PLASTICS INDUSTRY ASSOCIATION

BETTER INDUSTRY. BETTER WORLD.

End-of-Life Vehicle (ELV) Recycling

PHASE I TECHNOLOGY PACKAGE

January 2018

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ACKNOWLEDGEMENTS

The Plastics Industry Association (PLASTICS) would like to acknowledge everyone who contributed to Phase I of the End-of-Life Vehicle (ELV) recycling demonstration project. These participants and their companies agreed to participate in this project, which took on an entirely new model for evaluating recovery and end-market opportunities for a stream of materials that is not currently collected. The goals were lofty at the offset, but the end results have been tangible. Each of the companies listed in this report donated valuable time through attending meetings and calls, altering workflows to accommodate collection, material processing trials and lab testing time. This was done without compensation, demonstrating their commitment to the greater good of advancing recovering opportunities for plastics.

Due to the success of Phase I of this project, this model is being replicated for other plastics feed streams, and we hope it will serve as model that other associations and institutions will adopt. PLASTICS is deeply appreciative of the faith, commitment and patience of the companies who embarked on this journey with us.

PLASTICS End-of-Life (ELV) Vehicle Recycling Demonstration Project Phase

Company Members:

Asahi Kasei
Automotive Recyclers Association (ARA)
Boston Auto Wreckers
Canadian Plastics Industry Association (CPIA)
Erema North America
Fenix Parts
Gary's U-Pull It
Geo-Tech Polymers
Innovative Injection Technologies (i2Tech)
Kal Trading
Midland Compounding & Consulting
Milliken
Noble Polymers
Post Plastics
Ravago Recycling Group
Series One
Standard Auto Wreckers
Toyota
TPEI

EXECUTIVE SUMMARY

Plastics are playing an increasingly important role in improving the safety and comfort of vehicles as well as dramatically reducing emissions over the course of a vehicles life due to light weighting potential. With plastics progressively becoming a material of choice for major parts and components, PLASTICS set out to explore the feasibility of recovering plastics from end-of-life vehicles (ELVs). Because no large-scale recovery system currently exists for plastics in ELVs, PLASTICS set out to prove both the technical and economic feasibility of collection and reprocessing for bumpers in Phase I. Bumpers were selected for their homogeneity in material as well as sheer size, at an average of 20 pounds per vehicle.

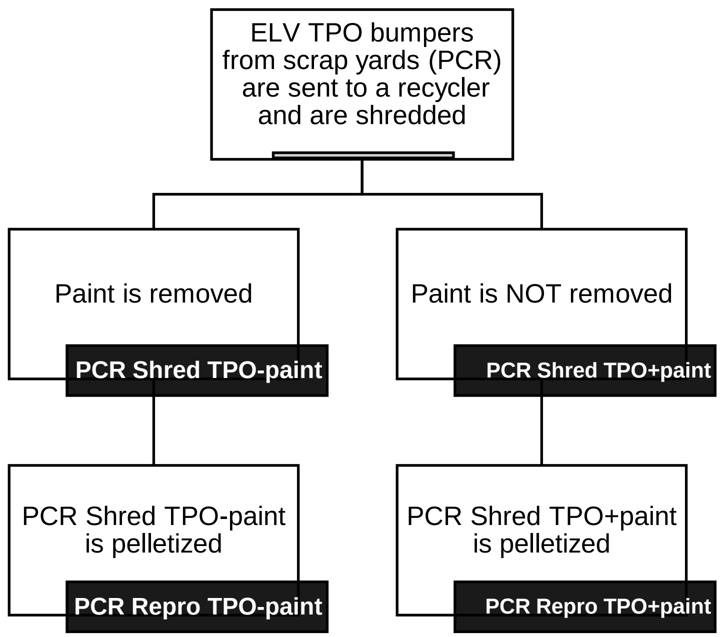
Because TPO is a higher value material, containing a valuable rubber package for improved impact and durability, the pilot demonstrated the technical recovery of ELV bumpers from a broad range of vehicles, and exhibited properties very similar to post-industrial bumpers reprocessed under the same conditions. The recycler participating in Phase I was also able to create very high-quality TPO pellets at a cost that is less than prime TPO. While the recycled TPO could not be a direct replacement for virgin TPO in a high-demand application like bumpers, the material exhibits very good properties that could make the material appropriate for non-critical applications on vehicles or feedstock for manufacturing in other industry sectors.

