City:		**State:**		**Zip:**	

Frequency of Collection:	☐ One-Time Event ☐ Ongoing, Limited Duration ☐ Ongoing, Indefinite Duration
Consolidation Point:	☐ Yes ☐ No
Days and Hours of Operation:	
Was Backhauling used from this collection location?	**(Backhauling is using an empty delivery truck to take recyclable electronics to the consolidation point and/or recycler.)** ☐ Yes ☐ No
Access to Service: **(Who is invited to take advantage of this service?)**	☐ Individuals ☐ Schools ☐ Businesses ☐ Non-profits ☐ County Residents ☐ Open to All
Political Jurisdiction served by this program/activity:	☐ Municipality ☐ County/Parish ☐ State
Materials Accepted (Select all that apply):	☐ Audio/Visual Equipment ☐ Batteries ☐ Cell Phones/PDAs and Accessories ☐ Computer Monitors ☐ Computers ☐ Ink Jet Cartridges ☐ Laptops ☐ Large Copiers ☐ Printers/MFDs/Fax/Desktop Copiers/Scanners ☐ Small Peripherals ☐ Toner Cartridges ☐ TVs ☐ Other
Materials Specifically Excluded:	

Collection Location Form

(Page 2 of 2)

PROGRAM/PILOT NAME:			
COLLECTION LOCATION NAME:			
COLLECTION START DATE:		**END DATE:**	

Collection Location Information

The reporting period start and end dates refer to dates for which the collection data is being reported. If you selected "ongoing" for the frequency of collection, you must specify a start and end date for the data that you are reporting. If you selected "one-time" for frequency of collection, the reporting period start and end date will be the same as the program start and end date.

Reporting Period Start Date:				
Reporting Period End Date:				
Number of Participants:		**Specify Units:**	☐ Vehicles ☐ Gov't Entities ☐ Individuals	☐ Businesses ☐ Other
Is brand sorting taking place at this collection location?	☐ Yes ☐ No			
If so, please indicate quantities by brand (by unit or by pound):				

What is the breakdown of the staffing for this collection activity?	**Staffing Type**	**Number of Staff or FTEs**
	Community Service	
	Paid	
	Volunteer	
	Work Release	

Recycler Form (Page 1 of 2)	
PROGRAM/PILOT NAME:	
COLLECTION LOCATION NAME:	
COLLECTION START DATE:	END DATE:
Recycler Information	
Recycler Name:	
City:	State: Zip:
Recycler Point of Contact	
First Name:	Last Name:
Email:	
Address:	
City:	State: Zip:
Country:	
Phone:	Extension:
Material Handling	
Total Units Reused:	
Total Pounds Recycled:	
Total Pounds Disposed:	
Total Pounds Processed for Waste-to-Energy:	
Brokering:	(Is some or all collected material being sent to a third party without any processing?) ☐ Yes ☐ No
Recycling Processes Employed:	☐ Automated Shredding with Material Separation ☐ Automated Shredding without Material Separation ☐ Manual Demanufacturing
Recycler Fees to the Sponsor	
Fee per Pound (applies to all products):	
Fee per Unit (applies to all products):	
Does Cost Include Shipping:	☐ Yes ☐ No
Additional Fees:	
Additional Fee Types:	☐ Gaylord Boxes ☐ Battery Removal ☐ Shrink Wrap ☐ Toner Cartridges ☐ On-Site Labor ☐ Reporting ☐ Information Destruction Management ☐ Trailer Rental

Recycler Form

(Page 2 of 2)

PROGRAM/PILOT NAME:			
COLLECTION LOCATION NAME:			
COLLECTION START DATE:		END DATE:	

Recycler Fee Per Product

Product	Fee Per Pound	Fee Per Unit
Audio/Visual Equipment		
Batteries		
Cell Phones/PDAs and Accessories		
Computer Monitors		
Computers		
Ink Jet Cartridges		
Laptops		
Large Copiers		
Printers/MFDs/Fax/Desktop Copiers/Scanners		
Small Peripherals		
Toner Cartridges		
TVs		
Other		

