MATERIALS RECOVERY FOR THE FUTURE

FLEXIBLE PACKAGING RECYCLING IN MATERIAL RECOVERY FACILITIES PILOT

RESEARCH REPORT

MAY 28, 2020

PREPARED BY: RRS | recycle.com

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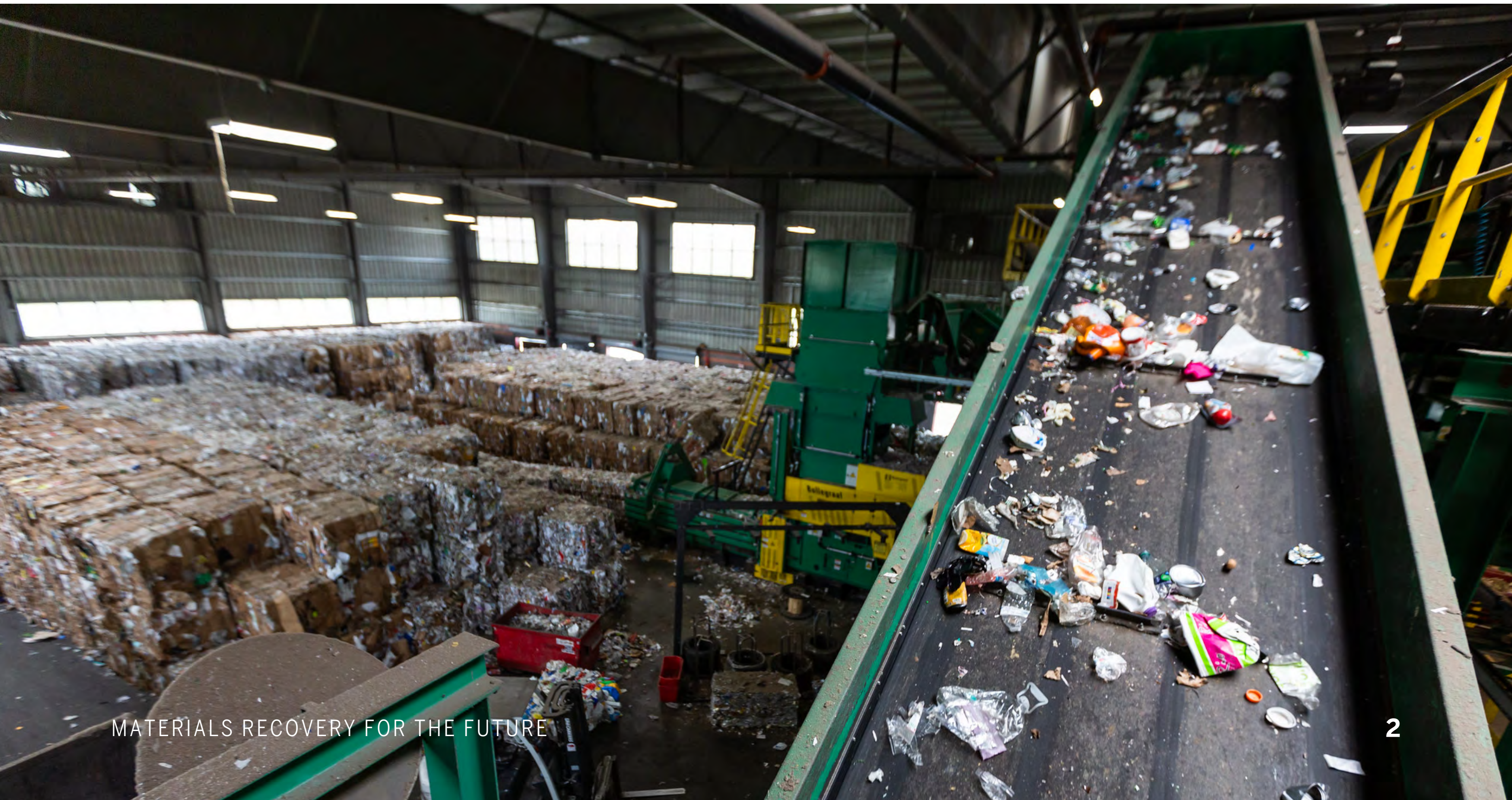

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CREDITS AND ACKNOWLEDGMENTS

CREDITS

Lead Researchers: Kerry Sandford, Christopher King, and Anne Johnson

Research Director: Susan Graff

Project Contributors: Beth Coddington, Erin Grimm, Melissa Radiwon, and Michael Timpane

The research reported herein was performed by Resource Recycling Systems (RRS) as an independent contractor. The findings, conclusions, and recommendations are strictly those of RRS. RRS makes no statements nor supports any conclusions other than those presented in this report.

ACKNOWLEDGMENTS

This research was conducted by Resource Recycling Systems (RRS) on behalf of the Materials Recovery for the Future (MRFF) project, a collaborative project administered by the Foundation for Chemistry Research and Initiatives (FCRI), a 501(c)(3) tax-exempt organization established by the American Chemistry Council (ACC). We gratefully acknowledge Steve Sikra, former Procter & Gamble; Brent Heist, Procter & Gamble; Brad Rodgers, former PepsiCo; and Diane Herndon, Nestle Purina for their leadership; and Sarah Lindsay with the American Chemistry Council for her assistance in managing the project.

The learnings from this pilot demonstration were made possible thanks to the significant contributions of J.P. Mascaro & Sons and the TotalRecycle team, the recycled plastic end market manufacturers and processors, and Van Dyk Recycling Solutions. The insights of Jan Rayman were extremely valuable to examining processes for making high performing green building products from post-consumer film plastics and beverage cartons.

RRS also acknowledges the external reviewers who volunteered to read and comment on this report, including experts in recycling and sustainable materials management from both private and public sectors.

SPONSORS

The MRFF research project is sponsored by the following organizations. RRS appreciates the vision and hard work of the passionate sustainability professionals from these leading brands, retail, resin production, manufacturing, and trade associations who contributed funding, test packaging, technical expertise, and extra labor in waste sorts and flow testing.

All of the following companies contributed funding for this research and championed this project through varying levels of guidance and research support.

MRFF STEERING COMMITTEE

P&G · J. P. Mascaro & Sons *If it's service, it's us!* · TARGET · DOW · PEPSICO · Nestlé · Nestlé PURINA · amcor · Walmart.org · KraftHeinz

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Westlake Chemical

American Chemistry Council

Association of Plastic Recyclers

Canadian Plastics Industry Association

Flexible Packaging Association

Plastics Industry Association

EXECUTIVE SUMMARY

This research report **Flexible Packaging Recycling in Material Recovery Facilities Pilot** was prepared by RRS on behalf of the Materials Recovery for the Future (MRFF) project. The goal of this research collaboration was to demonstrate in a large, high speed material recovery facility (MRF) whether flexible packaging collected loose in residential single-stream carts could be sorted into a commodity bale for reprocessing into recycled content products. The MRF was upgraded with a flexible plastic packaging (FPP) recovery system using state-of-the-art optical sorters and peripheral equipment that is increasingly utilized for automated MRF sorting.

This is the first such demonstration of MRF flexible packaging recycling in the U.S. The pilot was performed in partnership with J.P. Mascaro & Sons at the TotalRecycle MRF located in Birdsboro, Pennsylvania. The impetus for MRFF research was the research sponsors' shared vision that flexible packaging be recycled, and that the recovery community capture value from the material. FPP is the fastest growing, most popular category of plastic packaging today, with 12 billion pounds consumed annually in the U.S., including single resin and multi-layer bags, pouches, and wraps.

Within one year of FPP sortation equipment installation, completed February 2019, four of the five sortation performance goals established for this live MRF pilot demonstration were realized, and progress towards the fifth goal continues to proceed.

PERFORMANCE GOAL	METRIC	RESULT
1. Capture at least 90% of flexible plastic packaging (FPP) in feedstock	Capture Rate (% of inbound material captured by weight)	Needs improvement, 74% capture rate in February 2020 testing. Additional equipment tuning and minor upgrade in process.
2. Minimize paper in FPP product (less than 15% by weight)	rFlex Bale Composition (% of bale by weight consisting of each material)	Success, 11-14% over the last few months of monitoring.
3. Even with increased FPP in feedstock, reduce the amount of FPP going into fiber products	Fiber Bale Composition (% of bale by weight consisting of each material)	Success, reduction in newsprint (ONP) from 1.4% to 0.3% FPP, reduction in mixed paper (MP) from 1.6% to 0.5% FPP.
4. Reduce fiber QC staff requirement by a minimum of 25%.	Number of full time equivalent (FTE) staff required to perform quality control (QC)	Success, 38% reduction in QC staff.
5. Controls integrated with existing material recovery facility (MRF) control system	Qualitative (Yes/No)	Success, FPP recovery system integrated into current control system.

The most immediate benefit of the FPP system upgrade for the MRF was cleaner, higher quality paper bales. The reduction in contamination for two traditional commodity bales, Old Newsprint (ONP) and Mixed Paper (MP), was measured at over 70%. As part of their expansion plan, TotalRecycle has begun operational upgrades and equipment tuning improvements as of April 2020 that are expected to increase the FPP capture rate and improve against Performance Goal #1. Combined with the value created from sustained quality improvements in paper bales, this data is worth evaluating as investments are made to advance MRF sorting.

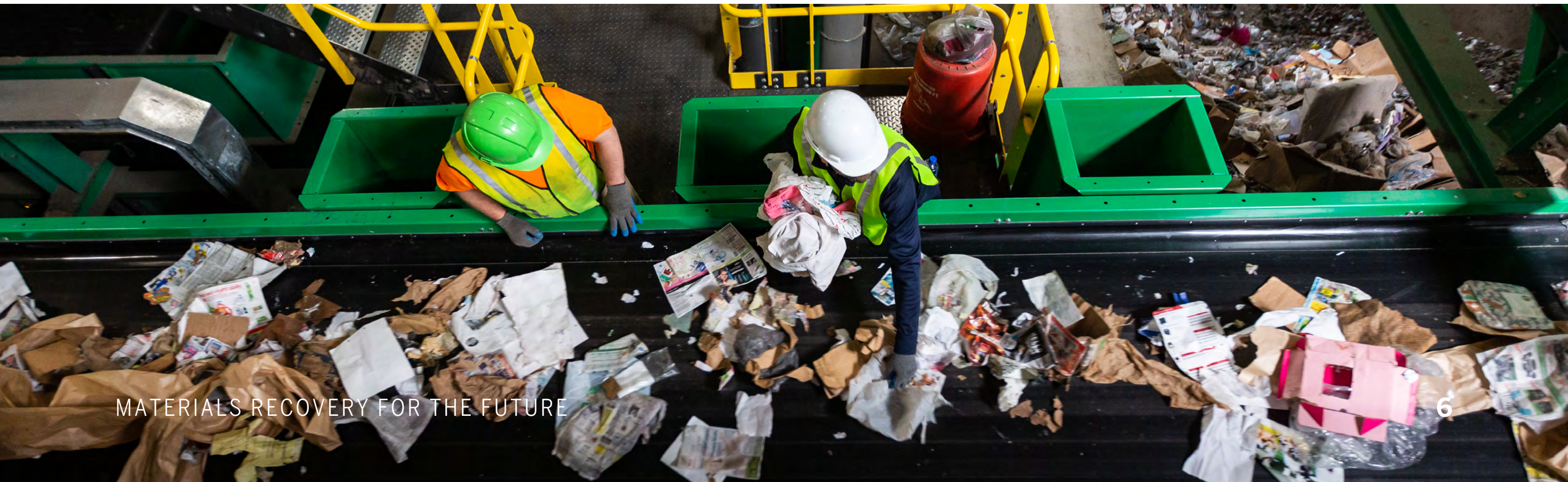
Once the new mixed bale called rFlex approached performance goals in November 2019, bales were shipped for testing over a 90-day period to highly qualified firms in film plastic reprocessing from the U.S. and Europe. Over one dozen priority end market product opportunities were identified by this expert group in collaboration with RRS, brand owners, and the Pennsylvania Recycling Markets Center. Construction materials were identified as the highest volume, most feasible "quick wins," with many more opportunities opening up once rFlex is processed into pellet or flake form. Explicit, demonstrated demand pull for these products will be critical to justify the investment needed to sort and create a marketable commodity.

