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New End Market Opportunities (NEMO) for Film

PHASE I TECHNOLOGY PACKAGE

July 20, 2018

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ACKNOWLEDGEMENTS

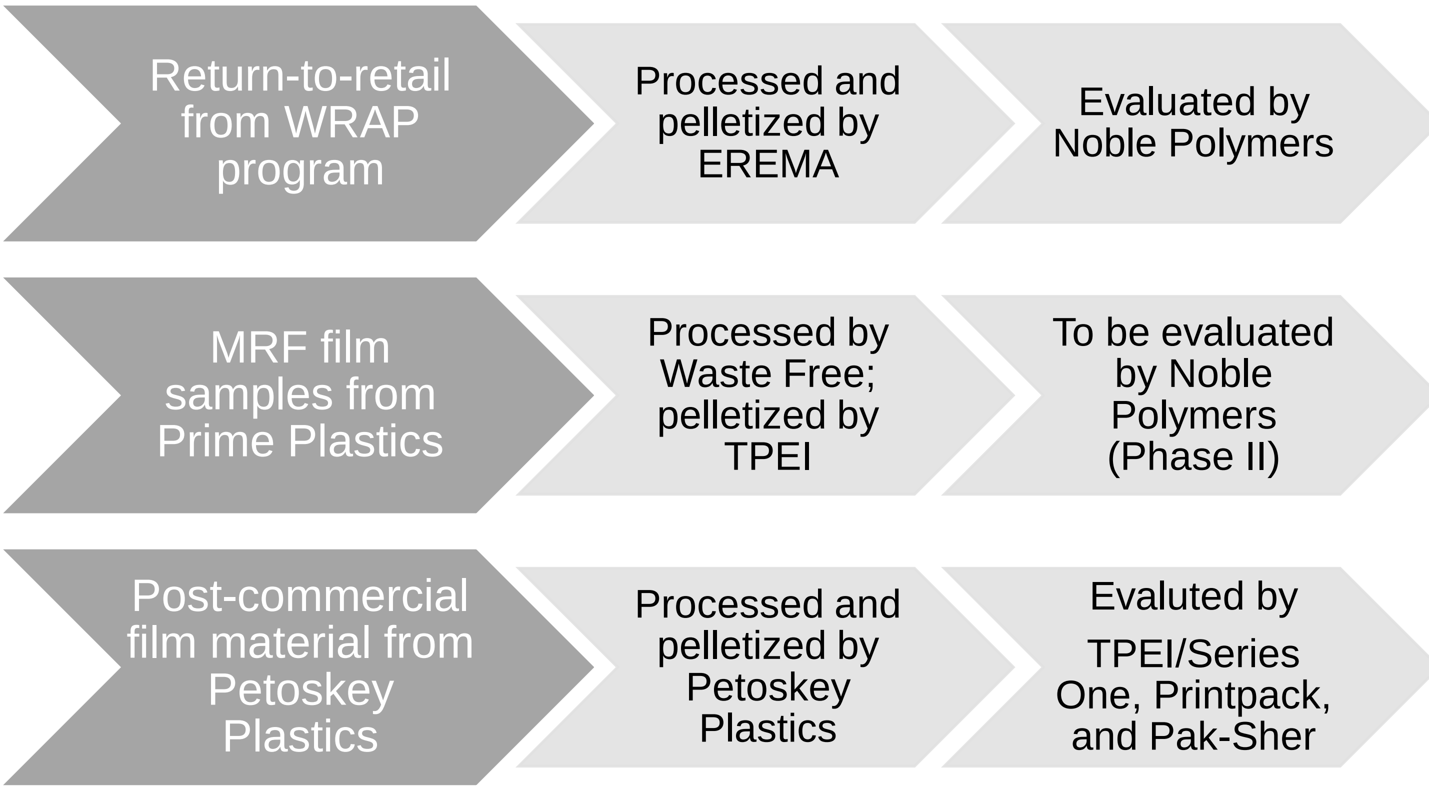
The Plastics Industry Association (PLASTICS) would like to acknowledge everyone who contributed to Phase I of the New End Market Opportunities (NEMO) for film recycling demonstration project. These representatives and their companies agreed to participate in this project, which is utilizing an entirely new model for evaluating end market opportunities for a stream of material that had limited and exhausted end markets. The goals of this project were lofty at the offset, but Phase I created a body of technical data we believe will accelerate end market identification in Phase II. Each of the companies listed in this report donated valuable resources and time through attending meetings and calls, altering workflows to accommodate material processing trials, and testing materials. This was largely done without compensation, demonstrating their commitment to the greater good of advancing recovering opportunities for plastics.

We hope this effort will serve as a model that other associations and institutions employ in pushing the boundaries of what is possible with recycled plastics. PLASTICS is deeply appreciative of the faith, commitment and patience of the companies that embarked on this journey with us and share our vision for recycling polyethylene (PE) films.

PLASTICS would also like to thank the American Chemistry Council (ACC) and Moore Recycling Associates for helping to obtain multiple Wrap Recycling Action Program (WRAP) samples through the course of Phase I research.

FLOWCHART

SAMPLE FLOWCHART



BACKGROUND

BACKGROUND

Since the inception of the Recycling Committee at the Plastics Industry Association (PLASTICS), efforts to promote recycling plastic products have been supported by focusing on creating demand for recycled materials. As the association that represents the consumers of plastics, through the Processor and Brand Owner councils, PLASTICS is uniquely positioned to convene cross-supply chain workgroups to meaningfully identify new opportunities for use of recycled plastics. PLASTICS members manufacture a wide variety of plastic products – including polyethylene films (PE) – for a wide variety of packaging and shipping applications.