Products Collected

Product	Pounds	Actual Units	Average Weight	Calculated Units	User Fees
Audio/Visual Equipment					
Batteries					
Cell Phones/PDAs and Accessories					
Computer Monitors					
Computers					
Ink Jet Cartridges					
Laptops					
Large Copiers					
Printers/MFDs/Fax/Desktop Copiers/Scanners					
Small Peripherals					
Toner Cartridges					
TVs					
Other					
TOTAL:					

Transporter Form

(Page 1 of 1)

PROGRAM/PILOT NAME:			
COLLECTION LOCATION NAME:			
COLLECTION START DATE:		END DATE:	

Transporter Name:					
City:		State:		Zip:	

Transporter Point of Contact

Point of Contact First Name:		Point of Contact Last Name:			
Email:					
Address:					
City:		State:		Zip:	
Country:					
Phone:		Extension:			

Bulk Transport Costs

Total Shipping Cost:	
Number of Trips:	
Average Load Per Trip:	
Number of Miles Shipped:	

Partner Form

(Page 1 of 3)

PROGRAM/PILOT NAME:					
COLLECTION LOCATION NAME:					
COLLECTION START DATE:		**END DATE:**			

Partner Information

Partner Name:					
City:		**State:**		**Zip:**	
Partner Organization Role for this Program:	☐ Coalition ☐ Non-Profit ☐ State Government ☐ Federal Government ☐ Recycler ☐ Regional Authority	☐ Local/County Government ☐ Retailer ☐ Manufacturer ☐ School ☐ Transporter			

Partner Point of Contact

First Name:		**Last Name:**			
Email:					
Address:					
City:		**State:**		**Zip:**	
Country:					
Phone + Extension:					

Partner Contribution

Contribution Type (select all that apply):	☐ Financial/Monetary ☐ In-Kind (specify below): ☐ Advertising ☐ Equipment ☐ Labor ☐ Space ☐ Transportation ☐ Other
Contribution Amount:	

Partner Form
(Page 2 of 3)

PROGRAM/PILOT NAME:					
COLLECTION LOCATION NAME:					
COLLECTION START DATE:		**END DATE:**			

Partner Information

Partner Name:					
City:		**State:**		**Zip:**	
Partner Organization Role for this Program:	☐ Coalition ☐ Non-Profit ☐ State Government ☐ Federal Government ☐ Recycler ☐ Regional Authority	☐ Retailer ☐ Manufacturer ☐ School ☐ Transporter ☐ Local/County Government			

Partner Point of Contact

First Name:		**Last Name:**			
Email:					
Address:					
City:		**State:**		**Zip:**	
Country:					
Phone:		**Extension:**			

Partner Contribution

Contribution Type (select all that apply):	☐ Financial/Monetary
	☐ In-Kind (specify below):
	    ☐ Advertising
	    ☐ Equipment
	    ☐ Labor
	    ☐ Space
	    ☐ Transportation
	    ☐ Other

Contribution Amount:	

Partner Form

(Page 3 of 3)

PROGRAM/PILOT NAME:			
COLLECTION LOCATION NAME:			
COLLECTION START DATE:		**END DATE:**	

Partner Information

Partner Name:					
City:		**State:**		**Zip:**	

Partner Organization Role for this Program:

- ☐ Coalition
- ☐ Non-Profit
- ☐ State Government
- ☐ Federal Government
- ☐ Recycler
- ☐ Regional Authority
- ☐ Retailer
- ☐ Manufacturer
- ☐ School
- ☐ Transporter
- ☐ Local/County Government

Partner Point of Contact

First Name:		**Last Name:**			
Email:					
Address:					
City:		**State:**		**Zip:**	
Country:					
Phone:		**Extension:**			