Approximately 56,000 households from municipalities across Berks, Bucks, Delaware, Lehigh and Montgomery counties, Pennsylvania, already using standard lidded roll-out recycling carts were invited to participate in the residential collection phase beginning September 2019. Customer feedback received by the MRF found residents were widely receptive and positive about recycling FPP. While there was no added cost to communities for participation in this pilot, all residential recycling services have net costs. RRS modeled the capital cost of adding the FPP system to the MRF to aid decisions in other regions where communities may be interested in upgrading their systems to collect FPP. The net cost was estimated at between $2.25-2.41/ton of recyclables processed and is highly sensitive to local landfill tip fees and bale revenue assumptions. This net cost is on par with the cost of adding other new materials to traditional single stream programs.

Recommendations for the short term and long-term scaling to achieve circular FPP value chain recovery in the U.S. market-driven environment are discussed, and include:

- Support for an Association of Plastic Recyclers Demand Champion category to track purchasing commitments to buy rFlex products.
- An investment strategy in post-MRF processing such as dry wash of the rFlex bale to recycle the plastics-only fraction. This will unlock manufacture of the majority of rFlex products identified through end market manufacturer peer review.
- Development of bale specification(s) that standardize supply while offering MRF operators flexibility to respond to local markets.
- Sustained, focused engagement and co-investment with owners of new MRFs under construction and end markets to simultaneously build demand and supply for rFlex.

In summary, the collective action of MRFF participants has yielded a useful, evidenced-based method to accelerate collection, sorting, and marketing of recycled flexible plastic packaging at scale, keeping the value of plastics in the economy and out of the North American environment. More work will be needed, but the journey and playbook for success have become much better understood during this collaborative research process. MRFF will share results of the 2020 equipment upgrades at www.materialsrecoveryforthefuture.com.



VISION, PARTNERS, AND PURPOSE

The U.S. recycling system in 2020 is facing challenges from multiple fronts, with rising costs, tumultuous end markets, and a rapidly evolving material stream. Flexible plastic packaging (FPP), a broad category including plastic pouches, wraps, and bags, is one material type experiencing rapid growth. FPP provides package sustainability benefits of reduced weight, smaller amounts of material required for packaging, and decreased food waste through extended shelf life – but it has also presented problems at end of life to reclaim value into new products. While 12 billion pounds of FPP is consumed annually in the U.S., only 4% of single resin formats are recycled.

Materials Recovery for the Future (MRFF) is a collaborative research project between leading members of the flexible packaging value chain created to research and pilot a scalable approach to recover the value from FPP rather than send it to landfill. MRFF is administered by the Foundation for Chemistry Research and Initiatives (FCRI), a 501(c)(3) tax-exempt organization established by the American Chemistry Council (ACC). The research has been conducted by Resource Recycling Systems (RRS) in collaboration with sponsoring organization packaging and sustainability professionals, the pilot MRF team and representatives of potential end markets for the material.

The sponsors' shared vision is "flexible packaging is recycled curbside, and the recovery community captures value from it." Through a methodical proof-of-concept research design, RRS evaluated the feasibility of recycling flexible plastic packaging collected from curbside carts and processed in a modern material recovery facility (MRF) to manufacture recycled content products.

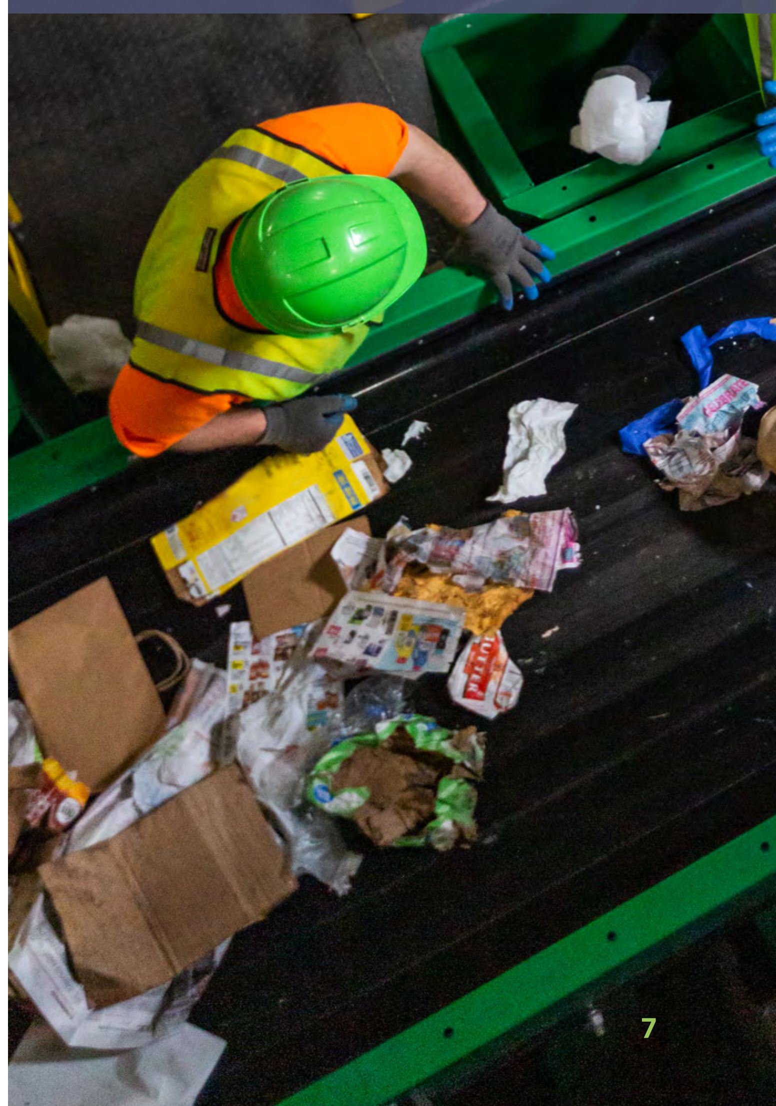
MRFF RESEARCH AGENDA

The MRFF research program launched in 2015 to investigate the technical and economic feasibility of collecting and sorting loose FPP through residential single stream recycling.

MRFF

VISION

Flexible packaging is recycled curbside, and the recovery community captures value from it



The program's initial research in 2015-16 demonstrated the technical feasibility of optical sorters to automatically remove flexibles from MRF fiber lines at efficiencies of 70% or greater. The full results of the MRF tests are available for download at www.materialsrecoveryforthefuture.com.[1]

While the early research provided a preliminary model that sorting loose residential FPP in a MRF may be technically and economically feasible, other aspects of recycling the material remained unknown. The second phase of research for MRFF focused on two of these:

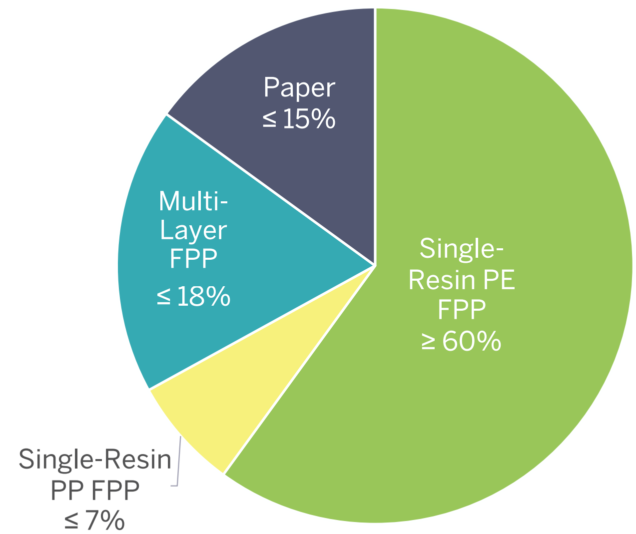
- Constructing a model pro forma for adding FPP to infeed at a large, single stream recycling facility.
- Developing a theoretical bale specification and investigating potential end market uses and pathways for the bale.

Economic modeling conducted in 2017 estimated the costs to add flexible packaging recycling in large MRFs are on par with addition of other materials to single stream, between $2-3/ton. This is particularly true in regions with economic incentives to promote alternatives to landfilling material. The cost model is highly sensitive to the variables of landfill tipping fees for residue and revenue per ton from sales of the recovered flexible packaging. Thus, the actual economic feasibility of sorting this material will vary based on local recycling policies, fee structures, and end markets.

To identify what end markets might be able to use FPP and in what products, the MRFF program developed an estimate of the composition of a theoretical bale of rFlex, as shown in Figure 1 based on data on the types and quantity of FPP produced and sold annually.[2] The bale was expected to consist primarily of polyolefins, including single-resin polyethylene and polypropylene; multi-layer laminated polyethylene; and a smaller percentage of fiber. RRS conducted testing in 2017 at qualified manufacturing facilities using post-consumer FPP sorted to match the theoretical bale specification as closely as possible. This testing included sizing, washing, blending, and molding of the sample materials. Products successfully produced using the sample materials included pellets, deck boards, roof sheathing, pallets, and small molded plastic products.

The second phase of research demonstrated again that the potential existed to recycle FPP from consumers' single-stream recycling bins. But how would the research translate over the long-term in a live, operating MRF? This question was the catalyst for MRFF partners to initiate a pilot U.S. recycling program for FPP.

Figure 1: Theoretical Bale Composition



Limited Contaminants	PET	≤ 2%
	PVC	≤ 1%
	Metal	≤ 1%
	Nylon	≤ 1%

1. Materials Recovery for the Future. (2016). Flexible Packaging Sortation at Materials Recovery Facilities: Research Report. Retrieved from https://www.materialsrecoveryforthefuture.com/wp-content/uploads/2016/09/Flexible-Packaging-Sortation-at-Materials-Recovery-Facilities-RRS-Research-Report.pdf
2. Resource Recycling Systems. (2017). Materials Recovery for the Future – rFlex Bale Characterization. Retrieved from: https://www.materialsrecoveryforthefuture.com/wp-content/uploads/2018/01/MRFF-FPP-rFlex-Bale-Characterization.pdf

WHAT IS FLEXIBLE PLASTIC PACKAGING?

Flexible Plastic Packaging (FPP) consists of single-resin plastic films and multi-layer packaging, including the following packaging types:

Bags, Wrap, Lay-Flat Pouches, Standup Pouches, Shrink Bundling

In March 2017, MRFF issued a public announcement seeking to identify a single stream MRF owner interested in partnering to conduct a flexible packaging recycling pilot. An important eligibility factor was operation of a large, high-speed automated MRF suitable for testing a scalable sorting solution. The pilot MRF also needed to employ modern equipment (anti-wrap screens, optical sorters for other sorting purposes) to provide the most cost-effective system for the sponsored upgrade. Over 50 facilities were identified as potentially eligible candidates, particularly in regions where the regulatory/economic environment supported increased diversion.

MRFF organized management consultations and facility visits to screen potential facilities and identify the selected pilot partner: TotalRecycle, Inc., a large single-stream MRF located in Berks County, Pennsylvania, owned and operated by J.P. Mascaro & Sons. Selection of TotalRecycle as the pilot MRF took several considerations into account. The MRF's 35-ton per hour processing capacity with anti-wrap screens, was considered ideal in scale and well-suited in its equipment configuration for implementing the pilot. The company was also well-positioned to deliver messaging to residents regarding their participation in the pilot, as it collects recyclables from dozens of nearby communities.

TOTALRECYCLE, INC. IS A MODERN 35 TON PER HOUR SINGLE STREAM MATERIAL RECOVERY FACILITY (MRF) IN BIRDSBORO, PENNSYLVANIA.