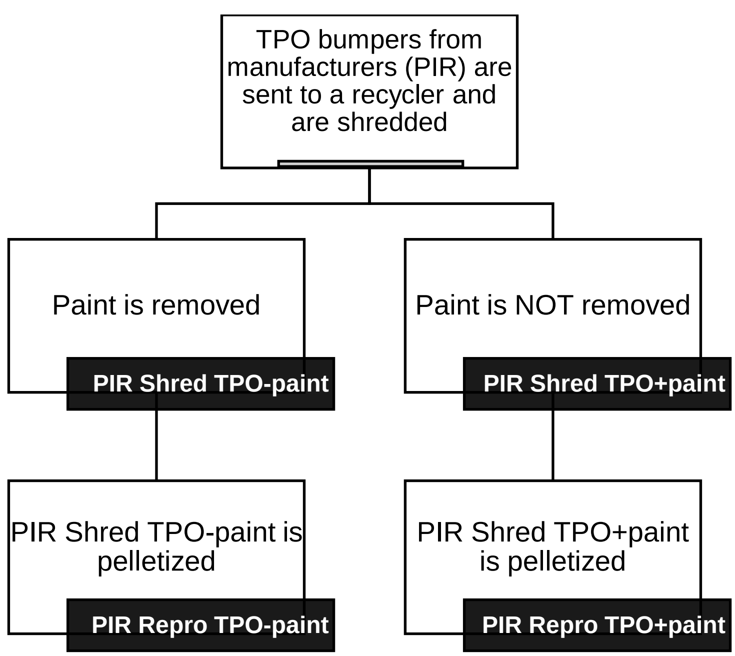
This technology package details the experience of those participating in Phase I of the demonstration project and the physical properties of the recycled TPO material. It also explores the economics of collection based on key cost variables. Some initial end market exploration was also performed for the TPO. This work ultimately resulted in the TPO material being specified for a non-critical part in a vehicle by a large, U.S. auto manufacturer, marking a very important milestone for this project. All results and learnings were promising in Phase I. Workgroup members therefore agreed that further demonstration work was warranted to prove out replicability and scalability in Phases II and III.

GLOSSARY

GLOSSARY OF TERMS

- TPO – thermoplastic polyolefin
- PCR – post-consumer recycled plastic
- PIR – post-industrial recycled plastic





BACKGROUND

BACKGROUND

Approximately 12-15 million vehicles are scrapped each year in the U.S. The average lifespan of a vehicle is estimated to be 11 years, according to IHS Automotive, and increasingly those vehicles are comprised of more and more plastics. Factors such as increased Corporate Average Fuel Economy (CAFE) standards and the unparalleled design freedom afforded by plastics are accelerating the use of plastics in new vehicle design. Recognizing the value of the plastics currently in vehicles, and the increasing amount of plastics that vehicles will contain in the future, the Plastics Industry Association (PLASTICS) sought to develop an effort to explore the recovery of plastics from end-of-life vehicles (ELVs). When the members of PLASTICS considered the best starting point to test recovery, bumpers were identified as an opportunity due to their significant volume per vehicle (approximately 20 pounds per vehicle) and the homogeneity of the material, which is typically thermoplastic polyolefin (TPO).

Currently, very few plastics are recovered before an ELV is shredded. Some scrap yards do recover bumpers for recycling, but this practice is few and far between across the U.S. and Canada. When a vehicle is retired, it is generally shipped to a salvage yard where non-damaged parts can be pulled for aftermarket sale. Once all resalable parts have been pulled, the car is then sent to an auto shredder, where the entire car is shredded and sent through a series of magnets to remove metals. What remains after metals recovery is called Auto Shredder Residue (ASR), which is landfilled. ASR is comprised of a mix of plastics, rubber, wood and other non-metal residuals.

To further explore the potential of expanding the practice of recovering bumpers before shredding, PLASTICS formed a partnership with the Automotive Recyclers Association (ARA). The goal was to identify an ARA member who operated an auto salvage yard that could test the practicality of bumper recovery on a large scale. PLASTICS chose two pathways for testing ELV bumper material: shredded TPO without paint removed (PCR Shred TPO+paint) as well as TPO after paint removal and re-pelletizing (PCR Repro TPO-paint). Through cross-supply chain engagement, this effort aimed to understand the opportunities and limitations of aggregating bumpers as well as end uses for the resulting material. With this information, PLASTICS can further explore unlocking new end-market opportunities and bridging the supply and demand gap to scale collection of bumpers across the U.S. If successful, auto recyclers can create a new revenue opportunity, and PLASTICS members create a new feed stream of TPO for remanufacturing.

METHODOLOGY

METHODOLOGY

Recognizing that establishing new collection models and cultivating new end-market demand occurs in stages and can take time, PLASTICS is approaching this project in three phases:

- Phase I goals:
  - Test technical and economic feasibility of recovery at auto salvage yards.
  - Understand how paint removal technologies that are widely used for post-industrial (PIR) bumpers could be applied to PCR ELV bumpers.
  - Understand what additional treatment needs to occur with bumper materials (i.e. metals removal, further resin separation, etc.).
  - Understand the resulting properties of the TPO once it has been thoroughly processed.
  - Evaluating how bumper material performs if the paint is not removed.

- Phase II goals:
  - Continue to demonstrate a viable collection process at auto shredding operations.
  - Further test recycling of bumpers, without paint removal as well as utilizing other paint removal technologies.
  - Understand physical properties of the TPO processed under different conditions.

- Phase III goals:
  - Seek potential end-market users of the recycled TPO from ELVs.
  - Mold and test products utilizing the recycled TPO.
  - Measure the potential demand for TPO across the U.S.

This report focuses on the learnings from Phase I, which was completed in November 2017, and offers the initial material testing and physical properties of the TPO. Based on the preliminary material testing of Phase I, the physical and mechanical properties of the material seem very promising.

PROCESS

PROCESS

After outreach to the ARA and approval from their membership to partner with PLASTICS on this demonstration project, the Canadian Plastics Industry Association (CPIA) expressed interest in simultaneously testing recovery and recycling potential for bumpers in Canada in partnership with the Auto Recyclers of Canada (ARC). ARA identified a candidate member to test and perform bumper recovery, which was Gary's U-Pull It (Gary's) in Binghamton, New York. The project officially launched in July 2016, with a kick-off event and tour at Gary's. The goals of that meeting included:

- Observe dismantling procedures,
- Provide real-time feedback on prohibitive items in the bumper shipment,
- Allow auto recyclers and plastics recyclers to ask questions, and
- Validate our target volumes and preparation methodology.