Partner Contribution

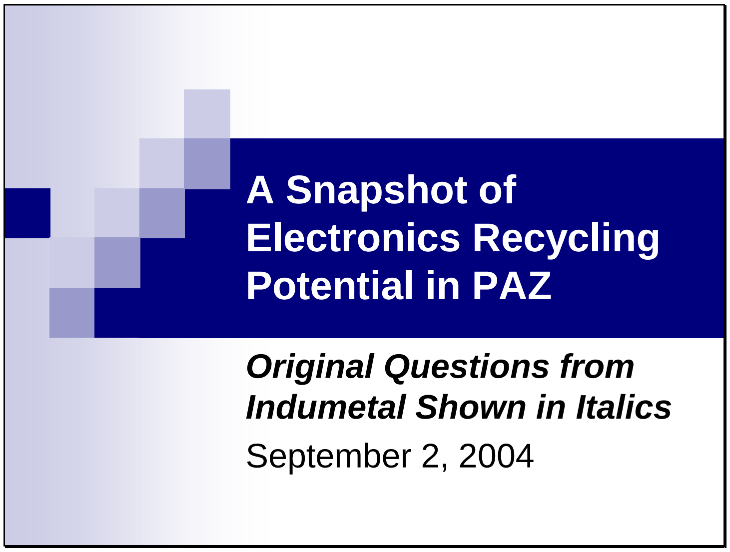
Contribution Type (select all that apply):

- ☐ Financial/Monetary
- ☐ In-Kind (specify below):
  - ☐ Advertising
  - ☐ Equipment
  - ☐ Labor
  - ☐ Space
  - ☐ Transportation
  - ☐ Other

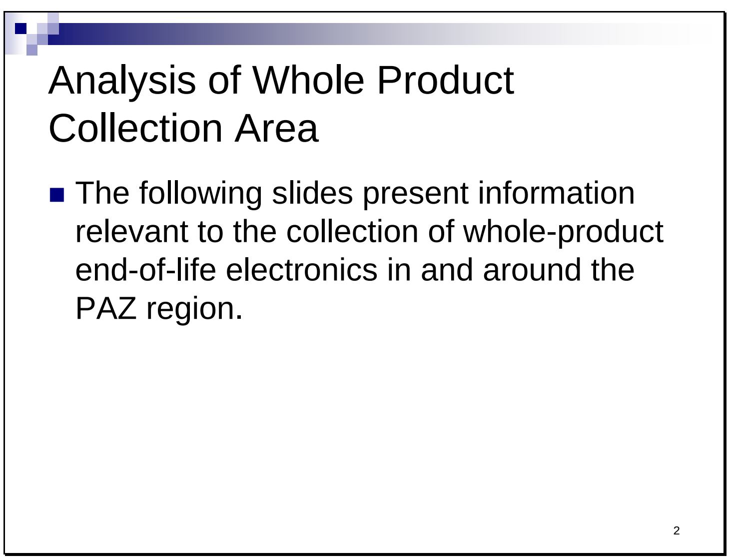
Contribution Amount:

Appendix S: Task 3.7

Slide 1



Slide 2



Slide 3

Background

- The data and analysis below provides information requested by Guillermo O'Shea, CEO of Spanish electronics and metals recycler Indumetal. In preparing answers to these questions, we assumed that the market information of interest is for whole end-of-life electronic products. The markets and relevant data for other businesses (e.g., metals reclamation) would be different from the information provided below.

3

Slide 4

Market Issues: Area of Influence

- The following slides are candidate areas for collecting whole end-of-life electronic products. Imbedded in this slide is also an Excel spreadsheet detailing electronics recycling activities by County in Ohio as provided June 10, 2004 by Jim Ankrom, Data Unit Manager, Ohio Department of Natural Resources.

Ohio Collection Events

4

Slide 5

Market Issues: Population Covered

Two options are presented for purposes of reviewing covered population:

- Option 1: 15 million people within 3 hours drive
- Option 2: 30 million people within 5 hours drive

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Slide 6

Option 1 Population Centers w/in 3 Hours

- Lexington, KY
- Columbus, OH
- Cleveland, OH
- Cincinnati, OH
- Dayton, OH
- Pittsburgh, PA
- Charleston, WV

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Slide 7

Option 1: 3 Hour Drive from Wood County, West Virginia

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Slide 8

3-Hour City/Highway Map

8

Slide 9

Option 2
Population Centers w/in 5 Hours

- Washington, DC
- Indianapolis, IN
- Lexington, KY
- Louisville, KY
- Columbus, OH
- Cleveland, OH
- Cincinnati, OH
- Dayton, OH
- Pittsburgh, PA
- Erie, PA
- Richmond, VA
- Charleston, WV

