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Recycling Market Development for Engineering Thermoplastics from Used Electronic Equipment

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Recycling Market Development for Engineering Thermoplastics from Used Electronic Equipment

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The Chelsea Center for Recycling and Economic Development, a part of the University of Massachusetts' Center for Environmentally Appropriate Materials, was created by the Commonwealth of Massachusetts in 1995 to create jobs, support recycling efforts, and help the economy and the environment by increasing the use of recyclables by manufacturers. The mission of the Chelsea Center is to develop an infrastructure for a sustainable materials economy in Massachusetts, where businesses will thrive that rely on locally discarded goods as their feedstock and that minimize pressure on the environment by reducing waste, pollution, dependence on virgin materials, and dependence on disposal facilities. Further information can be obtained by writing the Chelsea Center for Recycling and Economic Development, 180 Second Street, Chelsea, MA 02150.

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1.0 Abstract

Electronics recycling is on the rise in the United States and Massachusetts, which creates a growing waste stream of engineering thermoplastics (ETPs). As Massachusetts increases the supply of plastics through higher electronics recycling rates, a parallel plastics recycling industry is needed.

This project worked with the plastics supply chain to identify the capabilities of Massachusetts industry to process ETPs from used electronics; assessed the supply and identified markets for used electronic ETPs; demonstrated the performance of recycled ETPs derived from the electronics waste stream in injection molding applications; and initiated a series of Stakeholder Dialogues. These dialogues brought together the plastics supply chain to discuss barriers and opportunities in recycling and reuse of engineering thermoplastics. The Gordon Institute at Tufts University partnered with Nypro Inc., an international injection molder with headquarters in Massachusetts, to bring valuable industry know-how and manufacturing resources to the project.

Currently there is a limited capacity in Massachusetts to process ETPs from used electronic equipment and few viable markets for the predominantly mixed plastic stream. Recycled ETPs from used electronic equipment that were separated into single resin streams free of contaminants (such as metal and paper) performed well in a high performance injection molding application. A major barrier to the use of recycled ETPs is the cost-effective sorting of the mixed resin electronics waste stream to achieve a quality feedstream suitable for injection molding applications, combined with limited alternative markets for mixed plastics.

2.0 Background

Massachusetts is planning to ban the disposal of cathode ray tubes, computer monitors and televisions from disposal in the year 2000. To handle this diverted waste stream, the State is working to build an electronics recycling infrastructure to handle both CRT-containing products and other electronic goods. As Massachusetts increases its electronic recycling rates, the generation of engineering thermoplastics will increase proportionately. Engineering thermoplastic resins have a high intrinsic value, when first molded into a computer housing or television cabinet. Despite their intrinsic value, the majority of plastics from electronics demanufacturing operations are destined for incineration with energy recovery.

The major resins found in electrical and electronic equipment are from the styrenics family. The three most prevalent resins are acrylonitrile butadiene styrene (ABS), high impact polystyrene (HIPS) and polycarbonate (PC)/ABS blends. ABS and ABS/PC dominate the computer resins, while HIPS is the most common resin found in TV housings.[1] Table 1 provides a breakdown of resins from different types of equipment.

[1] American Plastics Council, "*Recovery of Plastics from Municipally Collected Electrical and Electronic Goods*," Washington DC: American Plastics Council, March 1999.

Table 1: Distribution of Resins in Electrical and Electronic Equipment

Resin	All Equipment[1]	Computers	Televisions	Stereos
ABS	26%	34%	14%	6%
HIPS	19%	10%	73%	28%
PC/ABS	16%	29%	-	-
PPO	8%	12%	5%	19%
PC	6%	5%	-	12%
PVC	5%	5%	4%	1%
Other	10%	2%	4%	16%
No Identification	10%	3%	-	18%

[1] Sample was predominantly computers (63%), TV housings (14%), vacuum cleaners (7%), stereos (4%), fans (3%).
Source: American Plastics Council, "Recovery of Plastics from Municipally Collected Electrical and Electronic Goods," March 1999.

This new and growing plastics waste stream presents numerous challenges, not unlike those faced by other commodities in their recycling infancies. Currently, technology is not the major obstacle to recycling engineering thermoplastics. Much progress has been made over the last several years in identification, sorting, processing and use of recycled-content resin. Today, the major obstacles appear to be both in supply and demand: in particular, 1) developing a consistent, quality supply of recycled material that meets market specifications; and 2) creating demand for the use of recycled ETP resins.[2]

3.0 Research Scope and Approach

The recycling of engineering thermoplastics encompasses three basic activities: material capture, material processing or conversion, and market development. Table 2 breaks these activities down further into 10 key elements of the ETP recycling process starting with equipment demanufacturing and ending with the use of recyclate in product applications.

