Applied Engineering Tools for Recycling

Targeting Plastics Manufacturers for Conversion to Recycled Plastics

RECYCLING TECHNOLOGY ASSISTANCE PARTNERSHIP ReTAP

Targeting Plastics Manufacturers for Conversion to Recycled Plastics

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[*] Clean Washington Center, 1997.

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1.0 INTRODUCTION

The following guidelines provide a structured technique to target plastics manufacturers for conversion to using secondary, recovered plastics in their manufacturing processes. Identifying the best candidates for successful implementation of conversions to recycled plastics is complicated because of the many economical and technical factors to consider.

A sequence chart of the entire conversion targeting and implementation process is shown in Figure 1.

The guidelines address two steps of this conversion process:

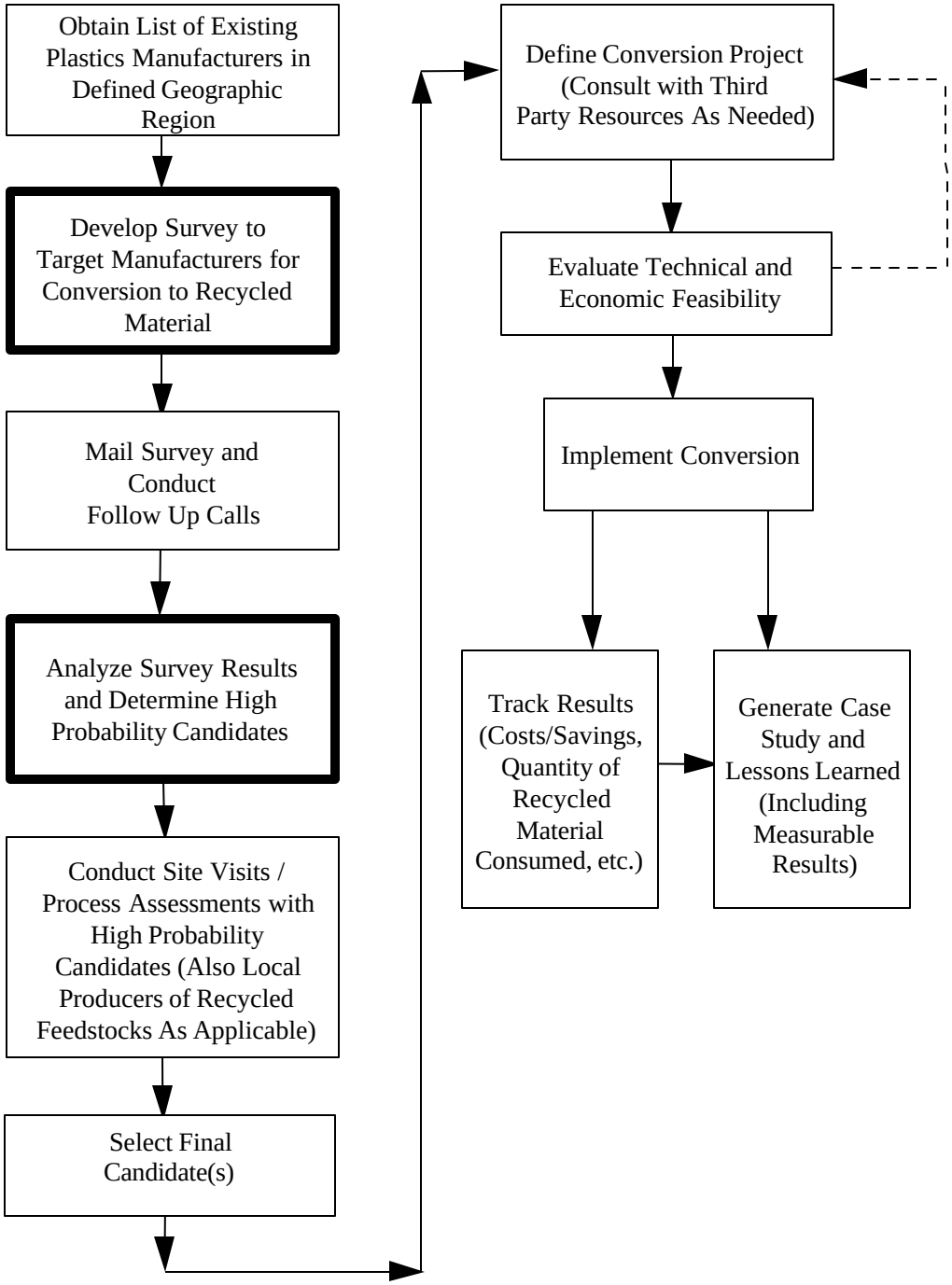
- Develop Survey to Target Manufacturers for Conversion to Recycled Material; and
- Analyze Survey Results and Determine High Probability Candidates.

The scope of these guidelines reflect current applications for recycled resins that are currently recycled in large volumes, specifically:

- Bottle-Grade Polyethylene Terephthalate (PET);
- Bottle-Grade High Density Polyethylene (HDPE) - Natural;
- Bottle-Grade HDPE - Pigmented;
- Film-Grade Low Density Polyethylene (LDPE) and Linear Low Density Polyethylene (LLDPE);
- Injection-Grade Polystyrene (PS) and Expanded Polystyrene (EPS);
- Bottle-Grade Polyvinyl Chloride (PVC);
- Injection-Grade Polypropylene (PP); and
- Film-Grade HDPE.

On-going research and product development will undoubtedly open up new uses and applications for these and other recycled resins in the future. Recycled resins other than those listed in Table 1 (see section 2.0) are not usually considered to be high probability candidates, although exceptions may arise in certain geographic or concentrated industry areas.