During that meeting, it was agreed upon how bumpers would be recovered and prepared for shipping to Geo-Tech Polymers (Geo-Tech), a recycler and member company of PLASTICS. Timelines and project targets were also determined at that meeting.

Within a few months, the staff of Gary's had recovered approximately 4,500 lbs. of bumpers which were sent to Geo-Tech for processing. Geo-Tech cleaned and pelletized the TPO for distribution to interested parties to perform further testing and evaluation. The contributions and roles of each participating company are outlined in the subsequent section. Unfortunately, due to space limitations at candidate facilities in Canada, none of the ARC members were able to collect bumpers during Phase I. However, Post Plastics in Canada was able to participate by providing samples of shredded bumpers, and the resulting analysis of their sample materials is captured in the *Evaluations* section.

Economic Feasibility of Recovery

Maintaining the right balance of supply and demand is critical to the lasting success of any recycling system. Auto Recycler Association (ARA) members were keenly interested in understanding the economic potential that existed for recovery of TPO bumpers. Offering pricing for TPO bumpers on a universal scale is not something that could be estimated as part of this project due to anti-trust concerns. The project team determined that an economic pro forma could be created that would account for all the profit and expense variables, and could be used as a tool for auto recyclers to determine if bumper recovery would be a profitable activity at their facility. In the economic pro forma, auto recyclers are asked to input variables, including:

- Number of vehicles process annually
- Employee average hourly wage for conducting bumper recovery
- Estimated number of bumpers recovered per hour
- Plastic recycler estimated price per pound payment for bumpers
- Transportation costs
- Method of preparation (loose, baled, shredded)

Once those variables are entered on the spreadsheet, the pro forma calculates what the auto recycler's estimated profit or loss might be if they perform recovery within the boundaries of the estimated variables.

This tool needs to be further vetted in Phase II of the research to better test reliability as well as determine profitability of recovery activities under different conditions for auto recyclers. The economic pro forma can be found in Appendix A.

EVALUATIONS

EVALUATIONS

Automotive Recyclers Association (ARA)

Established in 1943, the Automotive Recyclers Association (ARA) is an international trade association which has represented an industry dedicated to the efficient removal and reuse of automotive parts, and the safe disposal of inoperable motor vehicles. ARA believes it is critical to establish national policy that promotes effective competition in the markets for replacement parts and equipment to ensure efficient repair and maintenance of motor vehicles around the globe.

ARA services approximately 1,000 member companies through direct membership and more than 2,000 other companies through affiliated chapters. Suppliers of equipment and services to this industry complete ARA's membership. ARA is the only trade association serving the automotive recycling industry in twelve countries internationally.

ARA aims to further the automotive recycling industry through various services and programs to increase public awareness of the industry's role in conserving the future through automotive recycling and to foster awareness of the industry's value as a high quality, low cost alternative for the automotive consumer. ARA encourages aggressive environmental management programs to assist member facilities in maintaining proper management techniques for fluid and solid waste materials generated from the disposal of motor vehicles.

Gary's U-Pull It

The ARA was asked to produce at least one-member company to participate in the pilot study. Gary's U-Pull It proved to be an ideal candidate. The ELV project was officially launched with a meeting at Gary's in July 2016. At that meeting, an action plan was developed to test recovery of bumpers at Gary's facility and ship those bumpers to Geo-Tech Polymers. The result of this collaboration was the shipment of 4,500 pounds of baled bumpers to Geo-Tech in Fall 2016. Gary's was an ideal facility for testing for several reasons:

- Experience with pulling parts for mechanical recycling
- Past involvement in ARA recycling initiatives
- Owns a baler, which allowed them to achieve ideal densities for shipment

- Willingness to participate in demonstration work that would advance the recycling of plastic auto parts not eligible for resale

Brief History of Gary's U-Pull It

Mr. Gary Beagell founded Gary's U-Pull It in 1979 and still serves as its Chief Executive Officer. Mr. Beagell has served as President of the ARA and has owned/operated multiple self-service automobile recycling centers throughout the U.S. He has been a leader in the automotive recycling industry.

Gary grew up working at the family business and married his wife Linda in 1970, after which they opened several businesses, including Gary's U-Pull It in 1979. With humble beginnings utilizing a trailer as a sales office, a plot of land in Binghamton, NY, a few dedicated employees and a vision, Gary and Linda set out to build a successful self-service auto parts business. More than thirty years later, Gary's U-Pull It has expanded from a small self-service automotive recycling center to a mature facility, recycling 11,000 vehicles per year, keeping the community free of unwanted vehicles and providing quality used auto parts at affordable prices.

Gary is also a pioneer in recycling technology and holds patents in automotive fluid management systems and has developed yard management software. He is currently a director of Fenix Parts, Inc., a business that owns full and self-serve professional automotive recycling yards in the US and Canada and whose growing network services collision shops, mechanical repair shops and individual retail customers.

In addition to being a leader on the front line of the industry, Gary is committed to the state and international automotive recycling professional associations. He was twice president of the Automotive Recyclers Association of New York and served as president of ARA in 2007. He has travelled the world learning and educating others on best management practices in automotive recycling.