This research addressed several of these key elements -- issues critical to the successful recycling of ETPs from used electronic equipment -- including the material supply, the processing capabilities of the Massachusetts recycling industry, potential applications, and material performance in product applications. Since the challenges facing the industry are not isolated to any one sector, this project also convened two Stakeholder Dialogues that brought the supply chain together to identify barriers to recycling ETP resins and begin the process of working towards collaborative solutions.

[2] P. Dillon, "Recycling Infrastructure for Engineering Thermoplastics: A Supply Chain Analysis," in the Proceedings of the *IEEE International Symposium on Electronics and Environment*, Danvers, MA, May 11-13, 1999.

Table 2: Key Elements of the ETP Recycling Process

Elements of ETP Recycling Process	Research Scope
1. **Generation** of plastic waste through demanufacturing and scrap processing	X
2. **Sortation** of resins by color, type and quality	X
3. **Densification** by shredding and/or grinding	X
4. **Purification** for contaminant removal	X
5. **Compound** resins with additives to achieve desired characteristics	
6. **Qualification** to meet material specifications	X
7. **Identify Product Application** matched to material	X
8. **Parts Qualification** to meet processing and functional requirements	X
9. **Specify Recycled Material** on part drawing	
10. **Mold Production Parts** that meet quality & price targets	

Source: Dewey Pitts, IBM, Stakeholder Dialogue, June 22, 1999.

3.1 Assessment of Recycled Resin Supply

An assessment of supply is critical to assure potential end users of the viability and quality of the supply of "raw material" for proposed applications. In this task, the supply of plastics from demanufacturing operations in New England region was estimated, including a breakdown of plastics by resin type. The initial focus was on the five major resins used in the manufacturer of electronic products, and computers, in particular, since they represent a major portion of the plastics stream. These resins include ABS, ABS/PC, PC, HIPS, and polyphenylene oxide (PPO).

The potential supply was calculated using data from published sources. *The Electronic Product Recovery and Recycling Baseline Report* by the National Safety Council provided data on the volume of electronic equipment recycled in New England. This data was combined with data on the material composition of electronic equipment.

The supply of recycled resins was not limited to Massachusetts for several reasons. First, no data was available for Massachusetts. Second, an ETP recycling infrastructure will most likely need to be regional in order to capture the quantities of material needed to achieve economies of scale. A frequently cited barrier to the use of recycled resin in is an inadequate supply of quality recycled resin. While Massachusetts is expected to promote the collection and processing of electronics in the next several years, the supply of clean recycled plastics within Massachusetts will probably be inadequate in the short-term to meet the minimum volume of material necessary to assure an adequate supply. Collection of plastics from electronics recyclers operating in the New England region may be necessary to boost volumes. By tapping into the regional supply of recycled plastics early in the evolution of this feedstock, in the longer-term, Massachusetts can become the leader in this industry, expanding its plastics manufacturing base and creating additional jobs in Massachusetts.

3.2 Capabilities of Massachusetts Supply Chain

The goal of this task was to define the resources and capabilities of Massachusetts' industry for the processing of recycled engineering thermoplastics, and identify gaps in the infrastructure that need to be addressed in order to develop a viable recycling industry. The focus of this task was on the conversion of resin for market applications, including resin sortation, densification, and purification, as outlined in Table 2 (elements 2, 3 & 4).

Interviews were conducted with companies that process and use ETPs to determine their capabilities, limitations, and experience with recycling engineering thermoplastics and use of recycled content in the manufacture of new products. Companies were identified in several ways, i.e., prior knowledge of the industry, referrals from industry contacts, and published sources.[3] Approximately 40 interviews were conducted with electronics recyclers, plastics processors, brokers of recycled-content resins, molders, and potential end users of the recycled resins. Presentations and discussions at the Stakeholder Dialogues further contributed to the supply chain assessment.

3.3 Identify Potential End Uses for Post-Consumer Recycled ETPs

The goal of this task was to generate ideas and examples of successful applications of post-consumer engineering thermoplastics, including both high-tech and low-tech applications. This task was accomplished through networking and interviews with end markets and experts across the US, and presentations and discussions at the Stakeholder Dialogues.

3.4 Collaboration with End Users of Plastic Resins

Molders are a critical link in the supply chain, influencing the selection of polymers to meet product and customer performance specifications, and testing the performance of new materials in product applications. The research team worked with molders of both high tech and low tech products to identify promising applications for single and mixed thermoplastic resins. The initial preference was to explore high-end applications, including applications in electronic products. For such applications, the research team worked with Nypro Inc. of Clinton, Massachusetts, a custom blender and molder, to identify potential end use applications for recycled ETP resins, quality specifications, and obstacles to the use of these resins.