The MRF currently processes 120,000 tons per year and services nine counties with 90 municipalities under contract. The equipment installed is a Bollegraaf 35 ton per hour system, considered to be industrial grade, state of-the-art, and reliable. The owner J.P. Mascaro & Sons is a nationally recognized, privately-owned integrated solid waste and recycling company, servicing suburbs in the Philadelphia area, Lehigh Valley, and Bucks County.

Services include hauling, recycling collection, MRF processing, and landfill. TotalRecycle serves as a regional processing hub for multiple haulers.

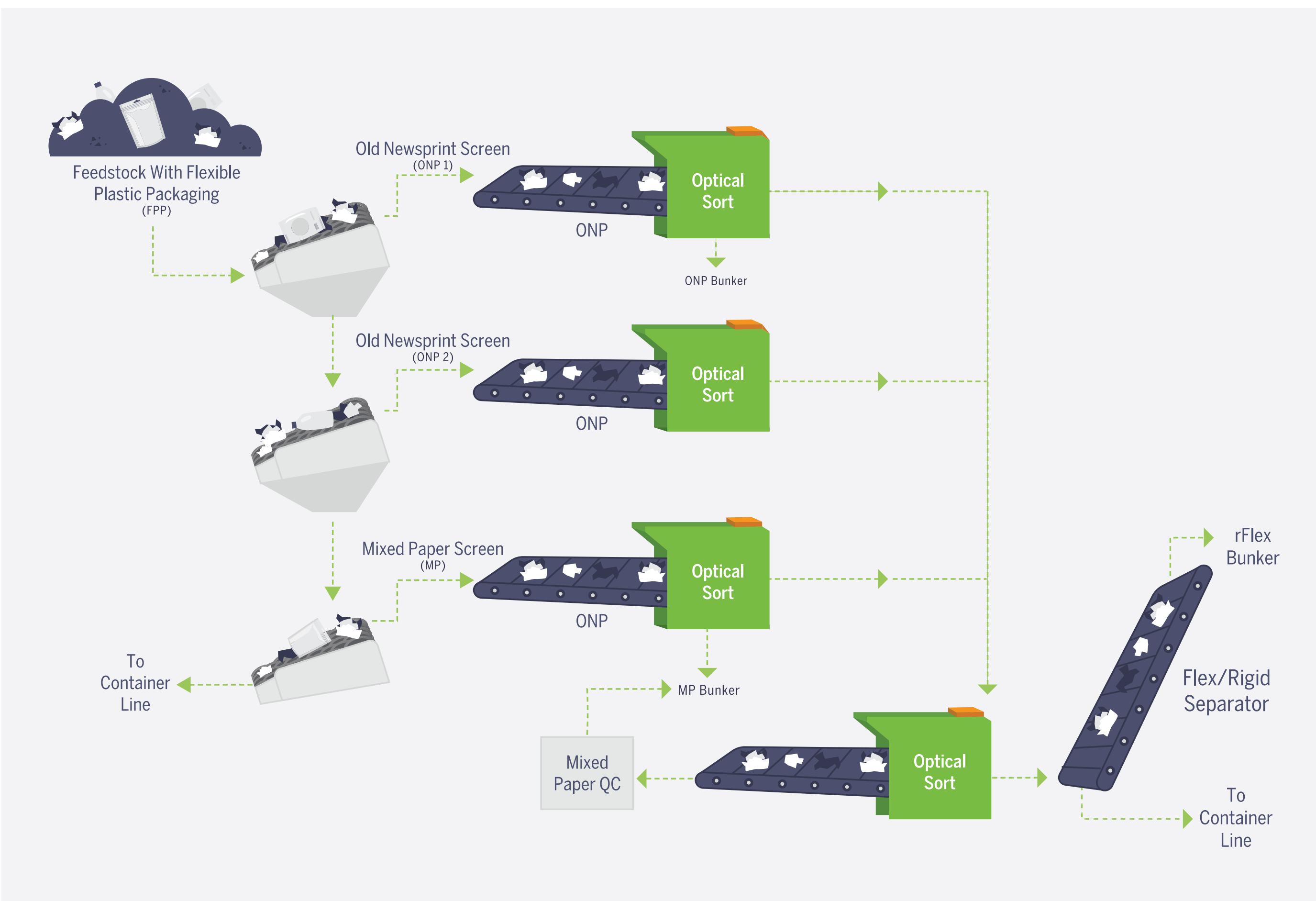
PILOT DETAILS

SYSTEM FOR SORTING FLEXIBLE PLASTIC PACKAGING

RRS conducted a competitive procurement process to aid TotalRecycle's selection of an equipment supplier for the MRFF pilot. All major equipment manufacturers in the MRF industry were invited to submit proposals for an equipment system to produce an rFlex bale from single stream feedstock, with FPP added as an accepted recyclable. After extensive review of all proposals, Van Dyk Recycling Solutions (VDRS) was selected to provide the sortation equipment. The equipment was purchased by J.P. Mascaro & Sons through a grant provided by MRFF sponsors and co-investment by the MRF.

As established during the MRFF research program's previous research, the geometry of FPP dictates its flow with other two-dimensional materials in the MRF. Thus, the equipment modifications to sort rFlex at the pilot facility were installed after the screens that separate two- and three-dimensional materials. The system, illustrated in Figure 2, consists of three Tomra Autosort 4 optical sorters that eject FPP from the fiber lines, followed by a fourth Autosort 4 that ejects fiber from the resulting FPP stream. The ejected stream from the fourth optical sort is manually quality controlled for any collaterally ejected FPP. The final component of the system is a Lubo Paper Magnet flex/rigid separator used to remove 3-D materials from the cleaned FPP stream. The resulting materials are conveyed via a suction system to a dedicated rFlex bunker.

Figure 2: Sortation System Diagram



RESEARCH CONDUCTED

The research conducted during the pilot program investigated three recycling system elements:

- **Processing:** Equipment performance monitoring and evaluation involved weekly bale breaks by the TotalRecycle team to monitor and report the quality of the rFlex bales; periodic RRS flow tests to measure how effectively FPP was being captured from the feedstock; confirmation of monitoring results; measurements of the improvement to MRF product bales; and observation of impacts to operation and maintenance of the facility.
- **End markets:** The research program investigated regional, North American, and international technologies capable of processing an rFlex bale. rFlex bale testing was conducted with a variety of end markets to understand the quality of output, technical issues with processing, and needs to address to advance supply chain development and scale market adoption.
- **Community collection:** Support included conducting a curbside cart gap analysis, providing a recycling coordinators workshop, monitoring and tracking the impact of adding FPP to curbside collection programs, documenting collection progress, and developing new practices for introducing the material to existing programs.

PROCESSING: EQUIPMENT PERFORMANCE MONITORING AND EVALUATION

Performance Goals

As part of the equipment procurement process for the pilot, MRFF established five performance goals for the FPP sortation system.

1. **Capture Rate:** Capture at least 90% of flexible plastic packaging (FPP) in feedstock
2. **FPP Bale Composition:** Minimize paper in FPP product (less than 15% by weight)
3. **Fiber Bale Composition:** Reduce the amount of FPP in fiber products, even with increased FPP in feedstock
4. **Staff Time:** Reduce fiber QC staff requirement by a minimum of 25%
5. **Control Integration:** Integrate equipment controls with existing material recovery facility control system

Over the course of the pilot, progress towards these goals was evaluated to determine whether the goals were being met and whether the equipment performance was at the specified level.

Measuring progress toward goals

Several methodologies were designed and used to provide quantitative and qualitative benchmarks for performance evaluation of the equipment. These included bale breaks, RFID testing, observation, and VDRS equipment lab testing.

Bale breaks measured FPP and fiber bale composition. Finished bales of these products were cut open so 100–200 pound samples of their contents could be taken. The samples were sorted into the target material (e.g. FPP or fiber) and different categories of contaminants (e.g. fiber or FPP, containers, and trash). Bale break data answered the question of whether the sortation system was creating bales meeting performance goals (2) and (3) of the pilot. Detailed bale audits of the rFlex product also provided data on the types of materials and packages found in the incoming stream, for comparison with the hypothetical composition based on analysis of packages produced.

Radio-frequency identification (RFID) testing measured the capture rate (performance goal (1) of the pilot) by tracking the flow of FPP through the entire MRF. In this testing method, RFID tags were attached to individual FPP test packaging which were then seeded into inbound material. The second part of the RFID system was the RFID readers. RFID readers detect the RFID tags, read their information and relay that information back to networked computers for display and storage. By placing RFID readers at strategic locations and comparing tag reads from one reader to another, RRS determined the system capture efficiency of each tagged package that flowed in the MRF.

Observation and VDRS equipment lab testing were performed periodically on identified areas needing improvement. This feedback provided information to tune the programming of the optical sorters, adjust peripheral equipment, and further refine design of the FPP recovery system.

Bale Monitoring – Results

FPP Bale Composition – rFlex Bale

The rFlex bale measured 77% FPP at the end of the pilot tuning period. This measure is based on averaging ten bale composition audits conducted from mid-November 2019 through mid-January 2020. The goal was to consistently reach 85% FPP or higher.

The FPP itself is primarily single resin polyethylene or polypropylene packaging (60% of the total bale) such as retail carry bags, storage bags, shrink bundling, and wrap (see Figure 3). This single resin FPP component is estimated to be nine tenths polyethylene and one tenth polypropylene. Multi-layer FPP such as standup pouches and chip bags makes up 10% of the bale. Since the bale is visually sorted to packaging categories, there is a component of material that is fragmented pieces of larger packaging and thus is not easily identified. This material is lumped together into a fragmented FPP category and makes up 7% of the total bale. The remaining 23% of the bale consists of fiber (12%), flattened containers including PET bottles, steel or aluminum cans (5%), and other contaminants such as organics or heavily contaminated packaging (6%). On average, the pilot facility is producing between 90-110 rFlex bales per month, equating to approximately 90-110 tons of rFlex produced per month based on an estimated rFlex bale weight of 2000 pounds. As community collection continues to expand, rFlex production capacity at the pilot facility is expected to increase.

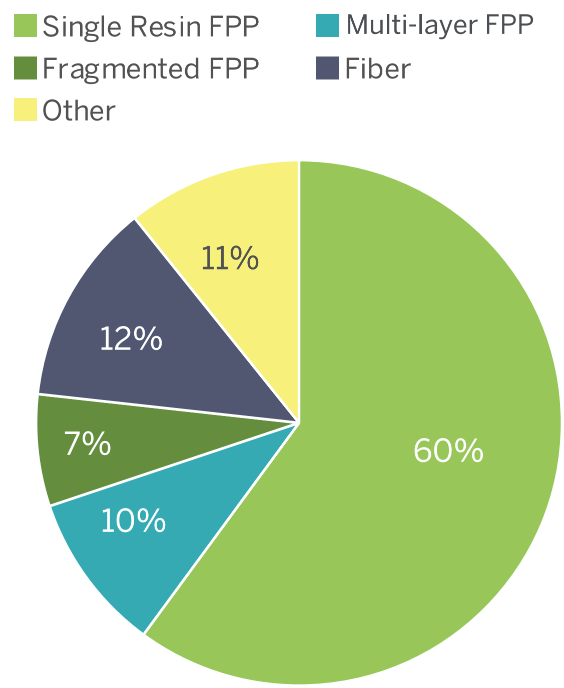
rFlex Bale Composition – Results Since Start of Pilot

The current production and quality of rFlex represents the results of nine months of tuning and continual improvement since the rFlex collection system was installed, as shown in Figure 4. The RRS MRF Processing Team assumed tuning would take six to twelve months for this first proof-of-concept system. The current bale purity has been enhanced greatly over the course of the pilot, with fiber now representing under 15% of the bale compared to over 40% shortly after equipment operation began.