Renewed emphasis has been placed on the collection of films, largely due to the recent signing of a joint memorandum by the American Chemistry Council (ACC) and the U.S. Environmental Protection Agency (EPA) to increase the recovery of PE films to 2 billion lbs. annually by 2020. This would be accomplished through the expansion of the ACC-backed WRAP return-to-retail program for PE films. This goal represents a near doubling of collection through the WRAP program, which was estimated at 1.2 billion lbs. in 2015. PLASTICS applauds the success and innovation of the WRAP program, as well as the bold stated collection goals. Based on success to date for return-to-retail film programs, there is little doubt the ACC will be successful in hitting the 2 billion lbs. collection mark. However, with challenging market conditions and limited end markets that are showing signs of exhausting demand, new concern arose about where those additional pounds of recycled PE film would go.

Based on the success of a previous demonstration model developed by PLASTICS, member companies of both PLASTICS and the ACC approached the association to develop a similar effort for PE film. PLASTICS' Flexible Film and Bag Division agreed to support this effort and a formal demonstration project was launched in January 2017.

Current market conditions

The film currently collected through return-to-retail programs by and large are remanufactured back into film products and plastic lumber. Due to residual pigments and inks from recycled shopping sacks and overwraps, putting post-consumer recycled (PCR) content back into clear film applications is very difficult. Rather, PCR-films usually go into beige, gray, or darker applications – most often these materials are used for garbage bag manufacturing. This means PE film opportunities for PCR film are somewhat limited. The second end market opportunity, plastic lumber, is currently using as much PE film as they can absorb. Despite healthy and consistent demand from these two markets, the current available supply of PCR outweighs demand and that situation will only be compounded when efforts to expand film collection are successful.

Further stressing the domestic imbalance of supply and demand is that traditional export opportunities for any oversupply of baled PE retail film has been largely eliminated with the imposition of the China National Sword actions, which ban the import of most grades of post-consumer and post-industrial scrap plastics.

If those combination of factors didn't make the situation challenging enough for growing PCR PE film for balancing supply and demand, lower prime pricing and higher prime production capacity will likely keep prime PE pricing low. Added capacity coming online also has the potential to produce a significant amount of off spec resins, which will also compete with demand for PCR PE in the market.

METHODOLOGY

METHODOLOGY

With very little control over changing these external export and market factors, the industry is challenged to find new end markets in an innovative and cost-competitive way. Not only will the films need to be processed in a less expensive fashion that will likely yield slightly diminished quality to the PCR PE film pellets currently available on the market, the performance of that PE film blend needs to be paired to the right end market application. Accomplishing this requires a fully collaborative, and open source approach to material processing, testing and evaluation.

Based on the input from the NEMO film work group, comprised of members from across the plastics supply chain, the following process was identified:

1) Secure various return-to-retail samples and understand the range of contamination and various processing methods that would not require substantial processing, including washing and drying.
2) Perform a standard set of tests on those processed samples to understand the mechanical and physical properties of the blended PE streams.
3) Identify potential end markets for the processed retail film, approach end markets with samples and data that would accelerate their evaluation process.
4) Begin to measure the size of the opportunity for this material based on positive outcomes from end market trials and communicate that back to the plastics recycling value chain so appropriate processing methods can be put into place to supply material to the targeted end market applications.
5) Work for Phase I comprised of steps one and two. Steps three and four will be undertaken in Phase II, which launched in Q4 of 2017. This report contains the qualitative and quantitative information obtained from participants in Phase I.

PROCESS

PROCESS

The NEMO film effort was officially launched January 18, 2017, when the first meeting of the workgroup was held at CP Chem's headquarters in The Woodland, Texas. At that meeting, the workgroup identified the primary goal of the NEMO film project as creating new end market demand for return-to-retail film. However, based on the input of the group, it became clear that secondary goals of the effort could be to also evaluate post-commercial film (film that qualifies as post-consumer, but is collected from businesses) as well understanding of the property differences of the streams as well as identify potential synergies in end market opportunities.

Based on discussions from the first meeting it was determined the following streams of materials would be evaluated:

- Return-to-retail film from the WRAP program
- Post-commercial film material from Petoskey Plastics
- MRF film samples provided by Prime Plastics

The Wrap Recycling Action Program (WRAP)

The Wrap Recycling Action Program (WRAP) is a rapidly emerging national public education initiative created to significantly increase recycling of polyethylene (PE) plastic bags, wraps, and film—and to divert this valuable material from the waste stream.

PE bags and wraps represent one of the fastest growing areas of recycling. Collection has surged over 1 billion lbs. and grown 84% over the last 10 years. Future program goals are to double PE film recycling to 2 billion lbs. by 2020 through greater public awareness and involvement.

All clean, dry PE film is recyclable, including grocery bags, bread bags, zip-top bags, newspaper delivery bags, dry cleaning bags, product overwraps, case wraps, shipping air pillows, and commercial wraps. But PE film requires a separate collection stream, as most municipal recycling facilities aren't equipped to handle film. Fortunately, this infrastructure already exists. An estimated 18,000 grocery and retail stores across the U.S. already collect used PE bags and wraps in bins located in storefront areas, and through this system and drop-off opportunities, 90% of U.S. consumers have access to a local PE film collection program. The U.S. likely leads the world in film collection. Because of the WRAP focus on retail take-back programs combined commercial collection, the PE recycling rate in the U.S. is 15% and quickly growing.

WRAP is an effort that has engaged the full PE film value chain including material suppliers, packaging manufacturers, brand owners, retailers and recyclers through the Flexible Film Recycling Group (FFRG) of the American Chemistry Council. FFRG has developed a variety of educational tools and best practices to engage more consumers, governments and businesses in PE film recycling. From the initial partnership with the State of Wisconsin, the ACC is implementing and planning additional partnerships with other state and local governments in the West Coast and other regions.

Testing Protocol

The NEMO film workgroup discussed the need to create a standard framework for testing various streams so the findings of evaluations would be comparable. The workgroup made it a priority to develop the following testing protocol to gather the necessary information to approach various potential end users. The tests determined necessary for potential end users for film, sheet, thermoforming, and pipe extrusion are all contained in Table 1. Tests necessary to obtain relevant data for injection molding, blow molding and compression molding are found in Table 2.