FIGURE 1: SEQUENCE CHART FOR TARGETING AND IMPLEMENTING INDUSTRIAL CONVERSION TO RECYCLED PLASTICS



2.0 FACTORS TO CONSIDER IN SELECTING CANDIDATE CONVERSION PROJECTS

This section discusses background information in developing criteria for conversion projects that will have a high probability of success.

2.1 Post-Consumer (PC) versus Post-Industrial (PI) Material

Post-Consumer collection of plastics typically takes the form of residential curbside collection, drop-off programs, and collection at institutions such as schools and colleges. In general, curbside residential collection of PC plastics is limited to PET and HDPE (bottle and film grade). Other resins may also be collected on a small-scale basis or in certain geographic regions only.

Residential drop-off and take-back programs include PET and HDPE, as well as, other plastics such as PP from battery casings vehicle battery return programs, and LDPE and HDPE film grocery bags collected at recycling stations at many grocery stores.

Post-industrial materials are generally defined as waste generated by processors or fabricators. Typical examples include drool, purgings, trimmings, or reject parts. These materials are best suited for recycling into similar applications (e.g., extrusion grade material into an extrusion process or blown film grade material into film processes).

2.2 Typical Sources and Applications for Most Commonly Recycled Resins

Table 1 lists some of the typical sources of the recycled resins discussed in these guidelines. The SPI (Society of the Plastics Industry, Inc.) Identification Code is also noted[1]. Compiling information on PC and PI resin supply for the defined geographic region will assist in determining target resins and processes. If possible, research supply availability, consistency, quality, and price.

Table 2 lists some of the end-product uses of the recycled resins discussed in these guidelines.

[1] Source: Earth Circle, Council for Solid Waste Solutions and Plastics Recycling Update, 1990.

Table 1: Typical Sources for Most Commonly Used Recycled Resins

Recycled Resin	Highest Volume Sources of Recycled Resin
Bottle-Grade PET SPI Code: (1)	Water bottles Two-liter (and other size) soda bottles Post-industrial
Bottle-Grade HDPE - Natural SPI Code: (2)	Milk and dairy jugs Post-industrial scrap
Bottle-Grade HDPE - Pigmented SPI Code: (2)	Opaque, colored detergent and soap bottles Post-industrial scrap
Film-Grade LDPE and LLDPE SPI Code for LDPE: (4) SPI Code for LLDPE: (7)	Grocery bags Film packaging Post-industrial scrap
Injection-Grade PS and EPS SPI Code: (6)	Spent food service products (usually from schools and institutions) Post-industrial scrap
Bottle-Grade PVC SPI Code: (3)	Bottles Post-industrial scrap
Injection-Grade PP SPI Code: (5)	Battery casings Post-industrial scrap
Film-Grade HDPE SPI Code: (2)	Grocery bags Agricultural film Post-industrial scrap

Table 2: Typical Applications for Most Commonly Used Recycled Resins[2]

Recycled Resin	Typical Applications for Recycled Resin
Bottle-Grade PET	• Fiberfill polyester for jackets, furniture, pillows, sleeping bags • Erosion-control geotextile fabrics • Sanitary landfill and pond linings • Recycled, repolymerized pet bottles
Bottle-Grade HDPE - Natural	• Bottles (e.g., laundry detergent, motor oil) • Semi-rigid food product containers (e.g., Margarine) • Base cups for pet bottles • Residential and commercial drainage pipe • Toys • Pails and drums • Traffic barrier cones • Milk bottle crates, trash cans, curbside collection bins • Grocery bags • Strapping
Bottle-Grade HDPE - Pigmented	• Interior layers of bottles • Flower pots • Plastic lumber
Film-Grade LDPE	• Trash, grocery, merchandise, and garment bags
Film-Grade LLDPE	• Wire, cable and pipe • Stretch wrap and shrink wrap
Injection-Grade PS	• Cassette and videotape casings • Office equipment • Hangers • Flower pots • Toys
Injection-Grade EPS	• Packaging “peanuts” • Insulation • Egg cartons • Hamburger “clamshell” containers
Bottle-Grade PVC	• Bottles (e.g., Shampoo, salad oil, and other)
Injection-Grade PP	• Battery casings and durable goods • Experimenting with new car bumpers
Film-Grade HDPE	• Bags (e.g., Grocery and trash bags) • Agricultural film

[2] American Plastics Council (Joint Initiative with The Society of the Plastics Industry, Inc.). *How to Collect Plastics for Recycling-Lessons from the Model Cities Demonstration Program.* Washington, DC. Mary 1995.

Integrated Waste Management Board. *Plastics: Waste Management Alternatives, Use, Recyclability, and Disposal*. State of California. May 1992.

National Association for Plastic Container Recovery (NAPCOR)

2.3 Discussion of Recyclability of Most Commonly Recycled Resins

2.3.1 Bottle-Grade PET

Recycling rates of post-consumer, bottle-grade PET are high because of consistent material characteristics. PET bottles are manufactured from the same grade of resin, yielding a homogeneous feedstream. Therefore, recycled bottle-grade PET can be used in a number of applications including fiber, sheet, film and injection-molded products. Recycled PET material can be processed from either pellet or flake depending on the equipment and mixing capability of the individual converter.

Recycling PET from PI sources is more challenging than from PC sources if material is not segregated by different grades. Mixing different grades may result in less-predictable blend properties as opposed to a homogeneous bottle-grade feedstream.

A key factor to successfully use post-industrial PET is segregating materials with similar melt index and intrinsic viscosity characteristics, then incorporating these sorted materials into virgin feedstreams that match their characteristics.

2.3.2 Bottle-Grade HDPE - Natural

HDPE - Natural has a high recyclability potential because virtually all are made from the same grade resins, a fractional melt index homopolymer. This leads to a homogeneous feedstream with consistent material characteristics evident in predictable performance properties and flow (processing) characteristics. Recycled HDPE material can be converted from either pellet or flake depending on the equipment and mixing capability of the individual converter.