Impacts on Other Commodities - Cleaner Paper

An important element of the pilot was to observe and measure the impacts of adding FPP on other commodities the MRF produces, including newspaper (Old Newsprint, abbreviated ONP) and mixed paper (MP). Fiber bale audits were conducted before and

Figure 3: rFlex Bale Composition (Last 10 Audits)



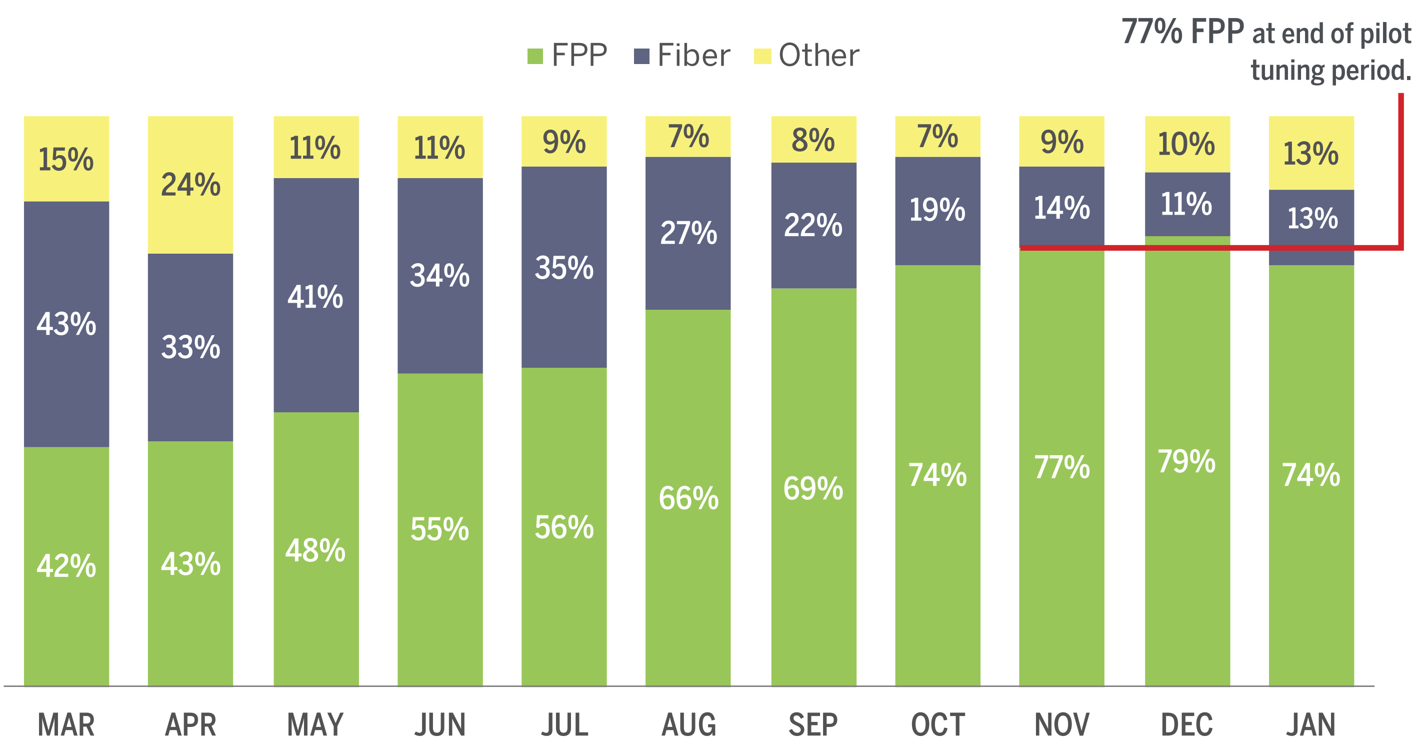
Single Resin FPP	Retail Carry Bags (grocery bags, retail bags)	16%
	Storage Bags (zip top storage and freezer bags)	2%
	Bags (bread bags, newspaper bags, produce bags, pet food bags)	15%
	Shrink Bundling (case wrap, shrink film)	12%
	Bubble Wrap/Mailers (bubble wrap, mailers, air pillows)	6%
	Cut/Wrap (paper towel/napkin overwrap, toilet paper overwrap)	9%
Multi-layer FPP	Standup Pouches (baby food pouches, detergent pouches)	1%
	Lay Flat/Pillow Pouches (salad pouches, cheese pouches, jerky pouches)	1%
	Chip/Snack Bags (potato chip bag, popcorn bag, pretzel bag)	7%
Fragmented FPP	Fragmented FPP (small pieces)	7%
Fiber	Fiber (newspaper, mixed paper, cardboard)	12%
Other	Containers (rigid plastics, steel cans, aluminum cans)	5%
	Residue (organics, heavily contaminated packaging)	6%

after the FPP capture system was installed. The results of those audits are shown in Table 1.

The "After FPP System" bale breaks were conducted in February 2020 after all eligible communities had added FPP to their recyclables collection. The FPP equipment upgrade positively impacted quality of fiber bales produced by TotalRecycle with a contamination rate well below 1.5%, the Institute of Scrap Recycling Industries (ISRI) specification level. The significant reduction in other contamination is likely due to quality control staff being able to focus their attention from FPP to other contamination with the addition of the FPP capture system. The pilot facility director reported that sales of their fiber materials are strong and that ONP and MP bales have gained an even better reputation for cleanliness on the market. The additional sales revenue cannot be measured given the variable market conditions before and after system install.

In addition to evaluating fiber bale quality, the RRS Project Team also looked at the quality of container stream bales. There are quality control stations before

Figure 4: rFlex Bale Composition Over Time



% Fiber Target = 15% % FPP Target = 85%

Table 1: Fiber Bale Comparison

	BEFORE FPP SYSTEM		AFTER FPP SYSTEM	
	ONP	**MP**	**ONP**	**MP**
FPP	1.4%	1.6%	0.3%	0.5%
Other Contamination	3.7%	4.1%	1.0%	0.9%
Total Contamination	5.1%	5.7%	1.3%	1.4%

each commodity bunker so the expectation was that FPP would be picked there and that there would be minimal FPP in the bales produced. As such the team found that there were only trace amounts of FPP in any of those bales. The team intends to quantify the labor level needed to remove FPP from container streams with quality control in future research.

RFID Testing

Test Plan and Methodology

Three tests using radio frequency identification (RFID) technology took place during the pilot to inform equipment acceptance and determine whether performance goal (1), a 90% capture rate, had been achieved. The tests combined RFID-tagged FPP test materials with a known quantity of single stream and then fed the entire mixture into the MRF infeed. Each test occurred over approximately 30-40 minutes of MRF operation time.

The RRS Project Team observed and recorded the cause of test materials ending up in specific locations, especially where this resulted in contamination of end products or loss of significant portions of the test sample. RFID data provided quantitative results, while human and video observation was used to understand qualitatively what caused sorting issues observed. MRFF sponsors also participated in the test activities to understand firsthand the hurdles and potential solutions associated with sorting different formats.

The FPP input rate simulated a 3% FPP content in the infeed single stream. It was assumed that the single stream material being run at TotalRecycle already contains 1% FPP, so an additional 2% was added to the test material. Test material was prepared by tagging sample packages with RFID tags and roughing up packages to simulate post-consumer condition. The test material was mixed with infeed on the tip floor or seeded into the infeed at the drum feeder. RRS placed RFID readers at 9 locations (indicated in Figure 7) to measure type and quantity of FPP that reached each reader location.

The location of RFID readers allowed for reading of tags as they enter the recycling system, enter and exit the paper cleanup optical sorters, enter and exit the fiber recovery optical sorter, flow with the 3D fraction from the flex/rigid separator and exit screening with the container stream. With these locations the FPP flow and equipment efficiencies were determined.

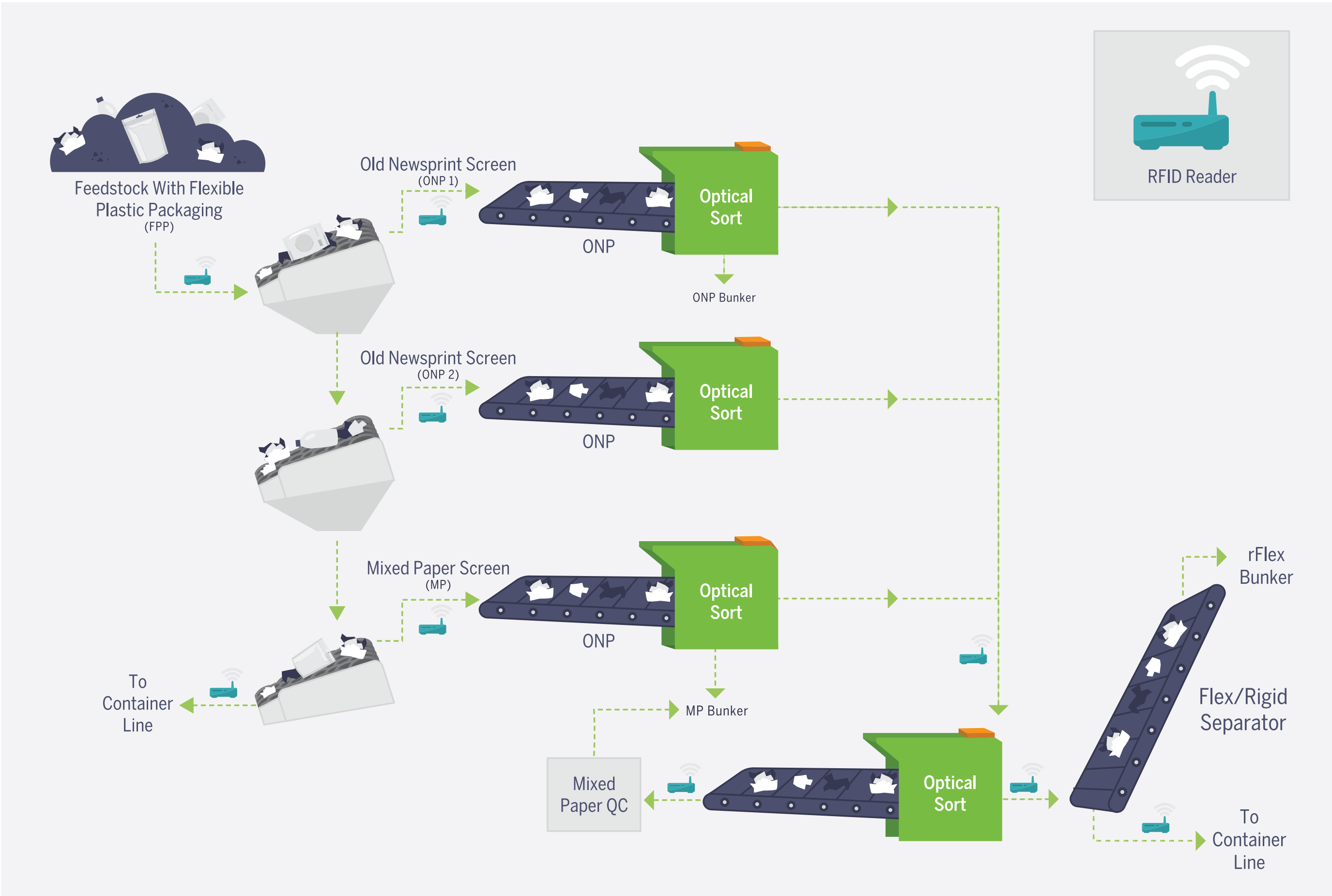
RFID TESTING GOALS

- Quantify how well the system is separating FPP
- Determine the degree to which FPP is being captured and lost at each relevant separation stage in the MRF
- Determine the places where non-FPP materials enter the FPP product stream
- Identify specific locations where improvements are needed to reach project goals

Figure 6: RFID Test Team performs August 2019 rFlex bale break

Figure 5: RFID Test Team: TJ Stinson, TotalRecycle; Brad Kurzynowski, Holly Halliwill, Chris King, Kerry Sandford, RRS; Erik Groner, Linda Roman, KraftHeinz

Figure 7: RFID Reader Locations



For each RFID test, three runs were conducted applying a similar methodology to allow comparison between tests.

The test mix represented the formats described in Figure 3 and are a fairly complete representation of the formats in production according to Flexible Packaging Association data. Juice pouches were added to the test mix beginning with August 2019 testing.