Table 1. Tests for Film, Sheet and Pipe applications

Test (X is Primary) (O is Secondary)	**Film**	**Sheet & Thermoform**	**Pipe**
MI (ASTM D1238)	X	X	X
HLMI (ASTM D1238)	X	X	X
HLMI/MI (Shear) (Ratio)	X	O	X
Density (ASTM 1505)	X	X	X
DSC Melting Point (ASTM D3418)	X	X	
Vicat Softening Point (ASTM 1525)		X	
Thermal Stability OIT (ASTM		O	O
Die Swell (ASTM D3835)	O		
Brittleness Temperature (ASTM D746)		O	O
Total Volatiles	X	O	
Ash (ASTM D5630)	X	O	
Tensile strength (ASTM D882) (ASTM D638) and Elongation	X	O	O
Flex Modulus (ASTM D790)		O	O
NCLS (ASTM F2136)			O
ESCR (ASTM D1693)		O	
Rheotens	O		
UCLS for HDPE with PCR (ASTM F3181 – 16)			O
Dart	X		
Gel Measurement	X		
Pressure Testing or Rate of back flush	X	X	X
Noticeable odor issues	X	X	X

Table 2. Tests for injection, blow and compression molding applications

Test **(X is Primary)** **O is Secondary)**	Injection Molding	Blow Molding	Compression Molding
MI (ASTM D1238)	X	X	X
HLMI (ASTM D1238)	X	X	
HLMI/MI (Shear) (Ratio)	X	X	
Density (ASTM D1505)	O	X	X
DSC Melting Point (ASTM D3418)	X	O	X
Vicat (ASTM D1525)	O		X
Die Swell (ASTM D3835)		O	
Brittleness Temperature (ASTM D746)	O	O	
Total Volatiles	O	X	O
Ash (ASTM D5630)	X		
Tensile (ASTM D638)	O	O	X
Flex Modulus (ASTM D790)	O	X	X
ESCR (ASTM D1693)	O	O	X
Durometer Hardness (ASTM D2240)	O		X
Pressure Testing	X	X	X
Noticeable odor issues	X	X	X

The PLASTICS team quickly began to coordinate initial sample collection and gathered data for these samples over the following 10 months. Sampling occurred in multiple stages and will continue in this fashion in Phase II. The sampling process begins with obtaining a primary sample, and then further processing and analysis of that sample is performed. Further processing includes some level of initial processing, usually resulting in a pellet, flake or densified material that can be further evaluated. The resulting material from the first processing step is then sent on for subsequent evaluation, either directly into product application or for physical and mechanical property testing in accordance with the protocols outlined in Tables 1 and 2.

While it was not possible to obtain values for all the desired tests, sufficient data was obtained that allowed the workgroup to determine moving onto Phase II was warranted. Based on the findings presented in the next section, the quality of the supply and resulting PE pellets suggest the material is very usable for a range of applications.

EVALUATIONS

EVALUATIONS

Of top priority for the work group was obtaining samples of return-to-retail PE film blends. Initial WRAP samples were sent to EREMA for evaluation. Secondary to that, the group wanted to take the opportunity to also evaluate MRF film, of which a sample was provided by Prime Plastics. It was determined that first densifying the MRF sample was the best option. The group also elected to test commercially-available samples of post-industrial and post-commercial (PCR) PE blends offered by Petoskey. The resulting material evaluation is detailed below.

Return-to-retail samples from WRAP program

EREMA

EREMA is one of the world's leading technology manufacturers for plastics recycling machines and system components. Founded in 1983 as a pioneer in the industry, EREMA is highly respected for their level of innovation, durability and operational reliability, with more than 5,000 systems in operation globally. In total, they produce more than 14 million tonnes of plastics pellets every year with the capability of hitting very tight material specifications.

EREMA employs more than 500 people producing several hundred systems each year. The company holds more than 100 patents, with a commitment to continue developing technologies that are better and more powerful.

EREMA systems handle all thermoplastics such as PE, PP, PET, PS, ABS, PA, PC, biopolymers or compounds. The equipment can process a wide variety of forms including films, regrind material, hollow bodies, foam, fibers, tapes, etc. EREMA manufactures recycling and melt filtration that produces quality pellets for a wide range of applications and at throughput ranges from as little as 100 lbs./hr. up to 6000 lbs./hr. The systems are used for in-house recycling, post-industrial and post-consumer plastic recycling.

EREMA offered to process and analyze material recovered through the ACC-managed WRAP return-to-retail program. EREMA initially requested three, 10 lbs. samples of material to evaluate and compare for potential contamination.

Table 3. Summary of contamination contained in the three, 10 lbs. samples of WRAP material received by EREMA.

Comment	EREMA Material No.	Initial amount [kg]	Impurity
There are some layers with paper labels and printed material [3 of 3]	2017245-1	4	> 3 % paper, > 3,8 % Multilayer (PET or PA with PO)
There is some printed material [1 of 3]	2017245-2	2	About 3,5 % PVC (soft), > 5 % paper, > 1 % Multilayer (PET or PA with PO)
There are some layers with paper labels and printed material as well as some alumina [2 of 3]	2017245-3	2,5	About 2 % PVC (soft), > 4,5 % paper, 10 % multilayer and other material (PET or PA with PO)

Examples of the type of contamination contained in the samples include:

- paper bags
- multi-layer flexible plastic packaging
- multi-layer e-commerce bags
- bags with paper labels
- water bottles
- PVC film

A complete set of photos of the contamination can be found in Appendix A of the report. Based on the piece evaluation, EREMA determined the contamination was manageable and could be easily sorted out. They agreed to perform a larger scale trial, pelletizing the mixed PE material found in a larger WRAP bale sample.

Approximately 800 lbs. of WRAP sample material was sent to EREMA for manual separation and processing and pelletization in the EREMA system. Obvious contaminants, visibly non-plastics and non-PE films were sorted out and removed before being fed into the system. Otherwise, EREMA was instructed to run the material “as is” to minimize processing costs. The material was not washed prior to entering the machine. Photos of this process can be viewed in Appendix 2.

The sample was processed on an Intarema 1108 TVE Plus.