Recycled HDPE - Natural is blended with virgin resins into blow-molded products such as shampoo and detergent bottles.

It is also commonly blended with virgin resins in injection-molding; however, bottle-grade has a very low melt index compared to injection-molding grade resins. Increasing the recycled content decreases the blend's overall melt index, which could lead to processing difficulties in injection molding. Accommodating this melt index shift may require a virgin grade with a slightly higher melt index.

Recycled HDPE - Natural is increasingly being used in blown-film applications. The material has been found to have superior properties compared to some HDPE-film grades; it does not substantially effect processing. Because of surface finish requirements, pelletized material is usually required.

2.3.3 Bottle-Grade HDPE - Pigmented

Post-consumer HDPE - pigmented material is composed from a variety of sources, most commonly opaque detergent bottles. Several homopolymers, copolymers, and different grades are used in the manufacture of these containers. A number of other materials often get mixed into this feedstream, including PP containers. Historically, this heterogeneous feedstream tend to limit the use of these materials to low or medium-value applications in which cost primarily determines material selection. Because the material is pigmented, it is limited to dark-colored products.

2.3.4 Film-Grade LDPE/LLDPE

Shrink wrap and stretch film is the major source of recycled material. The highest probability of successful conversion for recycled LDPE and LLDPE films is in applications of similar virgin materials with similar performance characteristics of melt index and tensile strength. Recycled LDPE and LLDPE film resins are commonly incorporated into other film applications and in the inner layer of a multi-layer film product.

2.3.5 PS and EPS

Polystyrene, especially expanded polystyrene (EPS), is not widely recycled, primarily because of collection difficulties. The PS (and EPS) that is recycled is generally from schools or other larger-sized institutions that collect spent food service products. This material is generally graded for low-value applications in injection molding.

2.3.6 Bottle-Grade PVC

PVC is not widely collected material. Major sources of post-consumer material include bottles and other packaging products. Other sources include durable goods from windows, pipe, tubing or automotive applications.

2.3.7 Injection-Grade PP

The major source of recycled PP is used battery casings. This material is generally recycled back into battery casings and durable goods, but can also replace HDPE in some injection-molded products. This injection molding capability of recycled PP may provide an advantage over HDPE because PP has superior inherent physical properties to HDPE. Note that PP must be used at 100 percent content in these applications because HDPE and PP are not compatible resins.

2.3.8 Film-Grade HDPE

The common sources of film grade HDPE are grocery bags collected at most grocery stores, and agricultural film. Because the material is segregated, it constitutes a homogeneous feedstream that can be used in film or injectionmolded applications.

2.3.9 Other Post-Industrial Materials

Other materials not mentioned above are considered PI material because they are rarely collected in residential collection or drop-off programs. The typical sources are factory trimmings, oversized drool, purgings, or reject products that for some reason could not be used as regrind.

2.4 End-Use Potential of Specific Resins in Specific Processes

2.4.1 Bottle-Grade PET

Injection molding: PET can be used in molding process, but this is currently a limited segment of the end-use market.

Injection molding-structural foam: PET is not utilized in this process.

Blow molding: PET is commonly reprocessed into many different types of non-food container applications. PET recycled through methanolysis constitutes the majority of PET resin that is recycled into food-grade applications, although food grade applications do use other sources of mechanically-recycled PET.

Blown Film: PET is generally not utilized in the manufacture of bags or overwrap.

Multi-layer: Recycled PET can be utilized in a variety of multi-layer processes. The resin, in pelletized form only, is commonly used in multi-layer processes. Many manufacturers are able to re-pelletize (off-site or in-house) and reuse in-house trimmings or post-industrial resin and incorporate recycled content in the inner layer. This technique utilizes the recycled resin between two layers of virgin material in co-extrusion blow molding or multi-layer extrusion to produce bottles, sheets, or film.

Extrusion-profile: PET is not widely utilized in this process.

Extrusion-fiber: A large volume of recycled PET is reprocessed into fibers. The material must be color sorted; however, and PVC contamination is a serious concern as it severely effects product performance and processing. Applications include clothing, carpeting, and fill. The processing, performance, and other characteristics of high-quality recycled PET fibers are very similar to those of virgin materials.

Extrusion-sheet or cast film: Recycled PET flake can be directly reprocessed into sheet or film products. Key characteristics for reprocessing are melt index and intrinsic viscosity. Drying and recrystallization are other important factors to consider when reprocessing.

Rotational Molding: PET is generally not utilized in this process because finely-ground material is required. Economics do not justify the process required to formulate the material.

2.4.2 Bottle-Grade HDPE - Natural

Injection molding: This resin can be injection-molded into many consumer or industrial products where performance requirements are minimal or negligible. In such cases, 25 to 50 weight percent content is achievable.

Injection molding-structural foam: Up to 40 weight percent recycled content is achievable in high-performance products manufactured with this process. Specific content rates vary depending upon performance requirements. Surface finish problems such as discoloration or blemishes are less of a concern because of the foaming nature of the process.

Blow molding: This recycled resin is often blow-molded into bottles in non-food applications, at about an average weight percent content of 25%. Performance requirements may preclude higher recycled content. Post-industrial, blow-mold grades have potential for reuse in film applications, especially multi-layer processes.

Blown film: The resin can be readily utilized in many film applications. Recycled HDPE - Natural has been shown to produce equal or superior performance properties compared to some traditional virgin grades of film HDPE. The material can be utilized in film applications when clarity is not an issue. Two examples of this application are trash can liners and grocery bags.

Multi-layer processes: The resin is commonly used in multi-layer processes by incorporating recycled content in the inner layer.

Extrusion profile: Depending upon specific application requirements, the profile extrusion process can incorporate recycled HDPE with virgin extrusion grade. However, HDPE is not a material that is widely used in profile extrusion applications.