Results

The test data was quantified and analyzed with two different performance metrics: individual equipment efficiency level and the overall system package flow level.

1. **Equipment efficiency:** This metric allows the components of the sortation system to be directly compared. It is calculated separately for each component of the sortation system. The metric corresponds to the percentage of packages entering the component that are correctly sorted and exit the component flowing towards the target destination bale. For example, of the packages entering the fiber screens, the percentage that correctly flow over the screens to the fiber lines corresponds to the efficiency metric for the fiber screens. Likewise, for optical sorters 1-3, the efficiency metric corresponds to the percentage of material entering the optical sorter that is appropriately ejected.

2. **Package flow analysis:** This metric identifies the percentage of each package type entering the system that ends up recovered in the target bale. It further identifies the points at which packages are lost to other streams and the percentage lost at each stage.

Over the course of the TotalRecycle pilot, the overall recovery rate of packaging improved from 55% to 71% to 74% as shown in Table 2. Test results are shown as a composition adjusted average, calculated by applying RFID results to the average bale composition measured during rFlex bale breaks to provide a weighted average.

Two primary factors contributed to the improvement during the course of the pilot:

1. the improved performance of optical sorters (OS) 1-3, as shown in the Equipment Efficiency Analysis Comparison in Table 3; and
2. the addition of manual QC labor after a more aggressive mixed paper ejection at OS 4.

As seen in Table 3 the efficiency of the fiber screens was relatively constant. The drop in efficiency at several points in the February 2020 test can be attributed to the condition of the screening equipment during that test. It was observed that many of the discs were worn and even a few were missing. The condition of the screening equipment had the largest impact on smaller packages (e.g. spouted pouches), causing the packages to flow to the container line rather than the fiber lines. The table also shows that the efficiency of optical sorters 1-3 improved greatly from April to August. This is due to VDRS's development of an enhanced FPP recognition program for the optical sorters. There was a slight drop in efficiency for the February test, but again this appears to have impacted mostly the smaller packages. An investigation into the cause of this drop is ongoing. The efficiency of optical sorter 4 had a continual drop from April – February; this was a purposeful change to reduce the amount of fiber in the rFlex bale. Optical sorter 4, which removes fiber from the FPP stream, was set to be more aggressive after the April test to remove as much fiber as possible, but with that increased aggressiveness, more collateral FPP is ejected. This is compensated for by the manual quality control station after optical sorter 4, which captures any of that collateral FPP. The flex/rigid separator showed a slight decline in performance in August. Some of the variation in the flex/rigid separator's efficiency is likely due to a ripped belt that was observed during August testing. Table 4 shows a comparison of recovery rates by package type and highlights areas of improvement.

Table 2: Capture Rate Comparison

TEST	LOSSES TO FIBER SCREEN SEPARATION	LOSSES TO MISSED FIBER LINE EJECTION (OS 1-3)	LOSSES TO MIXED PAPER (OS 4 AND QC)	LOSSES TO FLEX/ RIGID SEPARATOR	RECOVERY RATE
Capture Rate April 2019	5%	23%	13%	4%	55%
Capture Rate August 2019	5%	11%	3%	10%	71%
Capture Rate February 2020	2%	15%	3%	6%	74%

Table 3: Equipment Efficiency Analysis Comparison

TEST	FIBER SCREENS	OS 1-3	OS 4	FLEX/RIGID SEPARATOR
Efficiency April 2019	95%	75%	81%	93%
Efficiency August 2019	95%	88%	64%	83%
Efficiency February 2020	94%	85%	50%	92%

Table 4: Equipment Efficiency Analysis Comparison

PACKAGE	RECOVERY RATE APRIL 2019	RECOVERY RATE AUGUST 2019	RECOVERY RATE FEBRUARY 2020	% IMPROVEMENT (APRIL-FEB)
Small Chip Bag	29%	58%	36%*	24%
Large Chip Bag	43%	70%	64%	49%
Medium Standup Pouch	30%	57%	43%	43%
Spouted Pouch	17%	34%	1%*	None
Juice Pouch with Straw	Not tested	46%	13%*	None
Shrink Wrap	55%	70%	85%	55%
Small Storage Bag	30%	61%	Not tested	None
Large Storage Bag	55%	Not tested	76%	38%
Large Standup Pouch	41%	70%	46%	12%
Bread Bag	67%	80%	84%	25%
Cereal Bag	62%	69%	65%	5%
Retail Carry Bag	67%	80%	90%	34%
Composition Adjusted Average	55%	71%	74%	35%

**See fiber screening and optical sorting discussions above. None = no improvement due to screen maintenance. Juice pouches were not tested in April, they were added to test mix when The KraftHeinz Company joined the project July 2019.*

The majority of package types saw a recovery improvement between April and February. The outliers to this are all small packages. As noted in the previous section, there is continued work needed to fully understand the causes of this but there are some conclusions that can be drawn based on the current data. The first is that fiber screen maintenance plays a major role in ensuring that FPP is properly directed to the fiber lines and this is particularly true for small packaging. The second is that proper optical sorting calibration and programing is essential to identifying and ejecting FPP efficiently and appears to have a greater influence on smaller packaging.

The February 2020 equipment performance overall was largely similar to that seen in August 2019. The performance of the system remained relatively stable with a small improvement in capture overall. A maintenance issue of worn and missing discs on the fiber screens during the February test contributed to the loss of many small packages during the test. This result is somewhat of an outlier, as the parts involved would typically have been replaced; under normal conditions, the overall capture at February's test would have likely been higher than observed.

Observations during the testing identified that infeed conditions, in particular wet fiber and cardboard, have a large impact on the performance of the FPP sortation system. Moisture in the fiber increases the amount of cardboard in other fiber streams, as well as increasing the amount of ejections and collateral in the FPP recovery system. Lightweight film and smaller packaging formats were occasionally observed clinging to wet cardboard picked manually on fiber QC stations. The rainy conditions prior to the April test exacerbated this problem in the inbound material stream. Due to this finding, the MRFF group identified the use of covered collection carts as a strict requirement for community collection.

Between August 2019 and February 2020, the system ran without major modifications but received increased volumes of FPP to sort due to the rollout of community collection. In September 2019, the FPP collection pilot began in the first communities served by the pilot MRF. From September 2019 to February 2020, as described in Community Collection below, J.P. Mascaro & Sons' residential customers were notified in phases that flexible plastic packaging was now allowed in their recycling stream. Following the rollout of this program to all residential customers with lidded carts, a final RFID test was conducted to observe equipment performance with the actual post-consumer FPP in single stream.

Test Results Inform Equipment Tuning and Continual Improvement

Based on April 2019 results, samples of FPP were shipped to Van Dyk's equipment laboratory to calibrate the optical sortation equipment and provide an enhanced recognition program. Improvements were also made to the TotalRecycle system to provide better separation on the belts and avoid material clumping together. Scheduling maintenance to repair screens and maintain equipment has become easier as the MRF added a third shift as planned in 2020.

In addition, J.P. Mascaro & Sons have taken the initiative to make the following TotalRecycle system improvements with equipment currently on order for 2nd Quarter 2020 installation.

1. QC station added on rFlex stream
   a. Allows for manual removal of large paper and other contaminants
2. Air hood over optical sorter 4 QC
   a. Direct conveyance of picked FPP to rFlex bunker
3. Relocation of drum feeder
   a. Drum feeder and feed conveyor moved to be in line with presort
   b. Inline feeding to reduce clumping and increase material spread

All of the above actions are expected to improve the FPP capture rate.

Staffing

Performance goal 4 was to reduce fiber QC staff requirement by a minimum of 25%. Throughout the FPP recovery system tuning period the staffing was adjusted until the optimum result was achieved. Table 5 shows the result of the staff tuning.

The FPP recovery system was able to reduce the amount of labor needed by 38%; this takes into account the labor needed to staff the OS 4 QC sort station added mid-pilot. The scheduled addition of a QC station on the rFlex stream would add another QC person and result in an overall reduction in staffing of 23%. This is still quite close to the goal of 25% and will result in a much cleaner rFlex product. Note that no jobs were lost as a result of the additional automated sorting. The personnel no longer required for fiber QC were reassigned to other areas of the MRF and a third shift was added. The reduced manual sorting requirements also relieved some pressure on the MRF operator to continually recruit and hire manual sorters.

Table 5: Fiber QC Staffing

QC STATION	BEFORE FPP SYSTEM	AFTER FPP SYSTEM
ONP 1 QC	2	1.5
ONP 2 QC	2	1.5
MP QC	2.5	0
OS 4 QC	0	1
Total	6.5	4
% REDUCTION		38%

Pilot Performance Against Goals: Summary Table

The MRFF pilot aimed to test the sortability of flexible plastic packaging in the challenging real-world setting of an operational single-stream MRF. The sortation system in practice was able to realize four of the five performance goals established at the project onset. The performance goals and results of the pilot are summarized in Table 6. For details and further discussion on individual packages, please see Appendix A.

Table 6: Pilot Performance Goals Summary

PERFORMANCE GOAL	METRIC	RESULT
1. Capture at least 90% of flexible plastic packaging (FPP) in feedstock	Capture Rate (% of inbound material captured by weight)	Needs improvement, 74% capture rate in February 2020 testing. Additional equipment tuning and minor upgrade in process.
2. Minimize paper in FPP product (less than 15% by weight)	rFlex Bale Composition (% of bale by weight consisting of each material)	Success, 11-14% over the last few months of monitoring.
3. Even with increased FPP in feedstock, reduce the amount of FPP going into fiber products	Fiber Bale Composition (% of bale by weight consisting of each material)	Success, reduction in newsprint (ONP) from 1.4% to 0.3% FPP, reduction in mixed paper (MP) from 1.6% to 0.5% FPP.
4. Reduce fiber QC staff requirement by a minimum of 25%.	Number of full time equivalent (FTE) staff required to perform quality control (QC)	Success, 38% reduction in QC staff.
5. Controls integrated with existing material recovery facility (MRF) control system	Qualitative (Yes/No)	Success, FPP recovery system integrated into current control system.

END MARKETS

In a circular economy, demand for recycled feedstocks to replace virgin materials in products is required to justify the investment needed to collect, sort, and create a marketable commodity. Governments and industry have deployed several mechanisms to help create demand and drive supply:

1. **Regulation:** In regions of the world such as Europe where collection and recycling of films and flexible packaging is emerging under extended producer responsibility (EPR) laws and mechanisms like the Plastics Pact, significant investment and innovation has helped develop end markets and is expanding these applications through improved packaging design, sorting technologies, and advanced recycling technologies.
2. **Market Development Grants:** Several U.S. states have had success stimulating end markets through regulatory mechanisms as well as grant programs.
3. **Voluntary Corporate Commitments:** There has been a significant uptick in corporate commitments by end users of plastics to increase the use of recycled content in response to growing concern over ocean plastics. Coupled with the loss of export markets, this is beginning to catalyze investment in domestic end markets.

Theoretical Bale Specification

Early in the MRFF project, an End Market Work Group was established to help direct and inform research on end market development. The Work Group included members with equipment and film recycling experience, including representatives from the Association of Plastic Recyclers (APR) and Plastics Industry Association (PLASTICS). The group also benefited from members connected to CEFLEX, PLASTICS' New End Market Opportunities (NEMO) for Film Work Group, and many of the leading film and recycling initiatives globally. One of the first tasks of the group was to research existing film bale specifications and establish a theoretical specification for the rFlex bale.

The rFlex bale is a mixed material product containing both FPP and paper. The original theoretical specification for the bale was based on two years of MRF material flow testing and specific equipment testing to determine the likely composition to inform and set as a target for the actual pilot system design.

THEORETICAL rFLEX BALE SPECIFICATION (2017)

Bale is expected to consist of at least 60% single-resin polyethylene films and laminates, including grocery bags, product overwraps, and similar materials; and up to 18% multi-material films, bags, pouches and other laminates with the predominant material consisting of polyethylene and limited contaminants not to exceed the following levels: PET 2%, PVC 1%, metal foil 1%, nylon 1%; and up to 7% single-resin polypropylene films and laminates. A total of 15% paper contamination is allowed.