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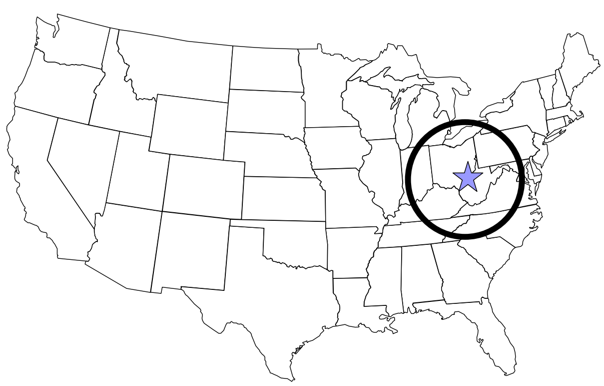
Slide 10



Option 2: 5 Hour Drive from Wood County, West Virginia

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Slide 11

Market Issues: Weight of Electronic Residues Expected Yearly per Inhabitant

- 2005 estimate @ 1 lb./inhabitant (includes business/institutional – consumer-only is perhaps 0.1 lb./inhabitant)
- Estimate is the same per inhabitant for both population coverage options

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Slide 12

Market Issues: Recycling Companies Working in the Area of Influence

Major players include:

- Envirocycle (Pennsylvania) does post-consumer and institutional electronics recycling throughout the mid-Atlantic and beyond
- United Recycling (Chicago) does post-consumer and institutional recycling throughout the mid-west and beyond
- Redemtech (Columbus) does higher-end hard-drive cleaning and refurbishment/resale nationally
- MicroMetallics Corporation (Nashville, TN) does post-consumer and institutional electronics recycling throughout the southern US and beyond
- Dlubak Glass Company (Upper Snadusky, OH) focuses mainly on TV and monitor recycling but reportedly will shred almost anything.
- Federal Prison Industries (Elkton, OH) uses prison labor to dismantle electronics.

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Slide 13

Market Issues: Recycling Companies Working in the Area of Influence (cont)

To obtain more information on existing firms:

- http://www.epa.state.oh.us/opp/recyc/comp-rc.html for a list of 30 reported electronics recyclers in Ohio.
- Lists of other recyclers reportedly operating in the United States can also be found at www.electronicsrecycling.org, www.iaer.org, and www.recycle.net.
- There are more than 400 companies claiming to recycle electronics in the United States.

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Slide 14

Market Issues: Volumes Expected per Year in the Next 10 Years

- Depends on legislative action. Three possible scenarios follow.
- Across all scenarios, volume of glass content expected to decline over time as CRTs are displaced.

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Slide 15

Market Issues: Volumes Expected per Year in the Next 10 Years, Scenario 1

Scenario 1: Slow Growth Scenario/No Legislative Mandates (driven by population growth)

Total Volume of Whole End-of-Life Electronics Collected for Recycling

	3 Hour Radius	*5 Hour Radius*
2005	15 million lbs.	30 million lbs.
2006	15 million lbs.	31 million lbs.
2007	16 million lbs.	32 million lbs.
2008	16 million lbs.	33 million lbs.
2009	17 million lbs.	34 million lbs.
2010	17 million lbs.	35 million lbs.
2011	18 million lbs.	36 million lbs.
2012	18 million lbs.	37 million lbs.
2013	19 million lbs.	38 million lbs.
2014	19 million lbs.	39 million lbs.

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Slide 16

Market Issues: Volumes Expected per Year in the Next 10 Years, Scenario 2

Scenario 2: Moderate Growth Scenario/1-2 State-Level Mandates in Region (population growth plus increased collection from state mandates)

Total Volume of Whole End-of-Life Electronics Collected for Recycling

	3 Hour Radius	*5 Hour Radius*
2005	15 million lbs.	30 million lbs.
2006	15 million lbs.	31 million lbs.
2007	18 million lbs.	35 million lbs.
2008	20 million lbs.	38 million lbs.
2009	22 million lbs.	42 million lbs.
2010	24 million lbs.	45 million lbs.
2011	26 million lbs.	50 million lbs.
2012	28 million lbs.	55 million lbs.
2013	30 million lbs.	60 million lbs.
2014	32 million lbs.	65 million lbs.