Extrusion-fiber: Contamination and melt flow characteristics limit the use of HDPE-Natural in this process.

Extrusion-sheet or cast film: Recycled material is easily incorporated into the sheet extrusion process. HDPE products such as "slip sheets" generally do not have rigorous performance requirements. However, if the sheets are to be further processed via thermoforming or compression molding, then performance and surface quality issues may preclude the use of recycled resin.

Rotational molding: This process utilizes finely-ground material. Economics do not justify the process required to formulate the material.

2.4.3 Bottle-Grade HDPE - Pigmented

Injection molding: High recycled content is achievable when processed into products with low performance requirements or into dark-colored products. Processing and performance characteristics of HDPE-Pigmented are less consistent than those of HDPE-Natural.

Injection molding-structural foam: High recycled content is achievable when processed into products with low performance requirements or into dark-colored products. Processing and performance characteristics of HDPE-Pigmented are less consistent than those of HDPE-Natural.

Blow molding: Recycled HDPE-Pigmented resins are not widely used in this process, although using the resin might be feasible in a multi-layer process.

Blown film: The resin can be readily utilized in many film applications. However, recycled materials are limited to products where performance or clarity requirements are not important.

Multi-layer: The resin has potential for use in multi-layer processes by incorporating recycled content in the inner layer.

Extrusion-profile: Except for commingled products such as plastic lumber, recycled HDPE-Pigmented is not widely utilized.

Extrusion-fiber: Contamination and melt flow characteristics limit the use of HDPE-Pigmented in this process.

Extrusion-sheet or cast film: Recycled material is easily incorporated into the sheet extrusion process. HDPE products such as "slip sheets" generally do not have rigorous performance requirements. However, if the sheets are to be further processed via thermoforming or compression molding, then performance and surface quality issues may preclude the use of recycled resin.

Rotational Molding: This process utilizes finely-ground material. Economics do not justify utilization of recycled materials.

2.4.4 Film-Grade LDPE/LLDPE

Injection molding: This resin can be utilized alone or blended with HDPE in low-end applications.

Injection molding-structural foam: The resin is generally not utilized in this process.

Blow molding: The resin is generally not utilized in this process.

Blown film: These recycled resins, in pelletized form only, are widely utilized in blown film applications. Many manufacturers are able to re-pelletize (offsite or in-house) and reuse in-house trimmings or post-industrial materials. Typical products include grocery bags, trash bags, and agricultural film.

Multi-layer: The resin, in pelletized form only, is commonly used in multi-layer processes. Many manufacturers are able to re-pelletize (offsite or in-house) and reuse in-house trimmings or post-industrial resin and incorporate recycled content in the inner layer.

Extrusion-profile: These resins are typically not utilized in this process.

Extrusion-fiber: Contamination and melt flow characteristics limit feasibility of this process with recycled resins.

Extrusion-sheet or cast film: These recycled resins, in pelletized form only, are commonly utilized in this process. Many manufacturers are able to re-pelletize (offsite or in-house) and reuse in-house trimmings or post-industrial materials. Compatibility issues may arise between blown film-grade resin and sheet or cast film resins.

Rotational molding: This process utilizes finely-ground material. Economics do not justify utilization of recycled materials.

2.4.5 Injection-Grade PS/EPS

Injection molding: The recycled resin is widely utilized in the process. Many manufacturers re-use in-house trimmings or post-industrial materials. Post-consumer resin must be washed and pelletized to be used in the process.

Injection molding-structural foam: The resin is generally not utilized in this process.

Blow molding: The resin is generally not utilized in this process.

Blown film: The resin is generally not utilized in this process.

Multi-layer: The resin is generally not utilized in this process.

Extrusion-profile: The resin has potential in a variety of applications. However, the melt flow index characteristics of injection-grade may not be compatible with some extruded applications. PC resin must be washed and pelletized for this process.

Extrusion-fiber: The resin is generally not utilized in this process.

Extrusion-sheet or cast film: The resin has potential in a variety of applications. However, the melt flow index characteristics of injection-grade may not be compatible with some extruded applications. PC resin must be washed and pelletized for this process.
Rotational molding: This process utilizes finely-ground material. Economics do not justify utilization of recycled materials.

2.4.6 Bottle-Grade PVC

Injection molding: The resin has the potential for a variety of applications. However, the melt flow characteristics of bottle grade may not be compatible with some injection molding grades of PVC.

Injection molding-structural foam: The resin is generally not utilized in this process.

Blow molding: Clear PVC resin can be readily utilized. Post-consumer resin must be washed and pelletized for the process.

Blown film: The resin has the potential for utilization in this application, although recycled resin is not widely utilized.

Multi-layer: The resin has the potential for incorporation into an inner layer in some applications.

Extrusion-profile: The resin is widely used in this process, mostly in lower performance pipe and profile applications.

Extrusion-fiber: The resin is generally not utilized in this process.

Extrusion-sheet or cast film: The resin has the potential to be utilized in this application, although recycled material is not widely utilized in the process.

Rotational molding: This process utilizes finely-ground material. Economics do not justify utilization of recycled materials.

2.4.7 Injection-Grade PP

Injection molding: The resin is widely utilized in this process. Applications include battery casings or other durable goods.

Injection molding-structural foam: The resin has potential for utilization in this application, although recycled resin is not widely utilized.

Blow molding: The resin has potential in a variety of applications. However, the melt flow characteristics of injection-grade may not be compatible with many blow molding grades of PP.

Blown film: The resin has potential in a variety of applications. However, the melt flow characteristics of injection-grade may not be compatible with many blown film grade PP resins.

Multi-layer: The resin has potential in a variety of applications. However, the melt flow characteristics of injection-grade may not be compatible with other various PP grades.
Extrusion-profile: The resin has potential in a variety of applications. However, the melt flow characteristics of injection-grade may not be compatible with many extrusion grades of PP.