Contact information for Gary's U-Pull It is:

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GEO-TECH Polymers

Geo-Tech Polymers, an AGNI International Family Company, is an Ohio-based processor of plastic that serves various industry segments such as consumer, medical, automotive, furniture, etc. and was recognized by the American Chemical Society in 2015 with an Award for “Green Environmental Innovation”. The ACS cited Geo-Tech's patented, low cost, process for recycling painted plastic; a process that is the greenest, lowest cost, large scale solution for the recycling of painted automotive parts. Geo-Tech uses its superior chemical free technology to generate the highest possible savings from waste material, and to deliver recycled plastic that can be 100% re-used, with no investment and best-in-class quality control standards across the board. http://www.geo-tech.com/top-ten/

Geo-Tech Polymers has been in business for 14 years, and employs more than 50 people at their Waverly, Ohio facility. Their core competencies are providing toll services for sorting, shredding, granulating, washing, de-coating, density separation through float/sink, extrusion, quality assurance testing and specialty compounding. Geo-Tech process a wide range of materials including: rigid and film PP – HFPP, LFPP, TPO, PC, PC/ABS, PS, ABS, PE, PET, and BOPP.

Geo-Tech Polymers received about 4,500 pounds of bumpers, baled from Gary’s U-Pull It, as pictured in Figure 1.

Figure 1. Baled Bumpers from Gary's U-Pull It

The material was generally prepared as agreed-upon; however, the bumpers did require some manual sorting and preparation prior to separation. Some of the contaminants that required removal include:

- PC headlamps
- metal clips
- nylon clips
- acetate bumpers that were not the target TPO bumper material that were mistakenly included.

The manual preparation required was relatively minimal. Examples of contamination requiring removal can be seen in Figures 2-4.

Figure 2. Metal Clips

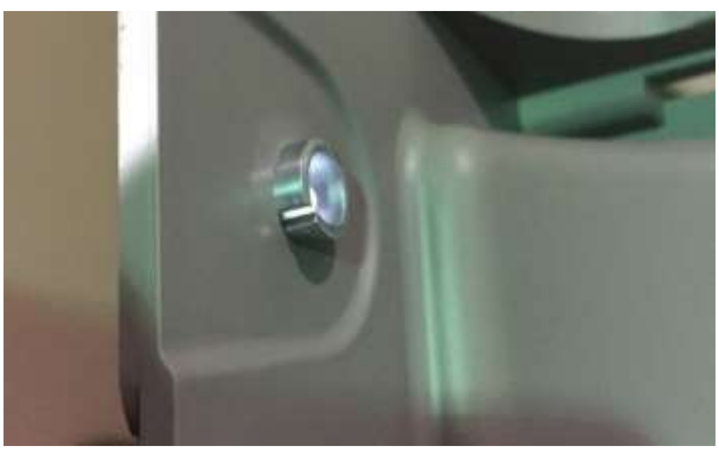

Figure 3. Metal Bushings

Figure 4. Nylon Clips

Once inspected and prepared, the bumpers were shredded, as seen in Figure 5.

Figure 5. Shredded TPO Bumpers, Before Paint Removal (PCR Shred TPO+paint)

Once the bumpers were shredded, the shred was fed into the patented cleaning technology developed by Geo-Tech. This technology can separate polymers, such as carpet fiber and backing, delaminate, de-metalize and remove paints and pigments.

The resulting material from the process is a very uniform TPO pellet, free of visible impurities, as seen in Figure 6.

Figure 6. Post-Consumer Recycle (PCR) TPO Pellet recovered from ELV Bumpers (PCR Repro TPO-paint).

Geo-Tech was able to perform some preliminary physical property testing on these pellets. The Geo-Tech lab analysis is contained in Table 1.

Table 1. Mechanical Properties of PCR Repro TPO-paint from Geo-tech

Test	ASTM Standard	Value
Ash content (%)	5630	19.7
Flex modulus (psi)	790	124479
Izod (ft-lb/in)	256	13.76
Melt Flow Index (g/10min)	1238	22.9
Moisture (%)	6980	0.388
Shrink (%)	955	0.91503
Durometer	2240	58

Based on the testing performed at Geo-Tech, it was determined that the PCR Repro TPO-paint had desirable physical properties, including high strength, low moisture and high resistance. Based on this information, several other participants elected to further test the sample for properties and potential end-use applications.

In addition to processing post-consumer recycle (PCR) ELV bumpers, Geo-Tech has extensive experience processing post-industrial (PIR) bumpers. Post-industrial TPO material is of high value and quality and can go back into many high-performance applications. Geo-tech shared a side-by-side comparison of the ash content and melt flow of both PIR and PCR TPO streams. Based on Geo-Tech's experience, PCR TPO material from ELV bumpers performs very similarly to PIR bumpers, which can be seen in Table 2.

Table 2. Properties of PCR v. PIR TPO from Bumper Scrap

	% Ash content (ASTM 5630)	MFI g/10min (ASTM 1238) 230°C @2.16 kg
PCR Repro TPO-paint	20%	15 g/10min
PIR Repro TPO-paint	19%	16 g/10 min.

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MIDLAND COMPOUNDING & CONSULTING

Midland Compounding & Consulting (MCC) compounds prime and post-industrial thermoplastics. Their mission since 1999 is to develop specialty thermoplastic compounds and offer unique solutions to difficult recycling opportunities, applying expertise in formulation and compounding to produce value-added materials. The MCC lab is designed for plastic recycling research with processes for validating materials, through fabrication and testing, to verify that new materials will work in commercial practice. Their expertise made them an ideal partner in evaluating TPO from ELVs for this demonstration project.