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Slide 17

Market Issues: Volumes Expected per Year in the Next 10 Years, Scenario 3

Scenario 3: High Growth Scenario/Federal Mandate Passed in 2006 (population growth plus collection at 2.25 lbs. per inhabitant)

Total Volume of Whole End-of-Life Electronics Collected for Recycling

	3 Hour Radius	*5 Hour Radius*
2005	15 million lbs.	30 million lbs.
2006	15 million lbs.	31 million lbs.
2007	20 million lbs.	40 million lbs.
2008	30 million lbs.	60 million lbs.
2009	35 million lbs.	70 million lbs.
2010	37 million lbs.	75 million lbs.
2011	40 million lbs.	80 million lbs.
2012	45 million lbs.	90 million lbs.
2013	47 million lbs.	95 million lbs.
2014	50 million lbs.	100 million lbs.

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Slide 18

Market Issues: Who Will Pay the Recycling Bill

- Three possible scenarios
  - Scenario 1: Business/Institutional generators of whole electronic scrap, sporadic support from individual localities (status quo)
  - Scenario 2: Same as Scenario 1 except in 1 or 2 States where a legislative mandate requires consumers or manufacturers to foot the recycling bill
  - Scenario 3: Federally mandated fees, either on consumers or on manufacturers

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Slide 19

Plant Issues

- The Polymer Technology Park (PTP) is a 156 acre facility located in Wood County, West Virginia. There is an existing 312,500 sf building on the site currently leased or committed to various uses, including the MARCEE plastics recycling demonstration project. The PTP site plan includes 12 additional building structures of more than 2 million additional sf at the PTP.

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Slide 20

Plant Issues: Dimension of the Plant for Electronic in MT. to be Treated per Year

- Projections for the volume of electronics processed in the PTP result from business decision to be made by PTP tenants based on an evaluation of the volumes of electronics potentially available, realistic market share, capacity of electronics recycling operations, and investment costs for achieving the desired capacity.

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Slide 21

Plant Issues: Cost of Land

- With the support of a state grant, the Polymer Alliance Zone of West Virginia (PAZ) has assumed all land costs of the PTP.

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Slide 22

Plant Issues: Cost of Warehouse

- PAZ will lease warehouse and processing space to electronics recycling tenants at favourable rates.

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Slide 23

Partners and Financing

- PAZ will work with companies interested in locating in the PTP to help find financing. Since its formation in 1996, PAZ has a solid track record of obtaining financing from public and private sources.

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Slide 24

Partners and Financing: Who are the Expected Partners

- Who the expected partners are depends upon the type of electronics recycling business established. For a whole-product electronics recycling demanufacturing, partners might down-stream partners such as a metals processor (e.g., MicroMetallics) or a plastics processor (Doug Ritchie), or one or more OEMs.

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Slide 25

Partners and Financing: Needs of Capital

- Capital needs vary by operational type. Capital needs of a manual demanufacturing operation are minimal; capital costs for more automated recycling operations using shredders are in the millions of dollars depending upon required capacity and shredding technology employed.

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Slide 26

Partners and Financing: Subventions

- Any request for grants or subsidies involving PAZ will be negotiated on a case-by-case basis. Determination of grant amounts shared with any PTP tenant/MARCEE participant will be made based on value provided to the MARCEE project. PAZ will evaluate other grant requests and help facilitate PTP tenants' acquisition of grant funds.

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Slide 27

Economic Figures: Volumes

- See volumes provided under “Market Issues” above. Projections for the volume of electronics processed in the PTP result from business decision to be made by PTP tenants based on an evaluation of the volumes of electronics potentially available, realistic market share, capacity of electronics recycling operations, and investment costs for achieving the desired capacity.