Extrusion-fiber: Contamination and melt flow characteristics limit incorporation in this process.

Extrusion-sheet or cast film: The resin has potential in a variety of applications. However, the melt flow characteristics of injection-grade may not be compatible with many extrusion grades of PP.

Rotational molding: This process utilizes finely-ground material. Economics do not justify utilization of recycled materials.

2.4.8 Film-Grade HDPE

Injection molding: The resin has potential in a variety of applications. However, the melt flow characteristics of film-grade may not be compatible with some injection-grade HDPE resins.

Injection molding-structural foam: The resin has potential in a variety of applications. However, the melt flow characteristics of film-grade resin may not be compatible with some injection-grade HDPE resins.

Blow molding: The resin has potential in a variety of applications. However, the melt flow characteristics of film-grade resin may not be compatible with many blow molding grades of HDPE.

Blown film: The resin is widely utilized in this process. Applications include grocery bags, trash bags, agricultural film or other film products where clarity is not an issue.

Multi-layer: The resin has potential for utilization in this process, typically as an inner layer. Applications include film products where clarity is not an issue.

Extrusion-profile: The resin is generally not utilized in this process, although it has the potential in low-end applications.

Extrusion-fiber: Contamination and melt flow characteristics limit the incorporation of the recycled resin.

Extrusion-sheet or cast film: The resin is generally not utilized in this process, although it has potential in low-end applications.

Rotational molding: This process utilizes finely-ground material. Economics do not justify utilization of recycled materials.

2.5 Compatibility of Recycled Resins With Other Resins and In Other Processes

In most circumstances, it is best to use recycled resins and similar resin grades (i.e., bottle grade into bottle grade, extrusion grade into extrusion grade, etc.) in similar processes. The reasons for this include:

- Higher quality end-products will result if the recycled resin has similar properties to the virgin material it is blended with.

- Considering designing for recyclability, a single resin product is typically more recyclable than products made of dissimilar, blended materials. Additionally, recycled content materials of same grades (bottle grade with bottle grade) are more recyclable at the end of useful product life.

2.5.1 Polymer to Polymer Compatibility

Some recycled resins may be blended with other types. The general compatibility of differing resins is shown in the matrix in Table 3.

Table 3: Resin Compatibility Matrix[3]

Polymer Type	LDPE	LLDPE	EC	HDPE	PP	PS	PVC
LLDPE	1						
Ethylene Copolymers (EC)	1	1					
HDPE	1	1	1				
PP	4	2	2	4			
PS	4	4	4	4	4		
PVC	4	4	(2)	4	4	4	
PET	4	4	(3)	4	4	4	4
1 = Excellent compatibility 2 = Good compatibility							

[3] This table was adapted from McMurrier, M. Assessing a Polymer's Recyclability. Plastic Recycling Machinery And Equipment Report (Supplement to Plastics Machinery and Equipment and Plastics Compounding). September, 1990.

3 = Fair compatibility
4 = Not compatible
( ) = Compatibility depends on composition

2.5.2 Recycled Grade to Process Compatibility

A matrix illustrating the general compatibility of differing recycled resin grades (blown, film extruded, injection molded, etc.) into various new processes is shown in Table 4.

Table 4: Resin Compatibility Matrix[4]

Resin Grade	Process								
	Injection Mold (IM)	IM Structural Foam	Blown Mold	Blown Film	Multi Layer	Extrusion (EXT) Profile	EXT Fiber	EXT Sheet or Film	Rota-tional Mold
Bottle-Grade PET	2	4	1	3	1	4	1	1	4
Bottle-Grade HDPE-Natural	1	2	1	1	1	3	4	2	4
Bottle-Grade HDPE-Pigmented	1	3	1	2	3	3	4	2	4
Film-Grade LDPE and LLDPE	2	4	4	1	2	4	4	3	4
Injection-Grade PS and EPS	1	4	4	4	4	4	4	3	4
Bottle-Grade PVC	1	4	1	3	3	1	4	3	4
Injection-Grade PP	1	4	3	3	2	4	4	3	4
Film-Grade HDPE	2	4	3	1	2	4	4	3	4

1 = Utilized successfully on a widespread basis throughout industry
2 = Utilized commercially by a moderate number of manufacturers
3 = Feasible, but not utilized widely on a commercial basis
4 = Uncommon, untested, or resin grades generally incompatible

2.6 Candidate Manufacturers Issues and Capabilities

2.6.1 Previous Use of Post-Consumer Resin

If candidates have experience using recycled material from outside sources, the probability of successful conversion increases. Useful information to gather includes the type or grade of recycled resin used, source, percentage content, and price.

2.6.2 Previous Use of Post-Industrial Resin

The majority of plastic manufacturers incorporate in-house scrap into their products. If the candidate either owns or uses in-house scrap, a high probability exists using PI or PC resin with similar characteristics (e.g., melt index). If a company cannot use in-house scrap (for reasons other than never researching the use of scrap or never attempting to use the scrap), then the probability decreases using PC or PI from outside sources.

2.6.3 Reason for Discontinuation or Prevention of Use of PI or PC Resin

It is important to understand the reasons that a company has discontinued use, or has not attempted to use recycled resins. Many companies may not be using recycled resins because of inconsistent quality and availability of supply (including contamination, etc.), difficulties with equipment or processing, performance concerns, color or appearance, high prices, or other previously experienced issues.

[4] Matrix was compiled from reference information provided in: Ehrig, R. J., Ed. *Plastics Recycling - Products and Processes."* Hanser Publishers. New York. 1989.

From 1995-1997, the cost of recycled resins has continuously decreased, but prices are still subject to the overall price fluctuations of the plastic market. Even though the price of recycled resin is typically less than virgin, manufacturers often utilize virgin resin because the price gap is narrow. However, economics sometime drive manufacturers to utilize more recycled resin when the cost gap widen between recycled and virgin.