With more than 50,000 square feet of industrial space, MCC provides capabilities and processing support suited for developing products from prototype through to pilot production completing case studies that demonstrate the benefits obtained from using recycled materials. MCC collaborates with groups like PLASTICS on the ELV demonstration project, and The Sustainable Research Group, as well as engaging colleges and universities in research projects. MCC offers commercial grades of post-industrial ABS, Acrylic, ASA, PC, PC/ABS blends, nylons (filled and unfilled), and polypropylene materials.

MCC's team comprises of a broad range of experience from materials formulating to process engineering of plastics. Current employment is twenty people in operations, engineering and maintenance positions. MCC works with several sectors including: automotive, defense, industrial materials, office furniture, packaging, sporting goods and the textile industry.

MCC has made many contributions to Phase I of the ELV project, including evaluation of PCR Repro TPO-paint as well as PCR Shred TPO+paint. Their efforts were conducted in two steps. For the first step, MCC received a sample of painted TPO regrind from an automotive Tier 1 injection molder. This sample was compounded with another functionalized polymer to make the paint compatible with the TPO base resin. The experimental sample and the original unmodified material were injection molded into ASTM test specimens and the mechanical properties compared. The results from the phase 1 experiment are listed in Tables 3 & 4.

Table 3. MCC Physical Property Testing of Post-Industrial Modified and Unmodified TPO+Paint

ASTM Method	D638						
	Tensile Yield	**Tensile Strength**	**Yield Elongation**	**Break Strength**	**Break Elongation**	**Tensile Modulus**	**Testing Speed**
Sample	**PSI**	**PSI**	**%**	**KSI**	**%**	**KSI**	**in./min.**
Unmodified Shred TPO+paint	2,435	2,437	5.29	1,934	27	195	2
Modified Shred TPO+paint	1,766	1,920	17.26	1,919	352	128	2
Notes: MFR Tested at 230°C/2.16 kg							

Table 4. **MCC Physical Property Testing of Post-Industrial Modified and Unmodified TPO+paint (continued).**

ASTM Method	D790			D256	D5630	D1238	
	Flex Modulus	**Flex Strength**	**Secant Modulus**	**Notched IZOD**	**Ash Content**	**MFR**	**Hardness**
Sample	**KSI**	**PSI**	**%**	**ft.lbs/in.**	**%**	**g/10min.**	**Shore D**
Unmodified Shred TPO+paint	169	3,648	171	7.7	16.1	21.5	61
Modified Shred TPO+paint	94	2,167	97	8.8	18.9	13.4	52
Notes: MFR Tested at 230°C/2.16 kg							

MCC concluded from this work that the residual paint can be made compatible with the TPO, due to the increased elongation and IZOD impact strength. However, the resultant modified material is too soft to returned for utilization as raw materials for automotive bumpers. Furthermore, the surface of the parts molded from both materials was “pitted” due to the presence of the paint.

For phase 2 of this study, a sample of recycled TPO from painted bumpers was provided by Geo-Tech from PLASTIC's ELV project. This sample was from ELVs and had been "washed" in the patented Geo-Tech process to remove the paint, then pelletized. The sample was injection molded into ISO test specimens and compared to the BMW specification for reprocessed PP/EDPM material. The results from this work are listed in Table 5.

Table 4. MCC Evaluation of PCR Repro TPO-Paint from Geo-Tech

Properties		Test Method	Mercedes Spec. PP/EPDMT 10	Reprocessed TPO
Physical				
	Specific Gravity, g/cc	ISO 1183	0.96	0.9975
	Ash Content	ISO 3541	10(+/-2)	13.7
Mechanical				
	Tensile Modulus, MPa	ISO 527-1	1000	1365
	Tensile Break, MPa	ISO527-1	12	14
	Ultimate Tensile Strength, MPa	ISO 527-1	_	18
	Elongation @ Break, %	ISO 527-1	80	50
	Flexural Modulus, MPa	ISO 178	-	1,495
	Flexural Strength, MPa	ISO 180	-	25
	Unnotched, Izod Impact, (kJ/m^2)	ISO 180		
	• @ 23°C		No Break	-
	• @-30°C		No Break	-
	Notched, Izod Impact, (kJ/m^2)	ISO 180		
	• @ 23°C		-	33.75
	• @-30°C		-	8.75
Rheological				
	Melt Flow Rate (230°C/2.16 kg) g/10 min.	ISO 1133		25

MCC concluded from this work that the PCR Repro TPO-paint from Geo-Tech offered good potential as a stream of recycled material.

A few weeks after completing this study, MCC was asked by an automotive OEM to provide a sample of reprocessed TPO material for a secondary mud flap on a small-volume vehicle. Its primary requirement was that it needed to have a melt flow rate greater than 20 grams per 10 minutes. MCC decided to submit the Repro TPO-paint from Geo-Tech. The material was molded in mid-February 2017 and was given an initial approval by the Tier 2 Injection Molding company. A picture of parts molded from the material is provided in Figure 7 below. MCC will continue testing on this material to provide all the necessary data to the OEM for final approval.