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Slide 28

Economic Figures: Financing

- See “Partners and Financing” answers above

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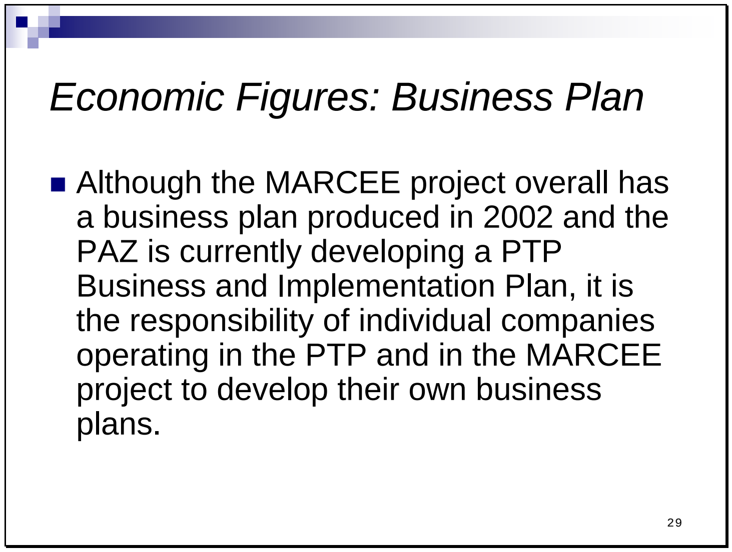
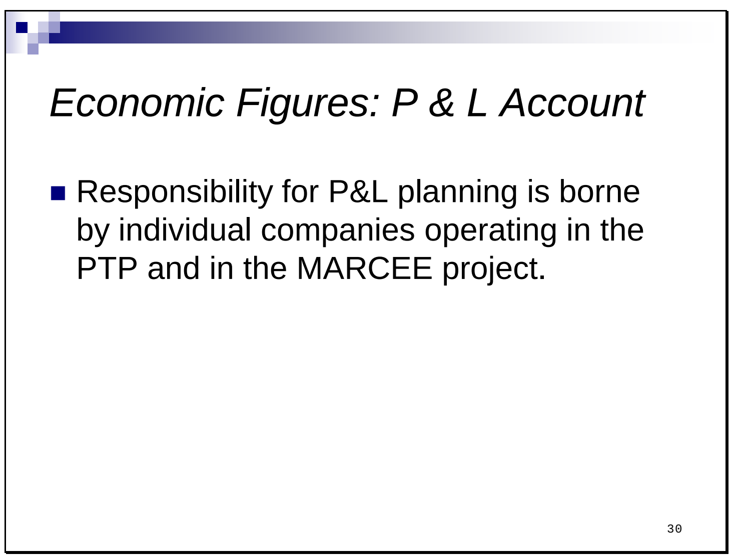
Slide 29



Slide 30



Slide 31

Accelerating Supply, Demand and Financing for Electronics Recycling

- Possibilities on the legislative front
  - Several states are moving forward to finance and implement electronics stewardship programs
  - National legislation is in its infancy, but could result in more funding in the near term for demonstration pilots

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Slide 32

Accelerating (cont)

- Several states are moving forward with electronics stewardship programs
  - California's SB20/SB50 (an advance fee program)
  - Maine's producer responsibility law (no fee)
  - 10+ other states anticipated to enact similar laws during coming 5 years if no movement nationally (Minnesota, Oregon, Washington, Florida, Maryland, etc.)
- Each state initiative should help increase supply, also create other opportunities for cross-state coordination

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Slide 33

Accelerating (cont.)

- Possibilities on the national legislative front
  - Manufacturers are working on model national legislation that will probably take years to enact
  - During the interim there are several activities requiring federal appropriations
    - Prototype of a Third Party Organization
      - Organization structure
      - Seed financing
      - Development of legal/administrative system

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Slide 34

Accelerating (cont)

- Voluntary/PR initiatives
  - HP/Office Depot are taking any single TV <27”, monitor, desktop, laptop, printer through September 6, 2004
    - Will feed HP’s recycling facilities in California and Tennessee
  - Numerous OEM- and retailer-specific pilots, demos
- The MARCEE project includes funding for a National Coordinating Entity to be a conduit for grant and infrastructure development funding
  - Activities might be integrated into other voluntary/legislative initiatives

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Slide 35

Possible Near-Term Role for Indumetal?

- Indumetal might be brought in as part of the demo and the pre-processing fix
  - Perhaps as on the front-end to help clean the metals from the plastics and working with others on the project such as GAIKER
- Unfortunately the market probably is not large enough now to set up a capitally-intensive shredding operation in West Virginia

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Slide 36

Possible Near-Term Role for Indumetal (cont)

- Indumetal might work with MARCEE project participant GAIKER to help tackle plastics pre-processing challenges

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