The recycled plastic processing industry has developed substantially over the last three years. The quality of recycled resin has continued to improve and many recycle processors have implemented sophisticated quality controls. This implement has led to consistent resin supplies that either improve or maintain consistent physical and processing properties. Additionally, increasing level of technical expertise has made it easier to overcome technical concerns in processing or performance. Furthermore, processors have diversified their feedstreams and supplies, and have become more reliable than in the past.

2.6.4 End-Product Characteristics

Products that have minimal performance specifications are likely candidates for incorporation of recycled resins; usually, the combination of darker-colored resins with low performance specifications have even higher probability. Example products include containers and industrial type products. In general, manufacturers that make products from commodity resins such as HDPE, PP, PET that will be used in non-food contact products, LDPE, and PVC, can potentially use recycled resins because some applications utilizing these products do not require high performance.

Multi-layered products present another opportunity to utilize recycled resins, where the recycled material is incorporated into the inner layer(s) of the product. The number of layers in these products can range from two to as many as ten layers in complex systems. Multiple layer products are formed through coextrusion, using a die designed with multiple flow channels so that multiple layers form.

Products made from engineering resins, such as polycarbonate, have a low probability of using PC or PI materials because of higher-performance specifications. In some instances, these products cannot even use in-house regrind. Because of fines which are common in regrind, products in which surface finish or appearance is a concern have little probability of using PC or PI resins.

The Food and Drug Administration (FDA) restricts or prohibits the use of post-consumer plastics in products that will have direct contact with food or beverages. The FDA restrictions may not apply to recycled resin in the inner layer(s) of a multi-layer film product as long as the outside barrier layers in direct contact with the food product are virgin material. Another exception to this FDA regulation is when chemically-recycled PET is used in a new PET food-grade product. Chemical recycling of PET involves dissolving or breaking down the resin into a pure polymer state before reusing in a new application, as opposed to mechanical recycling processes such as grinding and washing.

2.6.5 End-Product Customers and Markets

Proprietary manufacturers own the product that they produce and may sell one product to many different customers. Companies independently decide on their production material specifications, which expedites whether or not they decide to use recycled resins.

On the other hand, custom manufacturers produce end-products that are owned by their customer(s); therefore, these products are produced for and sold only to the designated customer. Although the manufacturer may have some influence in material selection and other matters, they are not the decision makers. This situation can make it more difficult for the manufacturer to convince their customer that using recycled resin is beneficial, especially if the owners of the tool or product generally have little or no materials knowledge or expertise.

2.6.6 In-House Equipment

Companies that own equipment with resin blending capability have an excellent probability of successfully converting to recycled resins. The ability to use flake or regrind in addition to pellets, and to blend multiple additives, demonstrates that the available equipment has blending capability.

2.6.7 End-Product Customers and Markets

Converting to recycled resins can be a demanding process and many companies, especially small sized or custom shops, may choose not to go through the process. Companies with well-trained staff, and years of experience in processing resins, are higher probability candidates. Companies with less experienced staff in processing will be apprehensive about converting due to possible complications of using the recycled resins.

2.7 Service Provider Capabilities and Resources

A list of service providers, third-party expertise, and capabilities will be helpful in selling the concept to candidate manufacturers.

3.0 SELECTION CRITERIA FOR CONVERSION PROJECTS

3.1 Generate Non-Specific List of Selection Criteria

Based on information assessed in Section 2.0, generate a list of selection criteria for the highest probability conversion projects and candidates. It may be helpful to group the criteria under headings such as Logistics, Impact, and Technical as shown in Table 5.

Table 5: Example Criteria for High Probability Conversion Candidates

Criteria Grouping	Criteria (Examples Only)
Logistics	Location (geographic boundaries)
	Consistent supply of desired resins
	Budget and/or funding
	Commitment of potential converter
	Proprietary product and/or custom product
Impact	Secondary resin reuse capacity: (e.g., significant increase in consumption of PC or PI resin, and/or significant percent content of PC or PI resin in end product)
	Assured end market or viable new market
Technical	Resin types and grades
	Processes
	Product performance/reliability

	In-house expertise and experience of potential converter
	Proven technology or unknown technology that addresses an important technical barrier
	Transferable process

3.2 Generate Specific List of Selection Criteria

List the specific requirements and limiting factors for each criteria from the list of criteria established in Section 3.1. Refer to Table 6 as an example.

3.3 Prioritize List of Selection Criteria

Identify each criteria as "critical" or "important." List the selection criteria from most important to least important, and label with a "C" for critical and "I" for important.

Table 6: Example List of Specific Selection Criteria for Conversion Projects

Criteria	Specific Requirements and Limiting Factors (Example)
Geographic boundaries	State of Massachusetts.
Supply of desired resins	PC and PI suppliers of selected resins known to be reliable, provide high quality, and reasonable price.
Budget or funding	Candidate must be able to pay for feedstream testing, product testing, and any equipment modification or purchase.
Commitment	Candidate must show willingness, interest and commitment.
Proprietary product	Limit to proprietary products, custom products not preferred.
Secondary resin reuse capacity	Must consume at least an additional 10,000 pounds per month of PC resin, or 11,000 pounds per month of PI resin, or 11,000 pounds per month combined total of PC and PI resins.
Significant increase in consumption of PC or PI resin Significant percent content of PC or PI resin in end product	Must utilize at least an additional 10% PC content if less than 11,000 pounds per month PC resin consumed. Must utilize at least an additional 15% PI content if less than 13,000 pounds per month of PI resin is consumed.
Assured end-market or viable new market	The product must be a customer-driven requirement to increase recycled content, or the end-product must compete favorably with the current product, or market research must indicate a viable market for the product.
Resin types	Limit to bottle-grade of film-grade HDPE, bottle-grade PET, and injection grade PP, and film grade LDPE.
Processes	Limit to extrusion, injection and blow molding. Blending capabilities (equipment and expertise) may be important.
Product performance/reliability	Candidate must have in-house testing capability for feedstream testing and end-product testing.
In-house expertise and experience	Required.
Proven technology or unknown technology that addresses a technical barrier	Either is acceptable.
Transferable process	Process must be transferable to other manufacturers.