ALLOWABLE MATERIALS:

Single-resin polyethylene films and laminates (≥ 60%)

Multi-layer films and laminates (≤ 18%)

- Limited PET (≤ 2%)
- Limited PVC (≤ 1%)
- Limited metal (≤ 1%)
- Limited nylon (≤ 1%)

Single-resin polypropylene films and laminates (≤ 7%)

ALLOWABLE LEVELS OF CONTAMINANTS:

Paper (Not to exceed 15%)

End Market Research

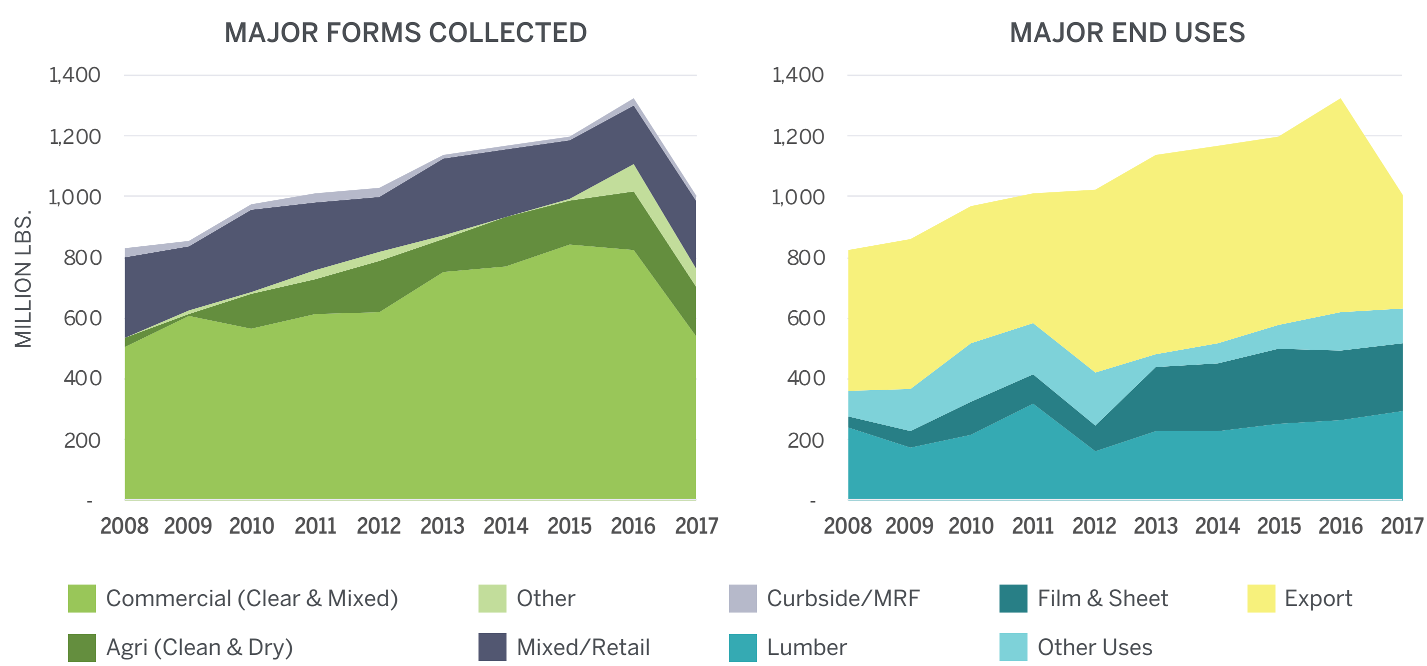
Once the likely composition of the bale became evident, the MRFF End Market Work Group wanted to understand the landscape of film and flexible recovery in the U.S. and specifically identify those end markets best suited for rFlex.

Extensive desktop research was conducted on an ongoing basis to evaluate the size and capacity of the U.S. film market and reclamation industry across a variety of technologies and products. This was followed by interviews of most PE film, mixed plastic, and mixed material processors in North America to determine what films they processed, determine their specifications for inputs, and identify the range of products they were producing. Companies that produced roof sheathing, rail ties, composite lumber, pallets, crates, mixed plastic pellets, various durable goods, plastic gravel, fuel products via pyrolysis, and asphalt were explored. The size, capacity, and growth rate of various end markets were compared relative to the quantities of film and flexible packaging put onto the U.S. market each year. This analysis cast light on those end markets most likely to have sufficient demand and scale to align with the scale and technical requirements from recovering rFlex, while also achieving environmental benefit. The U.S. marketplace for existing film and bag recycling efforts is shown in Figure 8.

The results of the desktop research indicated that there were few reprocessors in the U.S. that were prepared to accept a post-consumer mixed materials bale containing plastic and fiber components. The key findings of the desktop research and interviews were as follows:

- Most mechanical recycling end markets were sourcing post-industrial or post-commercial films for rail ties, lumber, sheet, and film-to-film applications. The volume of recovered PE films on the market is significant, and most was destined to export markets prior to National Sword (China's 2018 ban on the import of many grades of post-consumer plastic).
- The mechanical recycling markets for post-consumer films was limited to PE only and focused primarily on composite lumber.
- Some reprocessors had wash lines for post-consumer PE films to make film-to-film grade pellet. However, most film reprocessors did not have wash lines and so were very selective about their feedstocks.
- There were no commercially operating mixed plastic reprocessors in the U.S., but there were several in start-up phase. Commercially operating mixed plastic processors were identified in Canada, Europe, and Australia.

Figure 8: Historic Film and Bag Collection and End Market Use from U.S. Sources



Pre-Pilot Testing

The end of the pre-pilot end market research concluded with a series of tests using film and flexible material collected through the Energy Bag program supplemented with paper to create a bale that met the theoretical bale specification. The goal of testing was to understand the viability of selected end markets.

Reprocessors were then identified that had experience processing mixed materials and whose products were suitable for rFlex material. Testing was done in Europe at RePlastik, using a compression molding technology to produce a range of durable mixed plastic products like fencing, pallets, and sewer throats and caps. A representative mixed bale of rFlex material was sent to Europe and washed, and the agglomerated plastic-only fraction was mixed in a proprietary recipe to produce composite lumber. Testing was also conducted at ReWall (now known as Continuus Materials) to take whole rFlex bales, shred them, and use both the paper and plastic fraction to produce roof sheathing. Finally, a test was done with Zzyzx to test their shear pulverization technology to determine how well it could process rFlex and if a product could be produced. The result of this test was a very fine and extremely well mixed material which could be injection molded.

The results of all three tests were promising, pictured in Figure 9, but a few noteworthy findings were clear.

- Europe is much further along in experience with mixed plastic recycling. From producing post-consumer film bales, to the necessary washing infrastructure, to having molds for mixed plastic products, to the market for durable goods made from mixed plastics, Europe is better equipped than the U.S.
- While all tests were successful, the supply chains to take an rFlex bale, and get it washed, ground, and processed for a plastics-only market did not exist in the U.S.
- And, while mixed material markets like roof sheathing or cover board exist in the U.S. and pavers in Canada, they are regionally limited.

Pilot Phase End Market Research

During the pilot phase of the project, the end market research focused on opportunities in the vicinity of the TotalRecycle MRF. With support from the Pennsylvania Recycling Markets Center, mixed material and plastic reprocessors from across the region were identified, researched, and interviewed. In April 2019, an End Market Showcase was held to introduce invited reprocessors to TotalRecycle for

Figure 9: Product Samples from RePlastik

a tour of the MRF, and a view of the rFlex bale being produced during the equipment optimization process. Reprocessors and end markets from pyrolysis, roof cover board, durable goods, to films and compounded pellets were represented. The goal was to socialize the range of possible end markets with MRFF sponsors and identify those reprocessors that would be ready and interested to test rFlex once a representative bale was being produced.

As the rFlex bale composition approached performance goals in November 2019, end markets began conducting tests using representative bales from TotalRecycle. Getting data from processors on how the rFlex bale performs in real systems is a key step in determining which end markets are available for rFlex today, which ones need development, and what steps should be taken to drive development. An End Market Workshop was held in early March 2020 to peer review test results and to develop an end market roadmap for the rFlex bale that recognized a tiered approach to end market opportunities and identified the steps that would be needed to develop future markets. A brief summary of tests that were conducted are outlined below.

Mixed Bale Material Markets

CONTINUUS MATERIALS: Shred and Compression Molding

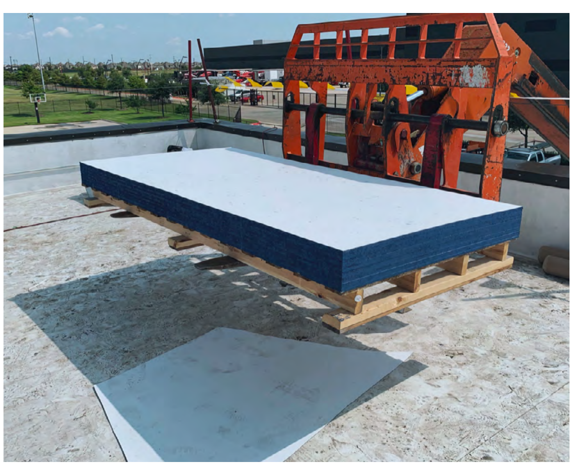
Continuus Materials provides circular economy solutions by converting discarded materials into high-performance building products. These recovered materials are currently used as feedstock to manufacture EVERBOARD™, a construction board engineered for low-slope commercial roofing applications. This product is a durable, extremely moisture and mold resistant alternative that gives roofing systems a much longer performance. The manufacturing process is designed for mixed materials, so it is robust when it comes to co-processing fiber and plastics. The bale yield is highest in this product application and estimated at more than 90%.

Testing of rFlex was done at Continuus' Forge production facility located in Philadelphia, Pennsylvania. Approximately 60 tons of material was received for testing. The majority of the remaining content was paper, which was also incorporated into the board raw material feedstock. The rFlex was blended with other Continuus material streams at varying rates (10-30%). These blended raw materials were then processed to make 4-foot by 8-foot by 1/2 inch EVERBOARD roof cover board panels.

Production trials indicate rFlex can be incorporated into Continuus Materials' feedstocks and used to make EVERBOARD. Quality testing indicated the trial boards met minimum building material performance requirements. Continuus also has a manufacturing facility in Des Moines, Iowa.

Continuus' new board manufacturing plant is scheduled to open January 2022 and will require 45,000 tons of LDPE material annually. While they will be sorting and separating LDPE material feedstocks from the City of Philadelphia, the company is also interested in discussing how they may be able to incorporate rFlex into their feedstock supply chain.

Figure 10: EVERBOARD® roof board containing approximately 25% rFlex



PAVERRECO: Washing, shredding and molding to durable product

PAVERRECO, based in Quebec, Canada is a mixed material recycler that produces durable pavers and bricks using recovered glass and plastic for use in sidewalks, patios, and municipal spaces. Intact bales of rFlex were shipped to the manufacturing facility. Post-consumer film bales are one of the primary feedstocks for the PAVERRECO product line of pavers. The product uses glass and a matrix of plastic for pavers used in municipal and retail spaces. Highly durable, these pavers can be recovered and recycled. The received bales were run through a trommel to liberate material and then fiber was manually removed. The standard procedure for this type of material would have been to run the bale through a wash and dry process; however, the wash equipment was out of commission at time of testing and would require tuning for the rFlex bale specifications. The remaining plastic fraction was first shredded and then granulated for preparation to be mixed with glass/porcelain and finally molded into the paver. The conclusions from the testing are as follows.

- Upon removal of the large fiber from the rFlex bale, the remaining plastic film was able to be used in PAVERRECO products without a change to the normal process.
- Bale odor and fiber contamination would require washing before material is usable.
- Current market conditions challenge the viability of using the bale as a feedstock, but the company is interested in looking at options for the future.