Figure 1. Intaremea 1108 TVE Plus by EREMA

The trial system used a continuous melt filtration system with a 110-micron screen. The optimal potential throughput of the system is 400 lbs./hour, however due to contamination levels of the unwashed and further unseparated material, the system ran at a throughput for 225 lbs./hour for this test. The discharge from filtration was 77.7 lbs./hour, or a 34% contamination rate. The Intarema equipment is an all-in-one processing unit, with the following features detailed in Figure 2.

Process

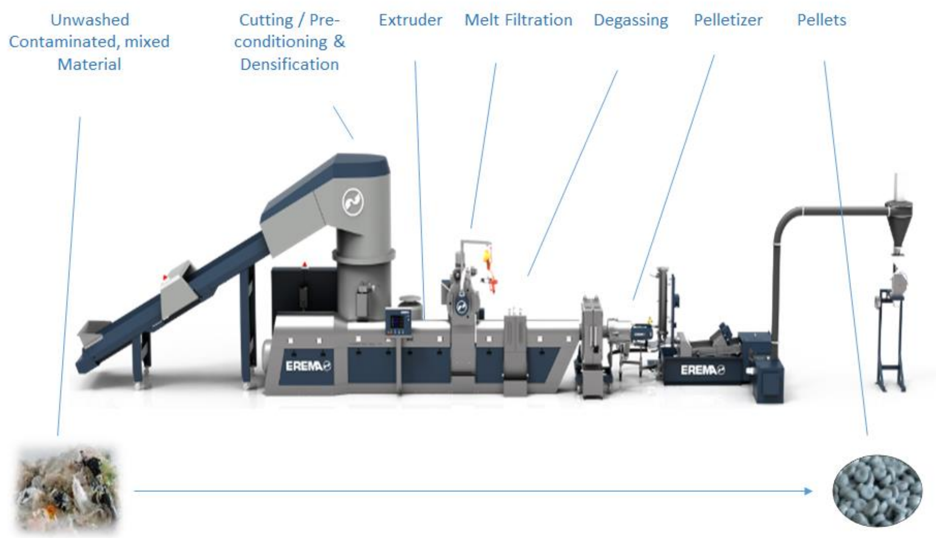


Figure 2. Intarema 1108 TVE Plus recycling process description.

Aside from the manual separation, no further value added (such as optical sorting or washing) steps were performed outside of the processing performed by this system. The resulting pellets and performance exceeded expectations for such minimal pre-processing.

Figure 3. Resulting pellets from EREMA processing of WRAP material.

EREMA preformed some initial material testing including basic mechanical properties, cast film processing and making tensile bars. The results for mechanical properties are as follows:

MFI: 0.82 g/10min

MVI: 1,07cm^3/10min (190°C. 2,16kg)

Melt Point: 122°C

The pellets were successfully processed on a lab cast as seen in Figures 4. A 15 lbs. sample of pellets was further sent to Noble Polymers for testing.

Figure 4. Cast film sample 1 and 2 from EREMA WRAP pellets.

Noble Polymers

Noble Polymers is a customer compounder of primarily polyolefin based products. The company possesses a full range of capabilities in material development, manufacturing, sourcing and logistics. They provide complete manufacturing support to customers including material selection, empirical testing, process development, and technical assistance.

Noble Polymer's product offerings consist of a complete line of standard products suited for multi-industry uses including Regis (rigid TPO), Ecobarrier (acoustic barrier soft TPO), Flextuff (TPE), and

FivePlus (filled PP) product lines. Beyond the standard product offerings, Noble Polymers specializes in formulating custom compounded resins to meet specific customer needs, as well as toll compounding and contract manufacturing services.

For the Phase I evaluation, Noble Polymers performed mechanical property testing and compared those values to a grade of LDPE that is currently utilized for making 90 gal. roll cart bins for garbage and recycling. The side-by-side comparison of properties can be seen in Figure 5. It was concluded that the values of the testing suggest this is a material that has potential in a variety of applications.

Table 4. Noble Polymers evaluation of EREMA WRAP pellets compared to commercial LDPE grade specified for a customer.

	EREMA LDPE (Aug 2017)	**Typical Cart Grade Recycled LDPE**
Flexural Modulus, ASTM D790, tangent, psi	40100	32000
Tensile Strength, ASTM D638, break, psi	2300	1500
Tensile Modulus, ASTM D638, psi	30900	30800
Elongation at break, ASTM D638, %	447	218
Gardner Impact, ASTM D5420, in-lbs	128	109
Izod Impact, ASTM D256, ft-lb/in	9.7 (NB)	8 (NB)
MFI, ASTM D1238, 190°C/2.16kg, g/10min	0.785	2.8
Specific Gravity, ASTM D792	0.9389	0.9230
Ash, ASTM D5630, %	1.30	NA
Melting Point, DSC. ASTM D3418, °C	125	NA
Hardness, ASTM D2240, Shore D	49	NA

Multiple pellet samples were distributed to end users for testing in direct end market applications as part of further evaluation in Phase II of the NEMO film project.

Return-to-retail samples from Novolex Bag-2-Bag program

Novolex

Novolex is a major player in North America's fiber based & flexible film packaging with full post-consumer & post-industrial reclaim process capabilities.

Under the Hilex (for retail bags) and WF&B (for can liner) brands, Novolex operates two post-consumer wash line reclaim plants. Most of the other Novolex film manufacturing plants also maintain full reprocessing (re-pelletizing) capacities for post-industrial film streams.

Novlex product offerings including a range of recycled content film products with varying ranges of post-consumer and post-industrial recycle content. Use of recycled content is guided by both the design limits of the product & the customer's desired specifications. Considering both of those requireents, recycled content typically ranges from 10% to 40%; however more is used where it is possible.

The two Novolex PE film recycling facilities are in North Vernon, IN and Shawano, WI. These two PCR recycling plants function very similarly, operating a full film wash line to include pre-sorting, grinding, washing, drying and pelleting.

Typical testing for Novolex includes - MF, Gels, Ash, Rheotens (melt strength), color (L, a, & b scale) & seal strength. Other testing may include FTIR, DSC, GSC (for material characterization) & moisture content.