3.4.1 Performance Demonstration

Initial discussions with Nypro led to the company's offer to manufacture and test product using recycled-content resin. The performance demonstration greatly enhanced the research results, providing the research team with the real-life challenge of sourcing recycled-content resin and obtaining material performance data from actual molding trials.

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[3] For example, 1998 Directory of North American Scrap Plastics Processors & Buyers; Chelsea Center for Recycling and Economic Development (CCFRED), "Electronics Vendor Survey", Technical Report #5, August 1998; CCFRED, "Strategic Plan to Promote the Use of Recyclable Materials in Massachusetts," May 1998; CCFRED, "Massachusetts Directory of Recycled Product Manufacturers," April 1997.

In conjunction with Nypro, the research team selected an application suitable for the use of recycled engineering resins, secured permission from the manufacturer to utilize existing molds, and sourced recycled-content resins (see section 3.4.2). The experimental design matrix in Table 3 guided the selection of potential demonstration projects. The goal was to select an application and source material that met as many of the "more desirable" variables as possible.

Table 3: Experimental Design Matrix

Variables	Less Desirable	More Desirable
Regrind Sourcing	Internal	External*
Regrind Origin	Post Industrial	Post Consumer*
	Non-electronic	Electronic*
	Outside Massachusetts*	Massachusetts*
Manufacturing Location -Demonstration Site -Production Site	 Outside Massachusetts Outside Massachusetts	 In Massachusetts* Potential for In Massachusetts*
Customer Involvement	No	Yes*
Test Method	Standard ASTM Test Piece	Production Mold*

** Criteria met by selected application*

The product selected was an injection-molded tray for a consumer product. The product currently uses a resin formulation consisting largely of virgin-grade high-impact polystyrene (HIPS) pellets with 15% post-consumer recyclate. The demonstration utilized 100% post-consumer HIPS originating from an electronics application. While the regrind originated outside of Massachusetts, the recyclate was further processed (e.g., cleaned) and pelletized by Massachusetts' companies.

Nypro molded sample product using the recycled-content resin at the end of a regular production run. The pellets were dried prior to processing. No changes were made to the process in order to document the basic effect of the 100% recycled resin on the part. Approximately 1000 pieces were made using the recycled HIPS. Five mold samples containing 8 pieces each (for a total of 40 product samples) were saved at equal time frames during the run for measurement against the quality control parameters for this product. Product performance measurements included two key dimensional features (length and warpage) and one function evaluation (retention of product in tray).

3.4.2 Sourcing Recycled Resin

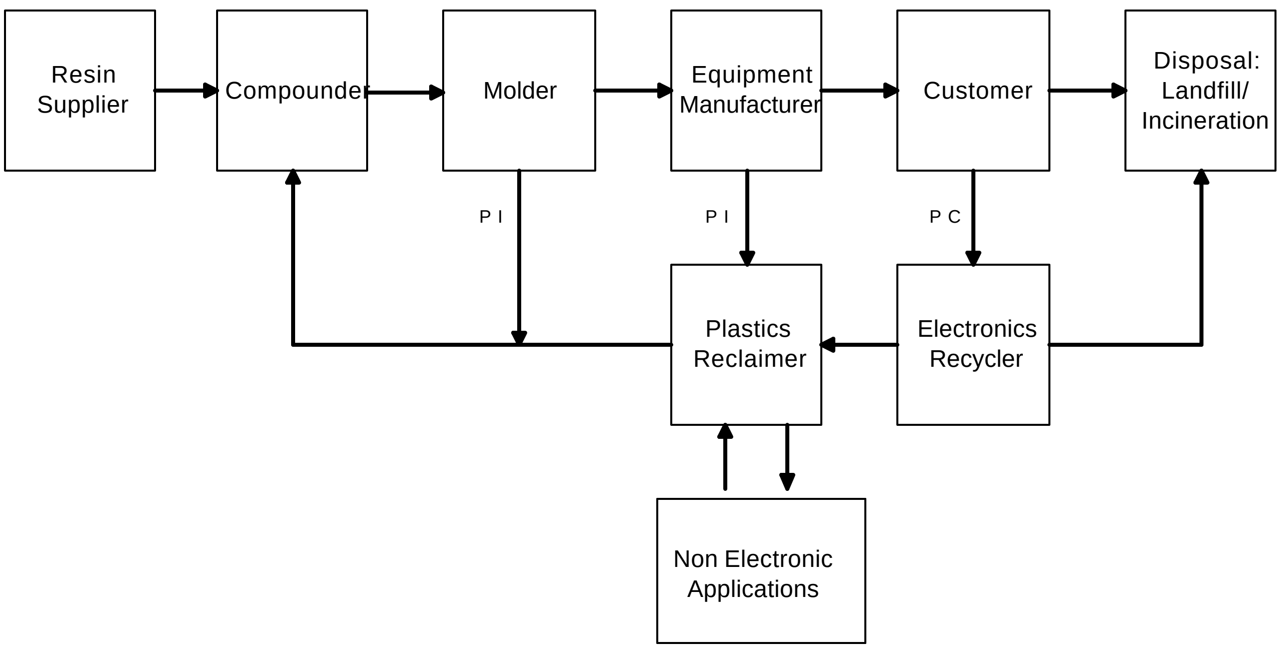
Several potential suppliers of recycled-content HIPS were identified for the demonstration project. The research team worked with them to identify resins that matched the material performance characteristics of the virgin resin. The most critical material performance dimensions for this product were IZOD impact strength (1.7 ft-lb/in) and melt flow index (3.8 gm/10 min.). In addition, the research team wanted to "meet or beat" the price of the currently used resin in order to make the switch to recyclate economically attractive.