Plastic-Only Markets

EREMA: Wet wash and extrusion to pellet

Erema is a manufacturer of equipment for plastic recycling and extrusion headquartered in Austria. A single whole bale of rFlex was shipped to Germany for wet washing. Due to the high level of paper in the bale, the screens on the wet wash became clogged and the test was suspended. The fact that there was no pre-sort of the bale prior to the wash most likely contributed to the problems encountered during the wash. The volume of material that was successfully washed was sent to Austria to Erema for extrusion filtration and pelletization and material testing. The pellets were considered too low quality for film to film recycling. Currently, CharterNEX and other MRFF sponsors are conducting tests to identify applications.

QRS-REPOLY*: Dry wash and agglomeration, extrusion and pelletization, compression molding to durable products*

QRS-RePoly, based in St. Louis, Missouri, specializes in sorting and processing hard to recycle post-consumer materials for secondary manufacturing markets. Three intact bales of rFlex were shipped to QRS-RePoly for inspection, pre-sorting, and shredding. Pre-sorting removed fiber, PET, aluminum, and other contaminants. Bales were shipped to Austria for dry washing. The dry washing removed fiber, moisture, organics, dirt, and other contaminates leaving the PE film fraction with light PET, PS, and some fiber. This fraction was agglomerated. After several rounds of equipment testing and modification were tried, successful mixed plastic pellets were produced. The moisture level of the pellets was too high for injection molding, but they were deemed suitable for compression molding. The most problematic issues identified were high moisture content due to the fiber, and the presence of PET, aluminum and metal contamination. Bale yield was around 50% with 700 kilograms (1543 pounds) of 100% rFlex pellets produced. Test results from compression molded pallets using a percentage rFlex and in rail ties are pending.

Figure 11: Paver made from rFlex

Figure 12: Samples of shredded and pelletized rFlex Product

ULTRA-POLY – Hand pre-sort, shred and extrusion to recycled content pellet

Ultra-Poly is a large-scale Pennsylvania-based reclaimer and compounder of thermoplastics and engineering resins with a strong focus on post-industrial materials. A bale of rFlex was shipped to Ultra-Poly to test how an unwashed bale would perform. This was the most challenging test due to the lack of washing and the fact that the heterogenous mix of polymers caused the extruder screens, which are designed for more homogeneous material, to clog with extreme frequency. Pellets were successfully produced using about 50% recycled rFlex content blended with post-industrial LLPDE to produce a pellet that was molded into test swatches, but not without great effort.

Pyrolysis and Carbon Renewal Technologies

Currently, several advanced recycling technologies are evaluating the suitability of the rFlex bale for use in their systems. rFlex is an attractive feedstock because of the potential volumes it represents when produced at scale. As of the writing of this report, the results of these tests are not available. However, fiber has been identified as being problematic by these technologies so some level of pre-processing will have to be done to remove the residual paper. The plastics-only fraction of the bale could be used to make recovered petrochemical feedstocks for use in fuel or new petrochemicals.

Key Findings from Plastics-Only Bale Testing

The key findings from the plastics-only bale testing were as follows:

- For the plastics-only markets, rFlex bale optimization needs to occur. The primary recommendations were to reduce paper to 10% or below, eliminate rigid PET, and reduce total contaminants to no more than 10%.
- Develop a rFlex bale specification for plastics markets that ensures a 70% polyolefin yield which would be useful for many plastics end markets, including advanced recycling technologies.
- Washing is going to be necessary. Dry washing was found to be effective with pre-sorting. It is recommended to be combined with an extrusion system with additional de-gassing and filtration in producing a grade sufficient for compression molding, low pressure injection molding, and extrusion molding.
- There is a deficit of washing capacity for testing film recycling in the U.S., especially dry washing. Most companies that do wash utilize their capacity fully and do not offer tolling services. This is different from Europe, where companies that specialize in wash lines are an integral part of the recovery value chain and offer these tolling services for testing and other purposes. Companies like HydroDyn, Herbold, and MAS partner with other technology providers to offer testing services. This was identified as a significant infrastructure deficit in the U.S.

End Market Workshop Results

The RRS Project Team and MRFF sponsors collaborated with numerous end market reprocessors who shared their expertise and testing facilities to identify the likely most promising rFlex recovery pathways and product opportunities for rFlex. The MRFF End Market Workshop identified opportunities available today and those that could open up with further development. Based on the testing results and the collective expertise of mixed materials and mixed plastic reprocessors, over a dozen priority product opportunities were identified. The reprocessing technologies to produce these products were assessed against several criteria:

- The percent of the rFlex bale they could use
- The relative scale of the end market (small e.g. integrating less than 500 tons of rFlex material per year, to very large e.g. utilizing thousands of tons of rFlex material per year)
- Time to market (1-5 years)
- Limitations (any technological hurdles to process rFlex; compatibility with current definition of recyclable utilized in New Plastics Economy Global Commitments)[3].

Table 7 summarizes these results. Products are grouped by manufacturing technology, with near term opportunities presented first.

3. The Ellen MacArthur Foundation New Plastics Economy Global Commitment defines recycling as mechanical or chemical, and excludes fuel products consistent with the definition of material recycling in ISO 18064:2003.

Table 7: End Market Product Opportunities for rFlex (produced through expert peer review March 2 2020 RMC Workshop)

PRODUCTS	TECHNOLOGY	PERCENT RFLEX	RELATIVE SCALE OF MARKET	TIME TO MARKET	LIMITATIONS
Roof coverboard and subflooring	Compression Molding	Up to 100% rFlex	Very large	1-2 yrs	• No materials limitations • Limited manufacturing sites
Pallets	Compression Molding	Up to 100% rFlex plastic	Very large	1-2 yrs	• no Fiber/rigid PET/AL • Prefer olefins • Odor testing req'd
Sheet stock for signage	Compression Molding	Up to 100% rFlex plastic	Medium	1-2 yrs	• no Fiber/rigid PET • Prefer olefins • Odor testing req'd
Rail ties	Compression or Injection Molding	Up to 25% rFlex plastic	Very large	1-2 yrs	• no Fiber/rigid PET • Prefer olefins
Pavers, decking, lumber, bollards, curb stops, misc durable goods for outdoor use	Compression or Injection Molding	Percent of rFlex plastic	Small to medium	1-2 yrs	• no Fiber/rigid PET • Prefer olefins
Trim (molding, footboards)	Compression or injection Molding	Percent of rFlex plastic	Small to medium	1-2 yrs	• no Fiber/rigid PET • Prefer olefins • Odor testing req'd
Industrial mats	Compression Molding	Percent of rFlex plastic	Small to medium	1-2 yrs	• Unknown
Pallet slip sheets and corner boards	Extrusion Molding, Profile Extrusion, Drum Casting	Percent of rFlex plastic	Small	1-2 yrs	• no Fiber/rigid PET • Prefer olefins • Odor testing req'd
Large tanks, drain pipes, cargo containers, kayaks. Thick walled products	Rotomolding	Percent of rFlex plastic	Small to medium	3-5 yrs	• no Fiber/rigid PET • Olefins only • Requires pulverization
Bottles and Containers. Thin walled products	Blow Molding	Percent of rFlex plastic	Small	3-5 yrs	• no Fiber/rigid PET • Olefins only • Requires pellets
Crates, buckets, auto and lawn mower parts. Misc durable goods that require abuse and heat resistance.	Injection Molding	Percent of rFlex plastic, likely blended with recycled rigids or virgin to control resin properties.	Medium	3-5 yrs	• no Fiber/rigid PET • Olefins only • Requires pellets • Would need higher level of cleanliness to reach req'd MFI
Fuels or petrochemicals	Pyrolysis or Gasification	Up to 100% of rFlex plastic	Medium	1-2 yrs	• no Fiber/rigid PET • Prefer olefins • No PVC • Recovery for fuel is excluded from New Plastics Economy recycling definition
Asphalt binder	Material substitution	Up to 3% of plastic can be used in asphalt	Very large	3-5 years	• no Fiber • Prefer olefins
Cinder blocks, retention wall block	Material substitution	Percent of rFlex plastic	Very large	3-5 years	• no Fiber • Prefer olefins

Next Steps

Research into end markets has resulted in a trove of learnings from the pilot that will be used to direct efforts to grow end markets for rFlex and to inform next steps for the project. The rFlex Recycling Work Group will reconvene when pending end market test results are submitted. The following are the most important learnings:

- For plastic end markets to economically use the rFlex bale the amount of fiber needs to be reduced to 10% or less.
- Rigid PET was an unexpected contaminant in the rFlex bale and is universally viewed as a problem for plastics end markets that generally prefer olefins. It is also lost revenue to TotalRecycle. Sources of PET are flattened water bottles and thermoforms.
- The rFlex bale has higher potential value the higher the polyolefin content. Designing olefin rich film packaging and eliminating PET in multi-laminates when possible will, over time, result in greater bale value.
- There are two distinct categories of markets that can utilize the rFlex bale – one mixed material and all others plastic focused. To be able to sell rFlex to the plastics market, a rFlex bale specification for the plastic market needs to be developed: 80% film and flexible plastic, no more than 10% fiber, and no more than 10% contamination. PVC is a problem for all markets and needs to be de minimis.
- Dry washing as a low-cost, intermediate step in the recovery value chain was identified as a key infrastructure hurdle to be overcome to allow more efficient rFlex processing and open the door to more end market applications for rFlex plastics. The MRFF project is investigating strategies around this as an important next step. Wet washing will probably be needed for higher end markets, using technologies similar to European systems with minimal water usage and associated drying lines.

No matter the ultimate end market, commitments from end users of recycled products are critical to encourage the use of rFlex by reprocessors, create confidence to drive needed capital investment in equipment, and scale the market to use rFlex as PCR. To support this, a category of APR's Demand Champions Program is being considered for rFlex products. Municipal, state and institutional procurement are seen as important allies in creating the future demand for rFlex products to grow recovery of films and flexible packaging and ultimately create a meaningful recycling rate for the billions of pounds that go onto the market each year.

COMMUNITY COLLECTION

The third area of research in the MRFF pilot was into the feasibility of collection of FPP from residential recycling programs via standard curbside operations. The TotalRecycle facility is located in Birdsboro, Pennsylvania, approximately 50 miles outside of Philadelphia. The region surrounding the MRF includes numerous small and medium-sized suburban communities. J.P. Mascaro & Sons hauls recyclables to the MRF from approximately 50 customer communities in nine counties and processes recyclables from additional communities with municipal recycling collection. The area has an average household size of 2.59 persons and a median household income slightly higher than the U.S. as a whole. Curbside recycling programs are well-established in the region with statewide mandates in place for over thirty years. J.P. Mascaro & Sons has offered single-stream recycling to its customers since 2014.

Residential participation in the pilot served several goals. First, the sortation performance on the incidental flexible plastic packaging that enters the infeed as contamination was not necessarily representative of system's performance on volume or mix of materials that would enter when residents were directed to recycle FPP. Second, the composition of the rFlex bale, estimated based on national market data from the Flexible Packaging Association, could vary depending on the actual mix of materials that residents end up placing in their recycle bins. Finally, the pilot research sought to establish certain best practices for communicating the acceptance of this mix of recyclables and working with community residents.

Pilot Communities

Ten of J.P. Mascaro & Sons' customer communities were selected to participate in the pilot, meaning that residents were instructed to add flexible plastic packaging to their existing single-stream recycling collection. The communities were added in a phased approach starting in September 2019, once the sortation equipment had been demonstrated to capture a sufficient level of FPP from infeed. The municipalities participating in the pilot are shown in Table 8.

The pilot communities all have their recyclables collected by J.P. Mascaro & Sons and processed at TotalRecycle. They range in location from 10 to 40 miles from the facility, and their locations are shown in Figure 13.