Figure 7. MCC Molded Parts from PCR Repro TPO-paint Provided by Geo-Tech

MCC further performed a comparative test of the Geo-Tech PCR Repro TPO-paint with the PCR Shred TPO+paint received from Post Plastics in Canada. Post Plastics largely recovers ELV bumpers from collision centers and auto body repair shops. Mechanical properties of the two samples can be compared in Table 6. The sample from Post Plastics shows higher strength and impact resistance than the sample from Geo-Tech PCR Repro TPO-paint sample that was washed and pelletized prior to molding. A primary contributing factor to the differences in mechanical properties could be due to the additional heat history of the pelletized Geo-Tech material.

Table 5. Comparative Analysis of Geo-Tech PCR Repro TPO-paint with PCR Shred TPO+paint Samples from Post Plastics

Properties	Test Method	Geo-Tech Sample	Post Plastics Sample
Physical			
Specific Gravity, g/cc	ISO 1183	0.9975	1.01
Ash Content	ISO3541	13.7	16
Mechanical			
Tensile Modulas, MPA	ISO527-1	1,365	1,640
Tensile Break, MPa	ISO527-1	14	18
Ultimate Tensile Strength, MPa	ISO527-1	14	18
Elongation @ Break, %	ISO527-1	50	23
Flexural Modulus, MPa	ISO 178	1,495	1,537
Flexural Strength, MPa	ISO 178	25	26
Notched, Izod Impact, (kJ/m^2)	ISO 180		
@23°C		33.75	43.36
@-30°C		8.75	Not tested
Rheological			
Melt Flow Rate (230°C/2.16kg) g/10 Min.	ISO1133	25	13

MCC molded two plaques from the Post Plastics materials. While the sample from Post Plastics shows higher mechanical properties, the residual paint created an uneven surface appearance on the plaque compared to the washed and pelletized Geo-Tech material. Based on appearance alone, this regrind would only be considered as feedstock for non-visible utility application. The aesthetic limitations of the shredded TPO+paint is visible in Figure 8.

Figure 8. Plaques Molded by MCC with PCR Shred TPO+paint from Post Plastics

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INNOVATIVE INJECTION TECHNOLOGIES (i2Tech)

i2Tech was founded in 1960 under the name Morton Custom Plastics. It has been i2-tech for 13 years. On an average basis, the company employs 180 people. The company's core competencies are widely varied and include:

- custom injection molding from 55 to 3300 tons
- in-mold labeling
- insert molding/over molding
- gas assist
- value-add such as assembly and decorative markings

i2Tech can process any injection moldable resin grades, and traditionally stocks more than 400 resins in house to meet varying customer needs. Because of the range of experience in resin and recycled materials, they were also an excellent partner for testing the two streams of TPO in the ELV demonstration project.

i2Tech received two samples of the ELV bumper material; PCR Repro TPO-paint and PCR Shred TPO+paint. The company did not perform physical property testing; rather, they took the samples directly into product application, molding the samples using transfer molds. For this particular application, which was pallets, the previous molder could not meet cost, quality and delivery expectations for the customer, so i2Tech was looking for cost-competitive materials to deliver on price point and performance expectations for their customer. Both TPO samples processed much better than the material currently being used for this customer. Current mix of material can be seen in Figure 9.

Figure 9. Current Material Mix Used by I2Tech for Customer Application

The PCR Repro TPO-paint sample was fully reprocessed, extruded and pelletized from Geo-Tech Polymers. The pellets visibly appeared to have virgin-like resin quality, and that is exactly how it performed, according to i2Tech's experience. They loaded the material and were making good, consistent, full parts from the very first trial.

The PCR Shred TPO+paint sample received was much less consistent, having simply been shredded and granulated. The paint is still visibly present, as seen in Figure 10.

Figure 10. PCR Shred TPO+paint.

The PCR Shred TPO+paint sample created processing challenges that i2Tech could not overcome. Upon loading the PCR Shred TPO+paint into the extruder, it immediately gummed up the machine barrel and began to smoke, and liquid began to ooze out of the back of the barrel. After contacting Geo-Tech to troubleshoot the issue, it was noted that the PCR Shred TPO+paint had been dried. The suggestion was to dry the PCR Shred TPO+paint. After drying, the PCR Shred TPO+paint performed better, but i2Tech still had some smoking and liquid from the second trial of the shredded sample.

In the end, i2Tech was able to mold two different version of pallets with the PCR Repro TPO-paint—a one-time use pallet and a more robust racking pallet. These pallets outperformed current materials and overcame some creep issues in molding that had been experienced with the traditional mix of material that had been used. Performance of the PCR Repro TPO-paint exceeded expectations for pallet applications. If the economics can be worked out, this could be a very good drop-in replacement material for some of i2Tech's customer applications.

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TOYOTA

As a member of PLASTICS's Transportation and Industrial Plastics (TIP) committee, Toyota evaluated the pelletized TPO with paint removed (PCR Repro TPO-paint) that was processed by Geo-Tech Polymers. The PCR Repro TPO-paint was shipped to the TMNA-R&D Ann Arbor facility where it was visually inspected before molding and evaluation per ISO. Key physical properties were then compared with common Toyota polypropylene/TPO specifications.

The initial impression of the PCR Repro TPO-paint material was very positive. There was no abnormal odor, which can often be present with PCR plastics. The pellets were uniform color (black) and shape (cylindrical), suggesting they would process well. The processing lab used magnet bars on hopper and found that no metal particulate was present in measurable quantities in the resin. Lastly, the pellets processed within parameters with 'conventional' TPO grades.