MRF material from Prime Plastics

NEMO film workgroup members wanted to take advantage of the opportunity to better understand the quality of MRF film as a potential feedstock for manufacturing, particularly in comparison to the return-to-retail film being evaluated in Phase I. Prime Plastics, a PLASTICS member, had a supply of MRF film they were willing to offer for evaluation.

Prime Plastics

Prime Plastic Products, Inc, operates a subsidiary, Prime Plastics Solutions in Ohio. At this facility they grind various thermoplastic scrap materials. They also sort film from post-industrial and post-consumer programs. Additionally, Prime has grinders set up at various plants under a joint venture program system. This allows them to ship product directly to end users, saving money in tight margin environments. Prime is currently focused on distributing off spec and virgin resins to processors.

Based on workgroup input, it was determined that this material, which would be more highly contaminated than return-to-retail film since it was collected at the curb, should be sent for densification. Prime Plastics prepared a 10,000 lbs. sample of mixed film, including positive-sort film and negative sort film from the MRF, as well as some return-to-retail material to Waste Free in Michigan for processing. The curbside and return-to-retail film that Prime Plastics was selling was generally going into low end lawn edging type markets.

Waste Free

The material received by Waste Free did require extensive manual sorting prior to entering the continuous blending and densification system. Because of the level of manual sorting required, only about 9,000 lbs. of that load was densified as it was determined that much of the MRF film was too highly contaminated for processing without extensive manual sorting, which would have been cost prohibitive. An example of the mixed materials received in the MRF film bale can be seen in Figure 6.

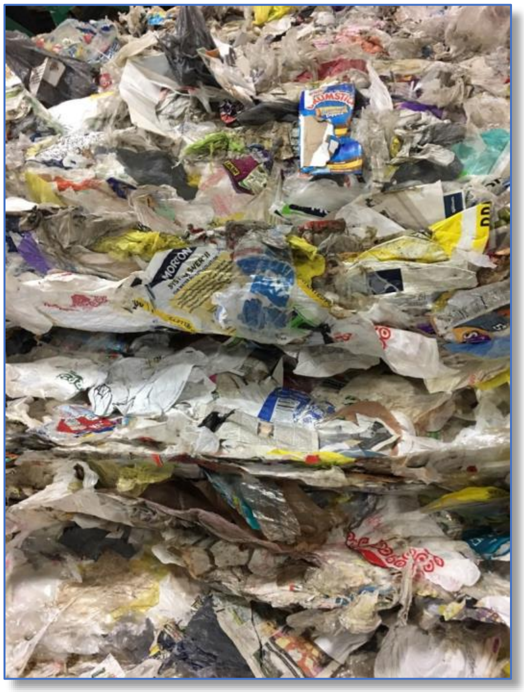


Figure 6. Example of mixed MRF film bale supplied by Prime Plastics and received by Waste Free for densification

Once sorted, removing all obvious non-plastic contaminants, the plastics were shredded, passed through a metal detector and then processed in Waste Free's unique continuous blending and densification system. Photos of the process can be seen in Figure 7.

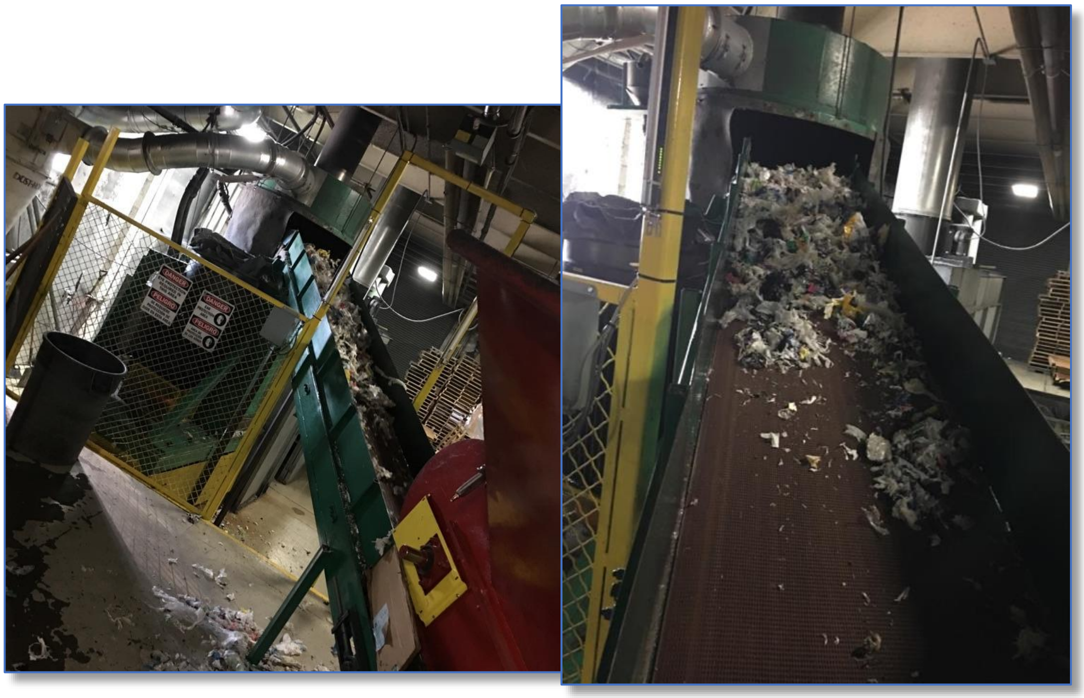


Figure 7. Waste Free continuous blending and densification system.

A 150 lbs. sample of this material was procured by Series One and transported to TPEI for pelletization. During pelletization at TPEI, the extrusion system very quickly blew the screen pack as the contaminants clogged the screen, creating pressure. The few pellets that were produced during this initial trial looked fairly good according to operators at TPEI. Due to these results, TPEI decided to install a continuous screen changer to manage the higher-level of contamination in the MRF material and again attempt to create a sample of pellets.