The research team also applied "preferred" sourcing criteria in the selection of vendors, as outlined in Table 2, in order to meet the overall project goals. The preferred sourcing criteria were: 1) post-consumer content, 2) resins originating from used electronic equipment, and 3) materials processed in Massachusetts.

3.5 Stakeholder Dialogues

Processing and reuse of electronic ETPs is an emerging industry. Prior research indicated that many of the existing barriers to recycling this waste stream would benefit from an increased understanding of the requirements of the supply chain and collaboration among industry sectors. To this end, the research team convened two one-day Stakeholder Dialogues in the Spring of 1999 that brought together the supply chain for ETP recycling and other experts, including resin suppliers and compounders, molders, original equipment manufacturers, electronics recyclers and plastics processors. Figure 1 depicts the ETP supply chain. See Chelsea Center Technical Report #21 for more information on the Stakeholder Dialogues.

Figure 1: ETP Supply Chain



PI = Post-industrial resin
PC = Post consumer resin

The goal of the Dialogue process was to stimulate cooperation within the supply chain to collect and process the growing volume of discarded plastics from electronics, and utilize these recycled materials in new markets and applications. The specific objectives of the meetings were to:

- generate ideas on applications for recycled thermoplastic resins;
- share experiences, case histories, and performance characteristics of recycled resins;
- foster a better understanding among stakeholders of the perspectives of others in the supply chain;
- develop material specifications for engineering thermoplastics that take into account the capabilities and needs of the supply chain;

- brainstorm possible solutions that address the limitations and opportunities, including technical, policy, market development and networking solutions; and,
- stimulate new partnerships and linkages in the supply chain that live beyond the life of the project.

The Stakeholder Dialogues had parallel, but not duplicative agendas. Each Stakeholder Dialogue was a combination of presentations, designed to showcase different perspectives and capabilities of the supply chain, and facilitated discussions in breakout groups. The agenda for the first meeting on May 10th was broad, covering the entire "reverse-logistics" plastics supply chain -- from electronics demanufacturing to plastics processing and reutilization for both high performance and low-end applications. Multi-stakeholder breakout groups were asked to address:

- **barriers and issues** in recycling engineering thermoplastics throughout the supply chain and recommended actions to overcome these barriers;
- potential **applications and markets** for recycled engineering thermoplastics and recommended actions to enable these markets to utilize recycled resins; and,
- **supply chain protocols** to enhance recycling of engineering thermoplastics.

The June 22nd Dialogue focused on the use of recycled ETPs in new applications, and leveraging the supply chain to "make it happen". The task of the breakout groups was to:

- explore the feasibility, successes and challenges in **using recycled-content resins** in injection-molded applications; and
- develop strategies to increase the use of recycled-content resins by leveraging the supply chain.

4.0 Results

4.1 Potential Supply of Recycled ETPs in New England

The supply of recycled ETPs was calculated based on data on electronic equipment recovery from the *Electronic Product Recovery and Recycling Baseline Report*.[4] In this report, the National Safety Council estimates that a total volume of 275 million pounds of electronics was recycled in the US in 1998. Less than 10 percent of the total equipment volume, or approximately 26 million pounds, was processed in New England.

On average, plastic accounts for approximately 19 percent (by weight) of electrical and electronic equipment.[5] The volume of plastics in recovered equipment in 1998, therefore, is estimated at 52 million pounds and 5 million pounds in the US and New England, respectively. Table 4 estimates the volume recovered by resin composition for the dominant plastics in the electronics waste stream.