After processing, a variety of testing was conducted to evaluate physical and mechanical properties of the PCR Repro TPO-paint pellets. Those properties can be found in Table 7.

Table 6. Toyota Evaluation of PCR Repro TPO-paint Pellets from Geo-Tech Polymers

Evaluation	Method	Units	Average
Specific Gravity	ISO 1183	-	0.99
Flex Stress at Yield	ISO 178	MPa	21.0
Flex Modulus	ISO 178	MPa	1166
Tensile Stress at Yield	ISO 527	MPa	18.1
Strain at Break	ISO 527	%	279.9
Modulus of Elasticity	ISO 527	MPa	1196
Notched Charpy (23°C)	ISO 179	kJ/m^2	50.6
Notched Charpy (-30°C)	ISO 179	kJ/m^2	4.4
Temp of Deflection (1.80 MPa)	ISO 75-A	°C	46.7
Temp of Deflection (0.45 MPa)	ISO 75-A	°C	79.7
Dynatup (total energy 23°C)	ISO 6603	J	28.1
Dynatup (total energy -30°C)	ISO 6603	J	26.7
Melt Flow Index	ISO 1133	g/10 min.	28
Ash Content	ISO 3451`	%	14.2

Toyota then compared the properties of the PCR Repro TPO-paint sample from Geo-Tech to the existing material specifications for TPO parts. The standard deviation and standard deviation as a percentage of the mean is displayed in Table 8. This comparison reveals how far off the PCR Repro TPO-paint is from the virgin material specifications. Overall, the PCR Repro TPO-paint performed very well, demonstrating wide variability in performance in only two areas – strain at break and Dynatup (total energy -30°C).

Table 7. Comparison of PCR Repro TPO-paint from Geo-Tech to Prime Resin Spec for Toyota Parts

Evaluation	Method	Units	Average	St. Dev.	(St. Dev as percent of Mean)
Specific Gravity	ISO 1183	-	0.999	0.001	0.1%
Flex Stress at Yield	ISO 178	MPa	21.0	0.265	1.3%
Flex Modulus	ISO 178	MPa	1166	14	1.2%
Tensile Stress at Yield	ISO 527	MPa	18.1	0.2	1.2%
Strain at Break	ISO 527	%	279.9	171.5	61.3%
Modulus of Elasticity	ISO 527	MPa	1196	27	2.2%
Notched Charpy (23°C)	ISO 179	kJ/m^2	50.6	1.5	3.1%
Notched Charpy (-30°C)	ISO 179	kJ/m^2	4.4	0.12	2.6%
Temp of Deflection (1.80 MPa)	ISO 75-A	°C	46.7	0.5	1.1%
Temp of Deflection (0.45 MPa)	ISO 75-A	°C	79.7	0.7	0.9%
Dynatup (total energy 23°C)	ISO 6603	J	28.1	0.77	2.7%
Dynatup (total energy -30°C)	ISO 6603	J	26.7	6.5	24.6%
Melt Flow Index	ISO 1133	g/10min	28	0.1	0.2%
Ash Content	ISO 3451	%	14.2		

Based on the testing performed, it was determined the PCR Repro TPO-paint has good toughness but is lacking in strength needed to meet material specifications for Toyota's automotive parts. The large standard deviation for elongation indicates possible defects in the compounded material leading to stress concentrations and early failure during elongation of some test pieces. It should be noted that no additional analysis of fracture/break surface was conducted to determine if inclusions exist and were the cause of failure during elongation.

While this batch of PCR Repro TPO-paint from Geo-Tech failed to meet any Toyota material specifications, for trim parts, filled PP, instrument panel (dashboard) or bumper fascia, members of the Toyota materials team believes this TPO has a promising future in other non-auto applications. The low density of the material is appealing. It is possible that the properties could be balanced by compounding with additives and minerals to improve applicability, which should be further explored in future phases of research, but specifically the variability in elongation would need to be addressed.

CONCLUSIONS

CONCLUSIONS

The initial evaluation of ELV bumpers in two forms, processed and pelletized with paint removed (PCR Repro TPO-paint) and simply shredded with the paint remaining (PCR Shred TPO+paint) have been promising. The testing of physical and mechanical properties has garnered enough interest amongst compounders and potential end users to warrant further continuation of this research. The areas of additional research needed in subsequent phases are outlined below.

Replicability

While initial testing has been promising, proving replicability of the performance of this material will be key in developing confidence in this material and unlocking end-market demand. To demonstrate consistency, multiple samples of ELV TPO materials need to be collected from different locations and processed by different recyclers. Testing potential variability of samples will be a primary focus of Phase II.

Economic Feasibility

One of the primary challenges of launching a platform for the collection of a new commodity is ensuring the economics are sustainable. While the workgroup that developed the economic pro forma has high confidence this tool will be effective in determining the economic benefit for collectors, it needs to be further tested under different conditions so it can be used with reliable predictability.

Also of importance is that the resulting ELV TPO material ready for manufacturing be cost-neutral or a cost advantage to the user. Because the rubber package in TPO is of significant value, the economics of recycling the ELV TPO balance in a way that makes the PCR TPO attractive to end users from a cost perspective. This will be an important value proposition in opening potential end-markets for this material. This needs to be further proven with end users.