Post-Commercial Film Material from Petoskey Plastics

Understanding what film-grade PCR and PIR materials are currently available on the market was another important data point for the NEMO film workgroup members. Petoskey Plastics is a vertically-integrated film product manufacturer that offers a whole line of recycle-content products that use film materials recycled and pelletized by Petoskey. In addition to recycling film for use in their own product line, Petoskey sells several commercial grades of surplus recycled film-grade pellets.

Petoskey Plastics

Pellets were requested by several NEMO film workgroup members, including Series One/TPEI, Printpack, and Pak-Sher. The results of their analysis are detailed below.

Figure 5. Pellets from Petoskey Plastics, tested by Noble Polymers. Photo by Series One.

Printpack

Founded in 1956 and headquartered in Atlanta, GA, Printpack is a privately-held manufacturer of flexible and specialty rigid packaging. Employing 3,000+ associates worldwide, the company operates 19 manufacturing facilities in the United States, Mexico and China. Printpack is a leading manufacturer of flexible and specialty rigid packaging with 60 years of experience helping brands improve retail visibility, heighten brand awareness and capture market share. Printpack combines unique insights on consumer preference with advanced technological capabilities in order to convert packaging concepts into reality. Headquartered in Atlanta, GA, Printpack is a privately held company that believes cooperation and integrity result in innovation. Printpack employs associates worldwide and operates manufacturing facilities in the United States, Mexico and China.

Printpack has a broad range of package manufacturing capabilities, including: blown and cast extrusion (film and sheet), adhesive and extrusion lamination, metallizing, flexographic and rotogravure printing, coatings, laser etching and scoring, pouch and bag making, and thermoforming of high barrier rigid containers. Their full product offerings can be found on their website, printpack.com/markets**.**

Printpack received Green PE #4 & #7 from Petoskey Plastics an offered a high-level evaluation of processing performance. As described in Figure 9, Green PE #4 is a blend of PCR and PIR and GreenPE#6 is clear PIR HDPE.

These PCR samples were collected from a Municipal Recycling Facility (MRF). Only a 150/180 mesh pack was used for filtration, and some homogenization was done prior to boxing. The material used in making these samples was sorted by hand; thus, some non-polyethylene contamination was likely present. The purpose of these trials was to assess the suitability of these PCR samples for film processing.

PO #: samples
Order #: 609149
Ship #: 159848

F.O.B.: Prepaid
Ship Via: ODFL
Carrier: Old Dominion

Ship Date: 3/22/2017
Weight: 100.00

PO: SAMPLES

Pkg Code: pallet **Length:** 48.00 **Width:** 40.00 **Height:** 42.00 **IN**

Line	Part Number/Description	Planned Qty	Shipped Qty	Back Order Qty
1	RM-RE0004 GreenPE#4 PCR & PIR Clear 50 LB	50 LB	50 LB	0 LB
2	RM-RE0006 GreenPE#6 PIR HDPE Clear 50 LB	50 LB	50 LB	0 LB

Figure 9: Excerpt of packing slip for Petoskey PCR samples showing grade names and descriptions.

Trial Information

Film samples using blends of virgin LDPE and the Petoskey PCR were produced on a small blown five-layer pilot line. Printpack often uses this film line for assessing the processing characteristics and basic film properties of resins and film constructions. The line does not have auto-gauge, nor does it have internal bubble cooling.

For assessing the Petoskey PCR resins Printpack ran an approximately 8” web width (1.65 BUR) and a throughput of 10-12 pph. Due to low throughput and the aforementioned lack of bubble cooling, relaxation time (i.e., how long the resin remained in a molten state after extrusion) was approximately five seconds. The films produced were monolayer constructions and the condition compositions are given in Table 1 below.

In Table 1, PCR%, LDPE% and AB% are the film’s blend percentage of Petoskey PCR, LDPE and antiblock master batch. The LDPE used was a Marlex® 5561 Polyethylene 5561, a film grade resin with a 1.3 g/10min melt index and 0.925 g/cc density (the Marlex® 5561 Polyethylene 5561 datasheet is linked here). The antiblock master batch was a 20% loaded diatomaceous earth master batch in an LDPE carrier resin.

Condition	PCR Grade	PCR %	LDPE %	AB %
Control	n/a	0	95	5
RE0004-20	RE004	20	75	5
RE0004-40	RE004	40	55	5
RE0004-95	RE004	95	0	5
RE0006-20	RE006	20	75	5
RE0006-40	RE006	40	65	5

Table 5: Test conditions for this study showing the PCR grade tested and the amount of Marlex® 5561 Polyethylene® 5561 Polyethylene and AB added for each condition.

Processing Notes

Both resin grades had a pronounced odor and off-color. The odor was charcoal or burned, and the color varied from pellet to pellet from grey to brown to black as can be seen in Figure 10. RE-0004 was perhaps more odorous and colored than RE-0006. A picture of representative PCR pellets is given in Figure 10 below. Some processing data was collected during the run (see Table 6 below).

Figure 10: Representative Petoskey PCR pellets showing the degree of coloration.

Table 6: Some run condition parameters from the Petoskey PCR Pilot Line assessment.

Condition	Web Width (in)	Line Speed (fpm)	C-Ext			D-Ext		
			Speed (%)	PR (psi)	Amps	Speed (%)	PR (psi)	Amps
LDPE Control	8.125	11.1	35	3580	6.7	35	3890	6.9
RE0004-20	8.25	11.1	35	4520	7.4	35	4090	7.4
RE0006-20	8	9.5	35	4820	7.3	35	4590	7.4
RE0006-40	7.125	9.5	35	5560	7.8	35	5210	8.1

A list of observations from the production of the film samples is given below:

- During production of the first test condition, RE0004-20, die lip build up was noted. After this initial spate of build-up was cleaned up, the five test conditions were produced without any additional die build-up issues.
- Bubble stability was compromised by the PCR – particularly when extruding RE0006. RE0006's impact on bubble stability precluded the production of a 95% RE0006 film.
- Compared to the 1.3 g/10min LDPE control, both PCR grades ran higher head pressure and amps.
- Gel/contamination content was lower than expected, but still at least an order of magnitude higher than commercial PCR products from companies like KW Plastics or Envision. On several occasions, holes were noted in the bubble, which were likely caused by these gels/contamination. However, considering only a 150/180 mesh pack was used for filtration, the resulting film had much less contamination than expected.