It is important to recognize that these figures are the estimated volume of plastics in the equipment recovered from electronics demanufacturing operations, and reveal nothing about its physical form (e.g., plastics in printed wire board or housings), or whether it is feasible to recover the plastic. For example, in 1998, it was reported that US electronics recyclers recovered 14.4 million pounds of plastics from

[4] National Safety Council. 1999. *Electronic Product Recovery and Recycling Baseline Report*. Washington, D.C.: National Safety Council.

[5] Association of Plastics Manufacturers in Europe (APME), *Plastics Consumption and Recovery in Western Europe 1995*, 1998.

the total 275 million pounds of equipment recovered.[6] This is 5.2 percent (by weight) of the electronics equipment processed in 1998. This figure is consistent with the amount of plastics (5.0 percent) recovered from IBM's material recycling facilities,[7] and is perhaps a more conservative estimate of recoverable plastic from today's electronics stream. The percentage of recoverable plastics should increase as later generation products, designed for recycling, reach end-of-life.

Table 4: Potential Supply of Recycled ETPs in New England in 1998

Resin	% of Total Resin[1]	1998 est. millions of lbs recovered	
		US	New England
All Resins	--	52	4.9
ABS	26	13.5	1.3
HIPS	19	9.9	.9
PC/ABS	16	8.3	.8
PPO	8	4.2	.4
PC	6	3.1	.3
PVC	5	2.6	.2

[1] *American Plastics Council, March 1999.*

The National Safety Council report predicts an annual growth rate in electronic equipment recovery of 18 percent annually until 2007. The electronic recycling forecasts, based on industry growth trends, may be low for New England. In the year 2000, Massachusetts plans to ban the disposal of electronic devices containing cathode ray tubes (CRTs), notably televisions and computer monitors. While the CRT, which contains leaded glass, is the target of the ban, it is most often collected as an intact product with its plastic (or in some cases, wood) housing. Therefore, the volume of plastics from electronics can be expected to increase when the ban comes into force.

4.2 Plastics Processing Capabilities

This research identified several Massachusetts companies that process engineering thermoplastic resins from used electronic equipment, or have the capability to process this material. Table 5 provides a summary of the processing capabilities of selected Massachusetts companies.[8] Companies that accept single resin feedstreams originating from post-industrial sources are most common. The technology to mechanically sort and purify mixed resins is not common among processors, but is available from at least one processor in the State. At least one other company processes mixed engineering thermoplastics for use in-house for the manufacture of an end product.

[6] National Safety Council, 1999, p. 36.
[7] Dewey Pitts, "Overview of IBM's DFE Initiatives," presentation at the Northeast Recycling Council Meeting, Albany NY, June 17, 1999.
[8] A previous Chelsea Center report, *Potential Markets for CRTs and Plastics from Electronics Demanufacturing* (August, 1998), identified additional companies that process recycled ETPs. Except for those listed above, the companies handle industrial scrap consisting of a single resin of known composition and free of contamination.

Table 5: Processing Capabilities of Selected Massachusetts Companies

Company	Sources	Currently Process Electronics	Incoming Material Specifications	Recycled ETP Resins Processed	Processing Capabilities	End Product
Carbon Polymers	PI, PC	No	Whole, granulate, single resin	PC, HIPS, ABS, PPO	Granulate, clean	Clean, single resin granulate
Civiera & Silver	PI	No	Whole, granulate, single resin	ABS. ABS/PC, PC, PPO	Granulate, separate metals	Clean, single resin granulate for export
Conigliaro Industries	PC	Yes	Whole, granulate, some metal contamination	Mixed resins	Granulate, manufacture end product	Paving product
Domino Enterprises	PI, PC	Yes	Granulate	Mixed HIPS/ PPO	None; contract for processing services	Clean, single resin granulate or pellets
Polymark Corporation	PI	No	Granulate	HIPS + commodity resins (e.g., PE, HDPE)	Compound, pelletize	Single resin pellets
Recycling Separation Technologies	PI, PC	Yes	Whole, granulate	Mixed ETP resins	Granulate, separate metals, clean, sort by resin type, remove paint	Clean, single resin granulate
SelecTech	PI, PC	No	Whole, granulate, mixed & contaminated plastics	Other resins (e.g., PVC, PE, HDPE, nylon)	Granulate, injection molding	Construction, traffic, lawn & garden

Some plastics processors, located both in Massachusetts and outside of the State, are capable of producing high-quality recycled resins from post-consumer equipment that are suitable for high performance applications. (For example, see Section 4.4 for discussion of material sourcing for the molding demonstration). Others process and supply ETP material for less demanding applications (such as paving material and construction products). The majority of post-consumer electronic ETPs that are currently recycled are destined for lower end applications, which can accommodate mixed plastic resins, as shown in Table 6.