4.0 DEVELOP SURVEY

Survey results must be simple and brief to maximize the return rate. Yet the survey must yield enough information from candidate manufacturers to:

- Ensure candidates with the highest probability for conversion are identified;
- Assess the technical and economical feasibility of the projects; and
- Assess preliminary compatibility with selection criteria and capabilities of service provider(s).

4.1 Survey Formatting and Design Tips

Limit the survey to two (double-sided) pages. Longer surveys may appear daunting or will take too much time to complete. If survey results will be compiled in a database, formulate questions for easy data entry.

4.2 Design Survey

Appendix A contains a list of possible survey questions and topics. These recommended questions are intended to provide a starting point for survey development and cover the important issues. Add other salient questions and edit or delete those presented, as deemed pertinent in targeting candidate converters.

After developing and formatting the survey, it may be helpful to have one or two outside parties, including a local converter, complete the survey to see if any questions might arise when respondents complete the survey. If desired, enter the 'fake' survey replies into a database to test if the wording of the survey lends itself to useful data entry for analysis.

4.3 Additional Follow-Up Information

After completed surveys are distributed, follow-up calls are completed, and survey responses are received, clarification of response(s) may be required through follow-up contact. Additionally, the survey responses may generate a few more in-depth questions that would further narrow the list of higher probability candidates. Review the information in Section 5.0 for ideas on follow-on questions.

5.0 ANALYZE SURVEY RESULTS

5.1 Categorize Candidates in Priority Tiers

Categorizing facilities into one of four tiers will assist in identifying the highest priority candidates. After reviewing surveys, rate each facility in one of the following tiers, as defined below and summarized in Table 7. Interpretation of the tier structure is somewhat subjective and one facility may not meet all the criteria for one tier. Categorization may require follow-up interview(s) or site visit.

5.1.1 Tier 1 -- High Probability Candidate Converters

- Currently using or have used PC or PI resin as a feedstream within the past year.
- Likely have in-house expertise on reuse or recycling of plastics.
- Interested in increasing recycled content in products already containing recycled content or introducing recycled content in additional products that do not contain recycled content; or want to introduce other grades and lower grades of recycled resins in their processes. Customer requirements drive use of recycled content in certain products.

5.1.2 Tier 2 -- Medium Probability Candidate Converters

- Not currently using PC or PI resin as a feedstream, and have not used recycled resin for at least the last two years.
- May have tried or researched applications.
- May have capability but needs assistance finding sources.
- May or may not have in-house expertise on reuse or recycling of plastics.
- Is aware of and interested in using recycled-content resins. Understands some of the benefits of using recycled-content resins.

5.1.3 Tier 3 -- Low Probability Candidate Converters

- Have never used, or briefly used PC or PI resin as a feedstream.
- Probably does not have in-house expertise on reuse or recycling of plastics.
- Is not aware of, or is not interested in using recycled content resins. Does not know of any benefits of using recycled content resins.

5.1.4 Tier 4 -- No Probability Candidate Converters

- Supply unavailable or inadequate at this time.*
- Does not meet selection criteria established in Section 2.0 above.*
- Technically infeasible because of reasons such as:*
  a) food-grade product regulations (or other regulations) restrict use of recycled resin;
  b) engineering resins/high performance resins;
  c) highly customized product prohibits use of recycled resin; and
  d) rotational molding.
- May or may not have used PC or PI resin as a feedstream in the past. If have used, they made a strong effort and know recycled resin will not work in given process(es).
- No interest after repeated contact, or hostile response to survey and phone calls.
- Insignificant quantity of PC or PI feedstream will be consumed.
- May or may not have in-house expertise on reuse or recycling of plastics.
- May or may not be aware of, or interested in using recycled content resins.
- Prohibitively expensive.

*Apply to all process capabilities or products for each candidate. If one process or product is feasible, evaluate the candidate for Tier 1, 2, or 3, based on the viable process or product.

Table 7: Summary of Tier Properties

Tier Number	Technical Feasibility	Economic Feasibility	Willingness and Commitment	Current or Recent Use of Recycled Content	In-House Technical Expertise
1	High	High	Proactive, eager	Yes	Likely
2	Medium	Medium	Moderate to keen	Maybe	Maybe
3	Medium	Medium	Little or no	No	Not Likely
4	*Not Possible	*Not Possible	Varies	No	Varies

*Apply to all process capabilities or products for each candidate. If one process or product is feasible, evaluate the candidate for Tier 1, 2, or 3, based on the viable process or product).

5.2 Eliminate No Probability Candidates

5.2.1 List the Candidates that Fall into Tier 4.

List the candidates that fall into Tier 4 and eliminate them from further analysis.

5.2.2 List the Candidates that Fall into Tier 1.

List the candidates that fall into Tier 1. Eliminate any candidates that are known to have maximized their use of recycled resin or are known to have in-house technical expertise to accomplish their conversion. These candidates may only require a few encouraging phone calls or site visits.

5.3 Rate Remaining Candidates and Select Highest Probability Candidates

5.3.1 Assign Each Candidate a Sequential Identification Number

Of the remaining candidates, start with those categorized in Tier 1, then Tier 2, and then Tier 3. Assign each candidate a sequential identification number (e.g., 1, 2, 3, etc.)

5.3.2 Compile a Matrix

Compile a matrix similar to Table 8 below. Example criteria and relative weight factors shown in italics in Table 8. List the candidate identification number across the top and the prioritized list of selection criteria developed in Section 3.3 above (Note: A spreadsheet is recommended for quick calculations).