End-Market Exploration

It is very encouraging that PCR and PIR Repro TPO-paint that has been processed by Geo-Tech and further compounded by MCC has already been qualified for an OEM automotive application. Further evaluation by workgroup members has also proven promising. Based on findings and experience, the workgroup has signaled that if the quality of the material remains consistent, both processed with paint removed and processed with paint remaining, identifying end markets for the material will not be a problem. The next phases of work will seek to better identify those end-market applications for the appropriate streams.

In particular, the lower the processing cost can be kept, the greater the cost savings value proposition can be pushed with end users. If the physical and mechanical properties of the PCR Shred TPO+paint can be better evidenced, a greater demand can be cultivated for this material. What is most encouraging is that the practice of recycling PCR Shred TPO+paint from ELV bumpers is already being practiced in other parts of the world, including India. Banyan Nation, a one-time participant in the ELV workgroup shared their experience with end-markets for PCR Shred TPO+paint bumper material. They identified the following applications as potential end uses for PCR Shred TPO+paint, including:

- 2-wheeler helmets
- side compartment of 2-wheelers
- flower pots
- shipping pallets
- buckets
- containers to carry grains, etc.
- transformer coil housing
- bobbins and cores to wrap cables, etc.

This information will help us explore options for PCR Shred TPO+paint materials in subsequent phases of research.

Next Steps

Due to the promising results from Phase I, PLASTICS plans to allocate resources and staff time to further exploring the economic and technical feasibility of recovering bumpers from end-of-life vehicles. Partnering with associations that represent different parts of the auto recycle value chain will be an important piece of the next phases of research.

To test the potential to scale ELV bumper collection to meaningful volumes, PLASTICS will be partnering with the Institute of Scrap Recycling Industries (ISRI) to engage their vast network of auto shredder members. This will enable PLASTICS to further explore the economic potential of collection. ISRI also has a bumper bale specification in place, which was developed to offer guidance on best practices for removal and preparation of these bumpers for sale to plastics recyclers. This experience makes ISRI and their membership an ideal partner.

PLASTICS will also continue to expand the range of workgroup members engaged on this effort, with particular emphasis on end users. While auto applications would be an ideal closed loop scenario for this material, use of TPO in other sectors with less demanding applications should also be explored.

PLASTICS launched Phase II and III of research in Q4 of 2017, with expectations to conclude the work by the end of 2018.

Companies can participate in this End-of-Life Vehicle Recycling Demonstration Project in a variety of ways from processing samples to evaluating samples to sharing samples with potential end-users. If your company can contribute to this project in any way, please contact a Plastics Industry Association staff member below:

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APPENDIX A

APPENDIX A – ECONOMIC PRO FORMA

Below are screenshots from the Economic Pro Forma tool. Please note that these photos are only meant to show a portion of the tool.

To receive a copy of the complete, fillable Excel file which will perform economic calculations when provided with requested data, please contact a member of the Plastics Industry Association (PLASTICS) staff, listed on page 35 of this report.

	A	B	C
1	**Potential annual volumes generated**		
2	Please fill in the requested data in the green-shaded cells, other cells will automatically calculate.		
3			
4	Number of vehicles processed annually		vehicles
5	Average wight of bumpers per vehicle	20	lbs
6	Estimated lbs. of plastics generated annually (4Bx5B)	0	
7	**Estimated lbs. of plastics generated montly (4Bx5B/12)**	**0.00**	**lbs./month**
8			
9			
10			
11	**Average estimates (use if individual estimates are not available)**		
12	Number of bumpers in a bale	110	lbs.
13	Average weight of a bale	1100	lbs.
14	Average number of bales to a trailer	33	bales
15	Average weight of 53 ft. trailer load - BALED	36,300	lbs.
16	Average weigth of 52 ft. trailer load - UNBALED	7,500	lbs.
17	Average weight of 53 ft. trailer load - SHREDDED	40,000	lbs.
18	How many cars does it take to fill a gaylord	55	vehicles

	A	B	C	D
1		**Economic Analysis for Plastic Auto Parts Recovery - Baled**		
2				
3	**Economic analysis for plastics recycling**			
4				
5	**Instructions:**			
6	Please fill in the requested data in the green-shaded cells, other cells will automatically calculate.			
7				
8	**1**	**Estimated Plastics Quantities for Recycling**		
9		Estimated weight of plastics generated on a monthly basis	0.00	lbs./month
10				
11	**2**	**Personell costs for recovery plastic parts**		
12		Raw labor costs (hourly wage)		$/hr
13		Estimated number of hours per month to recover plastic parts		hrs/month
14				
15		**Estimated monthly labor costs for plastics recycling**	**$0.00**	**$/month**
16		**Estimated labor cost per lbs. of material collected**	**#DIV/0!**	**labor $/lb.**
17				
18	**3**	**Transportaion Cost**		
19		Estimated lbs. shipped per trailer		lbs.
20		Estimated transportation costs to plastics recycler		$
21				
22		**Total transportation cost per lbs.**	**#DIV/0!**	**$/lb.**
23				
24	**4**	**Montly expenses for program maintenance and training**		
25		Estimated hours for employee training monthly		hours/month
26		**Estimated monthly employee training costs**	**$0.00**	**$/month**
27		Additional Misc monthly expense (tbd)		$/month
28				
29		**Total montly program maintenance costs**	**$0**	**$/month**
30		**Monthly program costs per lbs.**	**#DIV/0!**	**$/lb.**

Volume estimates | **Baled** | Unbaled | Shredded

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