Test Results

Film samples were tested for physical, tensile, and optical properties (see Table 7 below). In Table 7 the results are listed as two values separated by a slash "/". The number before the slash is the average value and the number after is the standard deviation.

Table 7: Physical property, tensile and optical property data from Petoskey PCR Pilot Line trials.

Test	Units	Control	RE0004-20	RE0004-40	RE0004-95	RE0006-20	RE0006-40
Notched Elmendorf Tear (CD)	Grams	787/92	1017/200	966/82	1100/116	1043/100	1673/152
Notched Elmendorf Tear (MD)	Grams	457/106	473/41	505/44	688/117	659/130	297/18
Un-notched Elmendorf Tear (CD)	Grams	1660/202	1740/344	1475/324	1286/229	1324/150	1830/207
Un-notched Elmendorf Tear (MD)	Grams	688/250	819/170	652/157	1033/318	758/205	419/102
Basis Weight	lb/ream	41.0/6.6	43.4/5.7	34.1/3.8	30.6/2.9	43.2/3.0	38.1/4.8
Average Gauge	Mil	3.39/0.08	4.26/0.18	3.54/0.14	3.79/0.51	3.34/0.10	3.12/0.06
Haze	Percent	19.2/2.4	29.4/2.4	36.9/2.5	52.1/0.8	31.6/0.2	36.9/2.2
Clarity	Percent	76.9/1.4	64.6/1.7	57.2/1.2	43.8/0.3	60.8/1.4	58.5/1.2
Yield	In^2/lb	10,628	10,055	12,793	14,220	10,087	11,437
Tensile Peak (CD)	Grams	2834/364	3028/397	2340/195	2253/162	3439/149	3467/237
Tensile Peak (MD)	Grams	3702/438	3569/482	2910/247	2585/170	4006/574	3930/521
Elongation at break (CD)	Percent	664/37	717/65	689/35	633/45	800/47	848/22
Elongation at break (MD)	Percent	587/16	633/53	488/33	633/39	578/28	579/40
Tensile at Break (CD)	Grams	2797/391	3017/393	2298/151	1974/340	3409/167	3453/256
Tensile at Break (MD)	Grams	3627/465	3407/569	2806/220	2383/325	3999/574	3854/447
1% Secant Modulus (CD)	Kpsi	28.3/4.7	20.9/2.4	24.4/4.4	26.3/3.4	52.6/5.8	71.4/7.2
1% Secant Modulus (MD)	Kpsi	25.2/1.7	21.6/4.7	23.4/3.5	21.2/3.3	43.5/8.4	48.5/13.3
Penetration, Slow Rate (0.9mm)	N	1.69/0.15	1.73/0.14	1.44/0.08	1.08/0.05	1.96/0.09	2.17/0.07

Resin samples underwent DSC, %Ash (TGA%), melt index, and volatiles testing. For both RE0004 and RE0006, light grey, grey, and dark grey pellets (see Figure 10) had DSC and Ash testing done separately. Further, each test was repeated once. For Melt Index testing a composite sample of light grey, grey, and dark grey pellets was used. See Table 8 below for the resin testing results.

Table 8: DSC, Ash, and Melt Index testing of the Petoskey PCR resin pellets.

Description	FTIR	DSC 2nd Heat (°C)	TGA Weight %	Melt Index g/10min @190°C/2.16Kg
(7) Light Grey -RE004 #1	PE	111.9-LDPE 124.9-LLDPE	2.95	---
(7) Grey -RE004 #1	PE	109.9-LDPE 124.3-LLDPE	2.24	---
(7)Dark Grey -RE004 #1	PE	114.4-LDPE 127.3-LLDPE	2.70	---
(7) Composite Sample - RE004 #1	---	---	---	1.72±0.02
(8) Light Grey - RE004 #2	PE	114.2-LDPE 126.3-LLDPE	3.85	---
(8) Grey - RE004 #2	PE	108.3-LDPE 124.9-LLDPE	2.40	---
(8) Dark Grey - RE004 #2	PE	108.7-LDPE 123.8-LLDPE	1.55	---
(8) Composite Sample - RE004 #2	---	---	---	1.67 ±0.02
(9) Light Grey - RE006 #1	PE	134.5-HDPE	0.13	---
(9) Grey - RE006 #1	PE	133.7-HDPE	< 0.01	---
(9) Dark Grey - RE006 #1	PE	132.4-HDPE	< 0.01	---
(9) Composite Sample - RE006 #1	---	---	---	0.16±0.01
(10) Light Grey - RE006 #2	PE	130.8-HDPE	< 0.01	---
(10) Grey – RE006 #2	PE	131.3-HDPE	< 0.01	---
(10) Dark Grey - RE006 #2	PE	131.7-HDPE	< 0.01	---
(10) Composite Sample - RE006 #2	---	---	---	0.17±0.01

Finally, resin samples also underwent volatiles testing via GC Headspace Analysis. The species tested for are given in Table 9 below, and the detection limit for each of these species was 40 ppm. None of the listed species were detected in either RE0004 or RE0006.

Table 9: List of species tested for during volatiles testing.