5.3.3 Assign a Relative Weighting Factor

Assign a relative weighting factor to each criteria and record in the table (Table 8 shows a simple weighting scheme of 2 for critical criteria and 1 for important criteria).

5.3.4 Review the Survey Data

For each candidate, review the survey data and any follow-up information. For each criteria, assign a rating (as suggested below) for that candidate. Record the rating in the left portion of the corresponding cell for the specific candidate.

Rating	Description of Rating
3	Meets or Exceeds Criteria
2	Almost Matches Criteria
1	Does Not Meet Criteria

5.3.5 Calculate the Score

Multiply the rating (entered in the left portion of the cell) by the relative weight factor and record the result in the right portion of the cell. Sum the calculated value (entered in the right portion of the cell) for each candidate and record the total score in the bottom row of the table. The highest probability candidates for conversion projects will have the highest total score.

Table 8: Scoring Matrix for Candidates
(Example Criteria and Relative Weight Factors Shown in Italics)

Criteria Priority	Relative Weight Factor	Criteria	Candidate Identification Number					
			1	**2**	**3**	**4**	**5**	etc.
Critical	***2***	*Geographic boundaries*	/	/	/	/	/	/
	2	*Resin types and grades*	/	/	/	/	/	/
	2	*Types of Processes*	/	/	/	/	/	/
	2	*Supply of desired resins*	/	/	/	/	/	/
	2	*Product performance/reliability*	/	/	/	/	/	/
	2	*Existing market or new market*	/	/	/	/	/	/
	2	*Significant increase in consumption and/or percent content of PC or PI resin*	/	/	/	/	/	/
	2	*Interest and commitment*	/	/	/	/	/	/
Important	***1***	*Budget or funding*	/	/	/	/	/	/
	1	*Proprietary product (not custom)*	/	/	/	/	/	/
	1	*In-house expertise and experience*	/	/	/	/	/	/
	1	*Proven technology or unknown technology*	/	/	/	/	/	/
	1	*Transferable process*	/	/	/	/	/	/
Total Score: (= sum of values in right portion of cell for each column):								

Contact Information (include SIC Code).

1. Is your company a plastics manufacturer? Yes / No. If no, please describe your operations.

2. What activities or processes are conducted at your facility?

DESIGN:

- Product Design
- Design of Material Testing and End Product Testing
- Mold Design
- Design for Recyclability
- Other

FABRICATION/MANUFACTURING:

- Extrusion-profile
- Extrusion-sheet
- Co-extrusion
- Injection molding
- Injection molding-structural foam
- Blow molding
- Blown film
- Thermoforming/compression molding
- Granulation
- Polymer synthesis
- Washing

(Specify:_____)

- Rotational molding
- Sheet manufacture
- Coating
- Compounding
- Foam plastics
- Pipe manufacturing
- Resin blending
- Melt filtration
- Plastication
- Finishing and machining
- Finishing and machining

4. **VIRGIN** Resins: Indicate the types, grades (e.g. injection mold), form (e.g., pellet, regrind), quantities (pounds per year), and prices of **VIRGIN** resins consumed at your facility.

Resin	Grade	Form (e.g. Pellet)	Quantity (lbs/yr)	Unit Price

5. **POST-INDUSTRIAL** Resins: Indicate the types, grades (e.g. injection mold), form (e.g., pellet, regrind), quantity, and percent content of **POST-INDUSTRIAL** scrap consumed from in-house processes and purchased from an outside source.

Resin	Grade	Form	Quantity (lbs/yr)	Percent Content	Source In-House / Purchased	If Purchased: Unit Purchase Price

6. **POST-CONSUMER** Resins: If applicable, indicate the types, grades (e.g. injection mold), form (e.g., pellet, regrind), quantity, percent content, and unit price of **POST-CONSUMER** resin consumed.

Resin	Grade	Form	Quantity (lbs/yr)	Percent Content	Unit Price

7. Indicate the types and quantities of scrap plastic wastes generated, the quantity of in-house scrap reused in-house or offsite, and the quantity that is not reused in-house or off-site (e.g., disposed of in a landfill).

Resin	Quantity Generated (lbs/yr)	Quantity Reused (lbs/yr)	Quantity Disposed Of (lbs/yr)

8. If recycled resins are not currently used at your facility, do you have any plans to use recycled material? Yes / No. If yes, how? If no, why not?

9. Name and describe four products that have the most potential for further recycled content development.
   - 9a. What are the primary resin(s) for each product?
   - 9b. What quantity of resin (pounds / year) are consumed in each of the products?
   - 9c. What percent of feedstock, if any, is from post-consumer resin? From post-industrial resin?

10. Is your company interested in working with us to identify strategies/resources to increase recycled content in any of your products? Yes / No. If No, why not?

11. If you are not using recycled content feedstock, what are the major barrier to its use?

    - unable to find consistently high quality recycled resin
    - concerned about markets for recycled content products
    - unable to find reliable sources of recycled resin
    - technical aspects of feedstock change

- recycled resin is too expensive
- other_____

12. What markets do your products serve?

    • Local • Regional • National • International

13. Who are your customers/consumers?

    • Households • Commercial/Contractors • Industrial/OEM • Government

14. How many years has your company been manufacturing and/or processing plastics?

    • 0 - 2 years • 2 - 5 years • 5 - 10 years • 10 - 20 years • 20+ years

15. Number of employees: _____

16. Would you be interested in finding other outlets for your post-industrial resins?

17. Does your company have any plans for expansion or any equipment purchases in the near future?

18. Does your company have other facilities in the region? (Please provide name and address)

19. What further information or workshop topics would you be interested in?

20. Do you know any manufacturers who might be interested in conversion to recycled resin?