End markets that utilize mixed ETPs are needed for today’s electronics waste stream, which typically contains a variety of resins with no one resin dominating the material stream, as shown in Table 1. As the number of resin types increases, the number of processing steps needed to sort and purify the resins increases, which in turn, increases cost. The economics of sorting mixed plastics improves when there are fewer different resins, or a dominant resin, in the waste stream.

Presorting the plastics waste stream to isolate dominant and marketable resins for further processing may improve the economics of recycling. Visual identification of plastics using available markings is the most prevalent technology used today, although it is labor intensive and unreliable, according to most sources. In some cases, like with toner cartridges, gross sorting by product type may reduce the variety of resins in the electronics waste stream to make mechanical processing economical (see Section 4.4.1). Several rapid identification technologies (e.g., near infrared, Raman spectroscopy) are commercially available or in the developmental stages, which should improve resin sorting in the future. For now, however, available technologies have limitations for electronics ETPs. Limitations for some technologies include the inability to identify black resins; ability to differentiate only a limited number of resins (e.g., 6 or less); time and handling requirements; and capital costs.[9]

4.3 Markets and Applications for Recycled ETPs

The potential for reutilization of plastic resins derived from used electronic equipment depends largely on composition and volume. Table 6 identifies some existing markets and applications for recycled ETPs, organized by resin type.

Table 6: Existing Markets and Applications for Recycled ETPs

Resin	Product	Company
Mixed	Road paving product	Conigliaro Industries, MA
Limited Mixed Resins: PC/ABS, ABS, PC	Flooring product	Wilsonart International, TX
ABS	Cable connectors	Advanced Recovery, NJ
	Electrical Boxes	Fortune, RI, NJ; export to China
ABS/PC	Internal parts for computer products	IBM
ABS	Computer housings	IBM

Available markets for plastics from used electronic equipment are limited at the present time. Electronics ETP recycling might benefit from the business model and processing capabilities of SelecTech; for example:

- **innovative process technology** that enables the company to turn plastic "junk" into quality products, using injection molding equipment modified to tolerate high levels of contamination;
- **attractive economic model** for processing plastics that opens up new opportunities for utilizing waste plastics, previously considered too costly to "clean" in order to compete with virgin resins; and,
- **willingness to experiment** with new materials and processes to improve the performance of existing products or develop new products.

In addition, while SelecTech does not currently utilize ETPs derived from used electronic equipment, the potential exists to develop products for the garden & landscape and traffic control product markets.

[9] American Plastics Council, "APC Durables Recycling Workshop II" presented at the Society of Plastics Engineers Annual Recycling Conference, Chicago, IL, November 11, 1998.

Table 7 provides an extensive list of applications and markets suitable for recycled-content ETPs, as brainstormed by industry experts during the Stakeholder Dialogue on May 10, 1999. As discussed below, the challenges are in developing a quality and consistent feedstream to supply these markets; and in getting these markets to consider the use of recyclate.

Table 7: Potential Markets for Recycled ETPs

- Telecommunications
  - spools
  - novelty phones
  - fax machines
  - modems, hubs for networks
- Automotive
  - bumpers, mirror housings
  - liners on pickup trucks
  - low temperature engine parts
- Electrical
  - fuse boxes, enclosures, connectors
  - wire nuts, wire coating
- Construction
  - flooring, counter tops
  - artificial lumber
  - concrete additives, insulation
  - supplies (e.g., scaffolding)
  - vinyl siding/windows, roofing
- Materials Handling
  - pallets, shipping containers
  - recyclable totes
- Computer/Data Processing
  - internal parts such as stiffeners, fan housings
  - external parts such as housings, pedestals, handles, painted parts
- Household Appliances
  - vacuum cleaners, coffee machines
  - power tools
  - TVs, radios, VCRs
- Yard & Garden
  - handles for rakes and tools
- Traffic Control
  - speed bumps, parking stops
  - guardrail posts

4.4 Performance Demonstration

4.4.1 Material Sourcing

Several vendors that offer recycled-content HIPS were located across the US, as outlined in Table 8. While this is certainly not an exhaustive list, it is probably representative of the material currently available. Unlike virgin resin grades, little data on the material performance characteristics was readily available from vendors.

Post-industrial resin grades were more prevalent in the market, which is not surprising given the prevalence of post-industrial scrap. The available post-consumer resins were derived from homogeneous product waste streams (e.g., disposable cameras, toner cartridges) of known resin composition. While recycling these products does require sorting and purification of resins, these waste streams are less complex than the typical mixed plastic waste stream resulting from electronics demanufacturing.