Volatile	Acronym
Methanol	MeOH
Ethanol	EtOH
acetone (dimethylketone)	DMK
Isopropanol	iPOH
n-propanol	nPOH
methyl ethyl ketone	MEK
ethyl acetate	EtAc
Tetrahydrofuran	THF
isopropyl acetate	iPAc
propylene glycol methyl ether	PM
n-propyl acetate	nPAc
methyl isobutyl ketone	MiBK
propylene glycol ethyl ether	PE
Toluene	TOL
2-ethoxy-1-propanol	PE2
acetyl acetone	AA
n-butyl acetate	nBAc
propylene glycol n-propyl ether	PnP
diacetone alcohol	DA

2-propoxy-1-propanol	PnP2
propylene glycol methyl ether acetate	PMAc
propylene glycol n-butyl ether	PnB
2-butoxy-1-propanol	PnB2
dipropylene glycol methyl ether	DPM
dipropylene glycol n-butyl ether	DPnB

The low melt index precludes the use of these PCRs in a cast film process except, perhaps, at very low levels. Conventional blown film extrusion is feasible, but several factors pose potential issues. Gel and/or contamination content will limit film quality and may make low gauge films impossible. Additional in-line filtration may mitigate this issue. Poor bubble stability and high operating pressures/amps may limit how much PCR can be added to a blown film. Due to discoloration, this material may be best suited to opaque films where the off-color can potentially be hidden. Overall, film quality will suffer with the use of these PCR streams in their current state. However, if used in moderation and for applications which can tolerate visual defects, potential off-odor, atypical coloration, and likely manufacturing inefficiencies, then this source of material may be usable.

Pak-Sher

Pak-Sher has been an innovator in the design and manufacture of plastic carryout bags and kitchen prep packaging since the early 1970's. Pak-Sher continues to find ways to increase the use of recycled materials and today has the capability, in our standard carryout bags, to include up to 50% PCR content sourced from recycled milk jugs. Pak-Sher continues to listen to our customers request for innovation and customization with a mantra of bringing customized solutions to their restaurants - "Where Custom is Standard". Pak-Sher has a single manufacturing facility in Kilgore, TX, where we employ 200 people.

Pak-Sher received two, 300 lbs. samples of pellets from Petoskey.

The first sample tested was an LLDPE from Petoskey. Overall, the material ran well. Pak-Sher was able to blow a 19" lay flat film at 1.0 mil with no issues. The film product did come out in a greyish color, which could likely be blended in with virgin and white color concentrate with no problem, if a white bag was required. The material did have a slightly lower the heat profile, but other than that it ran like normal polyethylene. A photo of the pellets can be viewed in Figure 9.

Figure 6. Pellets processed by Pak-Sher, supplied by Petoskey Plastics.

The second sample received from Petoskey was a PE blend of LLD+LD+HD. Due to a strong odor of burnt paper, a complete film sample was not able to be made and evaluated.

Series One/TPEI

Series One is an engineering consulting company that specializes in helping companies solve problems in the plastics manufacturing space. Their expertise includes plastics process development, plastics process improvement, industrial engineering, mechanical engineering support around design, manufacturing and testing. We also have specific expertise in manufacturing education, workforce development, non-profit development support, and professional photography.

Consultants at Series One have been instrumental in the development of recycled material formulations, material testing, recycled polymer compounding, sheet extrusion, and injection molding.

Most notably, Series One is responsible for the material formulations and the development of a process to convert waste automotive paint and waste powder coat paint into available filler for polyolefins.

Series One also has ties to the educational space through mechanical engineering faculty on staff. This allows Series One to offer capability in manufacturing lab and curriculum development, as well as workforce development experience.

Series One and TPEI received two samples from Petoskey Plastics, LDPE RME-0001 and LDPE RME 0012. Green PE #1 (RM-RE0001) is 100% PCR made from post-commercial stretch film and Green PE #12 (RM-RE00012) is 100% Post Consumer made from a blend of stretch and other films. Those samples were sent to Noble Polymers for further property testing. The results of that testing can be seen in Table 10. The results for these two samples from Petoskey are benchmarked against that same commercial grade specification for LDPE that Noble Polymers is currently providing to a customer.

Table 10. Noble Polymers testing and evaluation of Petoskey samples compared to commercial LDPE grade.

	TPEI LDPE RM-RE0001	TPEI LDPE RM-RE0012	Typical Cart Grade Recycled LDPE
Flexural Modulus, ASTM D790, tangent, psi	27900	37300	32000
Tensile Strength, ASTM D638, break, psi	1753	1901	1500
Tensile Modulus, ASTM D638, psi	22900	25900	30800
Elongation at break, ASTM D638, %	>450	>450	218
Gardner Impact, ASTM D5420, in-lbs	110	120	109
Izod Impact, ASTM D256, ft-lb/in	6.8 (NB)	8.18 (NB)	8 (NB)
MFI, ASTM D1238, 190°C/2.16kg, g/10min	2.54	1.65	2.8
Specific Gravity, ASTM D792	0.9196	0.9293	0.9230
Ash, ASTM D5630, %	NA	NA	NA
Melting Point, DSC. ASTM D3418, °C	NA	NA	NA
Hardness, ASTM D2240, Shore D	NA	NA	NA

CONCLUSIONS

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Having concluded initial sample evaluations for a variety of target film streams for phase I of the NEMO film project, the workgroup has determined that sufficient evidence suggests the quality of the return-to-retail material warrants exploration into phase II. The level of contamination of the MRF film samples raised concern about the economic viability of processing that material at this time. Due to the nature of the material, washing and further sorting steps would be required to bring the quality up to the level of the return to retail material being evaluated. For this reason, the group decided to put any further testing of MRF material on hold until end markets were identified for the higher-quality return-to-retail material. Likewise, the group felt sufficient analysis of the commercially-available grades had been conducted to offer a benchmark for performance of the return-to-retail film, and further analysis of that will be suspended in phase II.

There is ample support for continuing the NEMO film effort and advancing the project to phase II. This next phase will focus on testing direct end market application. In the April 2017 meeting, the NEMO workgroup offered the following list of potential end markets to explore in phase II:

- Agricultural plastics
- Industrial film
- Can liners
- T-shirt bags
- Bubble film
- Dimpled Sheets
- Trays
- Drums
- Buckets
- PP products
- Corrugated drainage Pipe
- Blow-Molding
- Bottles
- Jars
- Rotomoulding, big elements like containers, tanks, etc.

The PLASTICS team surveyed membership to gather information about which members might participate as consumers for these potential end markets. PLASTICS staff will follow up with those identified members as part of the end market outreach strategy for phase II, which will be launched in Q4 of 2017.

Companies can participate in this NEMO for Film 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 (PLASTICS) staff member below:

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