The final candidate for the molding demonstration was a black 100% post-consumer resin in pellet form. The recyclate fell within the acceptable range for the two key process parameters with an IZOD impact strength of about 1.9 ft-lb/min and a melt index of approximately 4.5. The material was derived from used toner cartridges processed in Massachusetts, and was available in pellets or flakes. Despite the higher cost, pellets were chosen over flakes for consistency with the virgin feedstream. At less than $0.40 per pound, the price for the recycled-content pellets was comparable, or less, than the cost of the virgin grade. The material is currently destined for disposal.

Table 8: Sources of Recycled HIPS

Company	**Available**	**Source**	**Composition**	**Material Characteristic**	**Comments**
MBA Polymers, CA	Variety of grades, including: • Black HIPS, mostly FR (non-brominated) • Black HIPS, non-FR "Computer white", mostly FR, some non-FR	TV panels Business Equipment Computer	Post industrial & post consumer	Not available, but can test	
Butler McDonald IN	Black HIPS non-FR	Disposable cameras	Post-consumer	1.4 IZOD (more medium impact)	Can be compounded to increase IZOD
RST, MA	Black FR HIPS, flake	Toner cartridges	Post-consumer	Not available	Processes material for broker, who sells resin
Domino Enterprises, MA	Black FR HIPS, flake and pellets	Toner cartridges	Post-consumer	~1.9 IZOD ~4.5 MFI	
National Polystyrene Recycling Company, IL	Black HIPS Non-FR		Post-consumer		
Carbon Polymers MA	Black HIPS	Non-electronic	Post-industrial scrap (pellets from resin suppliers)		
Polymark Corp. MA	HIPS	Non-electronic	Post-industrial		

FR = Flame Retardant grade

4.4.2 Molding Trial

When the 100% post-consumer recyclate was introduced into the molding process, there was little noticeable change. The injection pressure dropped about 50 bar at the same injection velocity profile, which is not uncommon when a material lot changes during production. The only processing change that was made was adding two seconds to the cooling time. This was done to correct a slight warpage in the part. The sample product was measured against the quality control parameters for this part. The overall length and warpage were found to be well within specification. While the mean overall length shifted by 0.0025", the Cpk value remained acceptable at 1.51.[10]

[10] Cpk is a measure of process stability, used as a quality measure to predict the expected number of reject parts.

Overall, the material processed well with only slight process changes and no major defects in parts.[11] The slight shift in overall length should be easily corrected by fine-tuning the process. While the cycle time increase may be a cost issue, this also should be correctable via process tuning.

4.5 Stakeholder Dialogues

Over 40 people, representing the diverse stakeholders in the ETP supply chain -- including resin suppliers, original equipment manufacturers, molders, plastics processors, and electronics recyclers, as well as representatives of government, academia and non-profit organizations -- attended each of the Stakeholder Dialogues. Participants almost unanimously agreed that the Stakeholder Dialogue process was worthwhile and should continue.

The presentations revealed positive developments across the supply chain to collect, process and reutilize ETPs, including:

- the introduction of recycled-content grades of ETPs by several major resin suppliers. These resins, however, are comprised mostly of post-industrial scrap or single resin post-consumer streams (e.g., water bottles, compact discs);
- the qualification and use of recycled-content ETPs, including PVC, PC/ABS, PC and PPO, in computer applications; and
- the development of plastics identification, sorting and cleaning technology.

Despite these successes, critical challenges remain in the processing and reutilization of ERP resins; for example:

- **Product recovery.** There is a need for more efficient collection systems for electronic equipment in order to accumulate and aggregate like resins and achieve the volumes of plastics needed for cost-effective processing and market development.
- **Economics of sorting and processing mixed resin streams**. Currently the economics of recycling ETPs are marginal. After collection and processing, the price of recycled-content resin may exceed the price of prime resin. This is a disincentive for OEMs who are looking for cost reductions, or cost parity at a minimum. Increasing the volume of material processed should result in greater efficiencies and cost reductions (i.e., economy of scale).
- **Continuity of supply.** Equipment manufacturers are reluctant to specify recycled resin without supply assurances. At the same time, resin suppliers are reluctant to make available recycled product without a strong commitment to recycled products and a consistent, quality feedstreams, resulting in a “chicken or egg” dilemma.
- **Lack of design protocols and material specifications.** Given time to market pressures, the use of recycled content is often hindered by a lack of readily available protocols and material specifications for recycled resins, compared to virgin resins. In addition, recycled resins are often scrutinized more than their virgin counterparts in the design and testing phases of product development.

[11] With the introduction of a any new material, it is common to have to redevelop the entire process from melt temperature to injection speed to cooling time.

A complete discussion of the results of the Stakeholder Dialogues is found in Chelsea Center Technical Report #21, *Recycling Market Development for Engineering Thermoplastics from Used Electronic Equipment: Summary Report of the Stakeholder Dialogue Meetings*.

5.0 Lessons Learned

The process of actually sourcing material was a valuable exercise, providing a pragmatic illustration of the gaps in the supply chain. For example, we found that resins meeting these criteria were not readily available. For recycled resins that were available, standard performance data, needed to assess compatibility with product design specifications, were not readily available. Difficult and time consuming sourcing handicaps the selection of recycled-content resin, given time-to-market pressures and the marketing presence of virgin resin suppliers.

For some applications, the performance of recycled-content resins does not appear to be the "show stopper". According to molders, manufacturers are often hesitant to specify internal regrind, even with a favorable cost differential, no less post-consumer resin. There appear to be a a variety of reasons, mostly revolving around the perceived quality of recycled-content resins by the manufacturer and their customers, as well as potential liability, for using "inferior materials." This may be despite proven material and product performance.

6.0 Recommendations for Further Work

Followup to Performance Demonstration

While this research project successfully demonstrated the use of 100% post-consumer recyclate in a consumer product application, several questions must to be answered before the recyclate becomes a true contender in this application:

- Last year 200,000 pounds of material were used to manufacture this product. Is there enough of a consistent supply to handle this volume?
- How does the cost of using recycled resin compare to the resin currently used?
- Will the product pass the additional tests performed by the manufacturer?
- Could additional savings be attained through use of flake versus pellets?

Continuation of Stakeholder Dialogue Process

The initial Stakeholder Dialogues brought together key representatives of the ETP supply chain, and began to lay some essential groundwork. The agenda, however, was far too ambitious to accomplish in two meetings. The Gordon Institute at Tufts University has received funding from the US EPA Office of Solid Waste to continue the Stakeholder Dialogue process. Future meetings will predominantly focus on flushing out priority issues, such as addressing key barriers, and the generation of action plans. A multi-stakeholder Advisory Committee will be formed to assist in the planning for future Dialogues.

Material Database for ETP Supply

In order for recycled engineering thermoplastics from used electronics to become a viable feedstock for manufacturing, a knowledge base must be created on this relatively new supply stream. For example, what are the various "grades" of recycled engineering resins, how "clean" is the resin, what types of contamination (e.g., other resin types, metal) is in the resin, from what products is the resin derived, and what is the price range for the various grades? Our experience in sourcing material for the demonstration illustrated that this type of information is not readily available without expending a considerable amount of time and effort, going from "supplier to supplier" to piece together the puzzle. Many of the manufacturers and molders we spoke to also did not have any connections to the suppliers and processors of this recycled feedstock. When time-to-market or staff resources are an issue, this resource-intensive "learning curve" is a significant disincentive to exploring this feedstream.

Demonstration of Low End, Robust Applications
This research identified potential applications for recycled engineering thermoplastics in robust applications such as landscape timber, construction products, and traffic control products. These applications are promising because they tolerate greater amounts of contaminated plastics. Utilization of "contaminated" plastics has the potential to capture additional feedstreams (which might not be economical to fully clean) and to reduce the cost of recycled feedstocks by eliminating cleaning steps.

Product Design Protocol
An outcome of the stakeholder dialogues (as well as our work with Nypro this year) was a clear statement that a significant barrier to the selection of recycled engineering thermoplastics is the lack of a design protocol for product development. A readily available and accessible design protocol would facilitate the sourcing of recycled-content material in a time-sensitive, cost-driven design community.

7.0 Conclusions

Currently there is a limited capacity in Massachusetts to process ETPs from used electronic equipment and few viable markets for the predominantly mixed plastic stream. Recycled ETPs from used electronic equipment that are separated into single resin streams, free of contaminants (such as metal and paper), perform well in high-end applications. A major barrier to the use of recycled ETPs is the cost-effective sorting of the mixed resin electronics waste stream to achieve a quality feedstream suitable for injection molding applications, combined with limited alternative markets for mixed plastics.

Recycled HIPS performed well as a virtual "drop in" replacement in the molding trials. Minor adjustments to the process parameters are needed to achieve the existing product performance requirements. Such fine-tuning of process parameters is a routine practice when a new material -- virgin resin, internal regrind, or recyclate -- is introduced into a product. Any slight adjustments needed to utilize this recycled resins, therefore, should be considered a "standard operating procedure" and not a flaw in the material feedstream.

Given a quality feedstream, the use of recycled-content resin is technically feasible. The greatest challenges are in processing the mixed resins to achieve quality standards, and in building the knowledge base and confidence in the quality of the recycled resins to facilitate its introduction in new product.