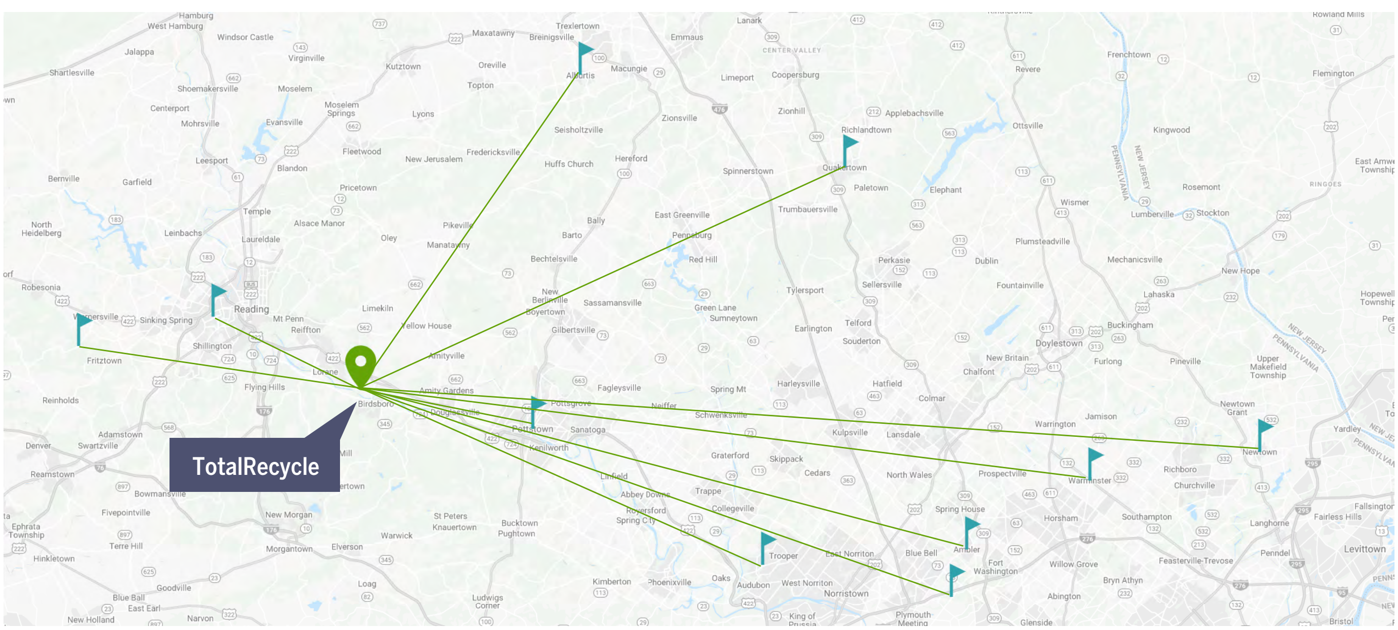
Barriers to Increased Community Participation

A key consideration in selecting the pilot communities was that all use lidded carts for recyclables collection. Due to the lightweight nature of the FPP, collection in open recycling bins was not considered suitable as it could lead to blowing litter on windy days. In addition, open recycling bins set out during rainy periods lead to higher levels of moisture in the recyclable stream;

Table 8: Municipalities Participating in Pilot

MUNICIPALITY	HOUSEHOLDS IN MUNICIPALITY	COUNTY	ROLLOUT DATE
Pottstown Borough	9,321	Montgomery County	Sep-19
Lower Providence Township	8,769	Montgomery County	Nov-19
South Heidelberg Township	2,590	Berks County	Dec-19
Alburtis Borough	881	Lehigh County	Jan-20
Ambler Borough	2,604	Montgomery County	Jan-20
Newtown Township	4,871	Delaware County	Jan-20
Quakertown Borough	3,649	Bucks County	Jan-20
Warminster Township	12,874	Bucks County	Jan-20
Whitemarsh Township	6,744	Montgomery County	Jan-20
Wyomissing Borough	4,612	Berks County	Jan-20
TOTAL HOUSEHOLDS IN PILOT COMMUNITIES	**56,915**		

Figure 13: Location of Pilot MRF and Communities



moisture content in fiber materials was noted during the equipment tuning phase as a factor lowering performance of the entire sortation system.

While J.P. Mascaro & Sons processes recyclables from a service area of roughly 300,000 households, the 56,000 included in the pilot represent only those communities directly collected by the company that utilize lidded carts. The company also collects recyclables from over 120,000 households using open recycle bins or cans without attached lids. An additional 123,000 households are in communities that collect their own recyclables and use the TotalRecycle MRF as a processor. While some of these communities, representing 22,000 households, already had the necessary equipment for collection, they typically conduct their own messaging, marketing, and outreach for their recycling programs, and thus were seen as less suitable for full participation in the first year of the pilot.

The lack of lidded collection carts, both in this area and in recycling programs nationwide, has been identified as a significant infrastructure gap to implement best practices in single stream recycling collection. Carts used in curbside recycling programs cost roughly $50 per household; closing the gap to provide carts to all residents in TotalRecycle's processing area alone would represent an investment of over $11 M.

Communications and Outreach to Residents

Residents were encouraged to participate in the pilot with a coordinated outreach campaign using multiple points of contact: at home, via media and internet, and in the community.

- Home-based communication included direct mailers and stickers on recycle carts. The mailer, shown in Figure 14, and the sticker both featured full-color images of twenty varieties of FPP to demonstrate the wide range of materials included in the program.
- Media/web communications included press releases and resulting news coverage; updates to J.P. Mascaro & Sons' and individual community websites; and social media.
    - Press releases were targeted to local media rather than national. The program was clearly described in these communications as a pilot and emphasized its unique status among recycling programs. These messages were considered crucial to avoid confusing residents of other areas not participating in the pilot.
    - Web communications reused the same set of images featured in the sticker and mailer to visually reinforce the messages on what materials were allowable in the program. FPP collection is clearly described on the individual community sections of J.P. Mascaro & Sons' website, shown in Figure 15, which are heavily used as references by residents to determine their collection day, holiday closures, and other service information.
- Community representatives were invited to a Customer Showcase event at J.P. Mascaro & Sons' headquarters in February 2019 to learn about the project and the upcoming opportunity

Figure 14: Mailer Announcing Start of FPP Collection

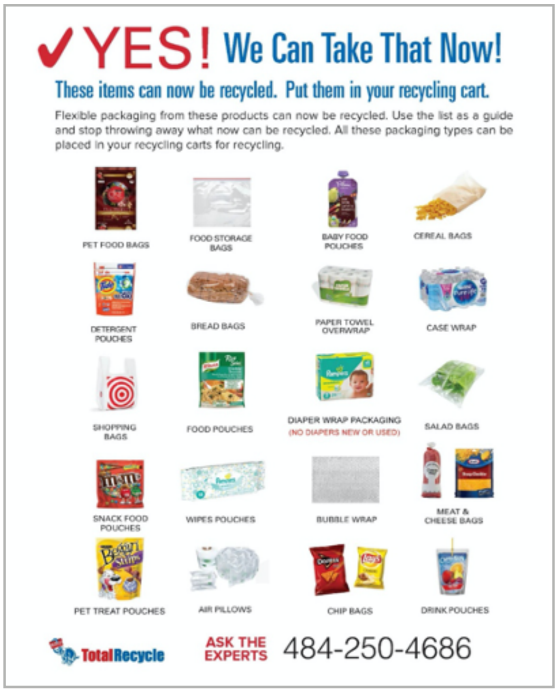
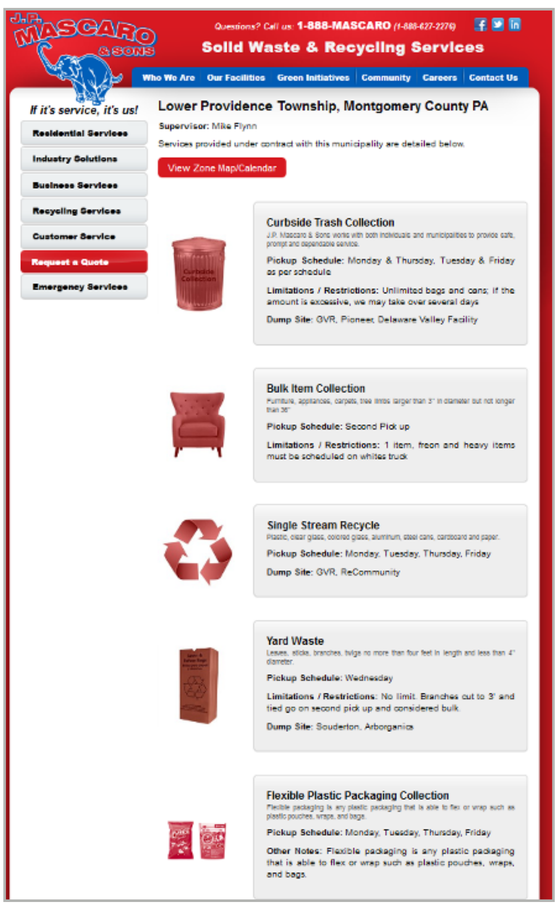


Figure 15: Hauler Website for Participating Community



to add FPP collection to their recycling programs. This event allowed the MRFF Pilot team led by J.P. Mascaro & Sons the opportunity to educate coordinators on pilot requirements and identify communities that might be interested in participating. The Recycling Partnership also presented their tools and resources for collection best practices, specifically cart equipment grants.

- Community-based outreach included physical displays showing FPP that could be recycled, placed at prominent locations including libraries, borough halls, etc. Examples of displays are shown in Figure 16.
- Residents were also provided with an FPP-specific phone number to reach a J.P. Mascaro & Sons staff member with any questions; participating communities were given FAQ responses for their resident-facing representatives, in case they received questions directly.

Community Collection: Feedback and Results

Resident response to the launch of FPP collection in the first community, Pottstown, was widely positive and community representatives were pleased to be selected to participate in the program. J.P. Mascaro & Sons staff reported that the main inquiries received were specific clarifications about whether certain materials could be included. Based on the positive response to the first community rollout, the materials used were replicated for rollouts in Lower Providence Township and South Heidelberg Township in late 2019. These rollouts proceeded without any issues reported from the MRF, collection division, residents, or township officials. The final group of pilot communities was launched after the busy holiday period, in late January 2020, using the same communications tactics and materials.

Based on the response to community collection in this pilot area, residents are widely receptive and respond positively to the inclusion of FPP in their recycling programs. Suitable collection equipment (lidded carts) is an important consideration to avoid any potential issues with lightweight FPP blowing out of containers and causing litter. Among communities that already have cart collection, FPP inclusion was not reported to cause any issues with setout or hauling of recyclables.

Figure 16: Displays at Community Locations Promoting FPP Collection

Economic Feasibility of Adding FPP to Collection

In 2017, prior to the MRFF pilot, RRS developed a pro-forma model to estimate the costs, benefits, and net cost to a MRF to add flexible plastic packaging to their incoming material stream. The model showed that for a large single stream MRF in a region of the U.S. with higher than average landfill tipping fees for MRF residuals, and revenue per ton for the sales of the rFlex material at $10 per ton, the net cost to process the material was around $2 per ton (at that time, alternative fuels had some positive value reflected in the model assumptions). This cost was considered on par with addition of other new materials to single stream recycling systems.

The economics of recycling have changed dramatically since 2017 with plunging market values for many MRF commodities, raw virgin materials, and alternative fuels. The pilot provided an opportunity to re-visit the economics of adding FPP to curbside collection programs with better informed and realistic data on capital costs, labor savings, volumes of FPP, and updated material revenue. Keeping other assumptions constant, the revisited modelling exercise concluded that the net cost to process the material was now closer to $2.25 per ton. In a scenario where the MRF receives no revenue for the sale of FPP, the cost to process increases to $2.41 per ton. The breakeven point at which the revenue for the sale of FPP would offset additional costs to process was found to be between $100 and $150 per ton, roughly equivalent to the current market value of sorted polypropylene (PP #5). Two keys for future revenue modeling are the continued improvement of the removal of paper to acceptable levels, so polyolefin capture is a viable proposition for downstream markets, or the continued growth of roof and wall board where rFlex provides a premium input.

Additional detail on the economic model for adding FPP can be found in Appendix B.

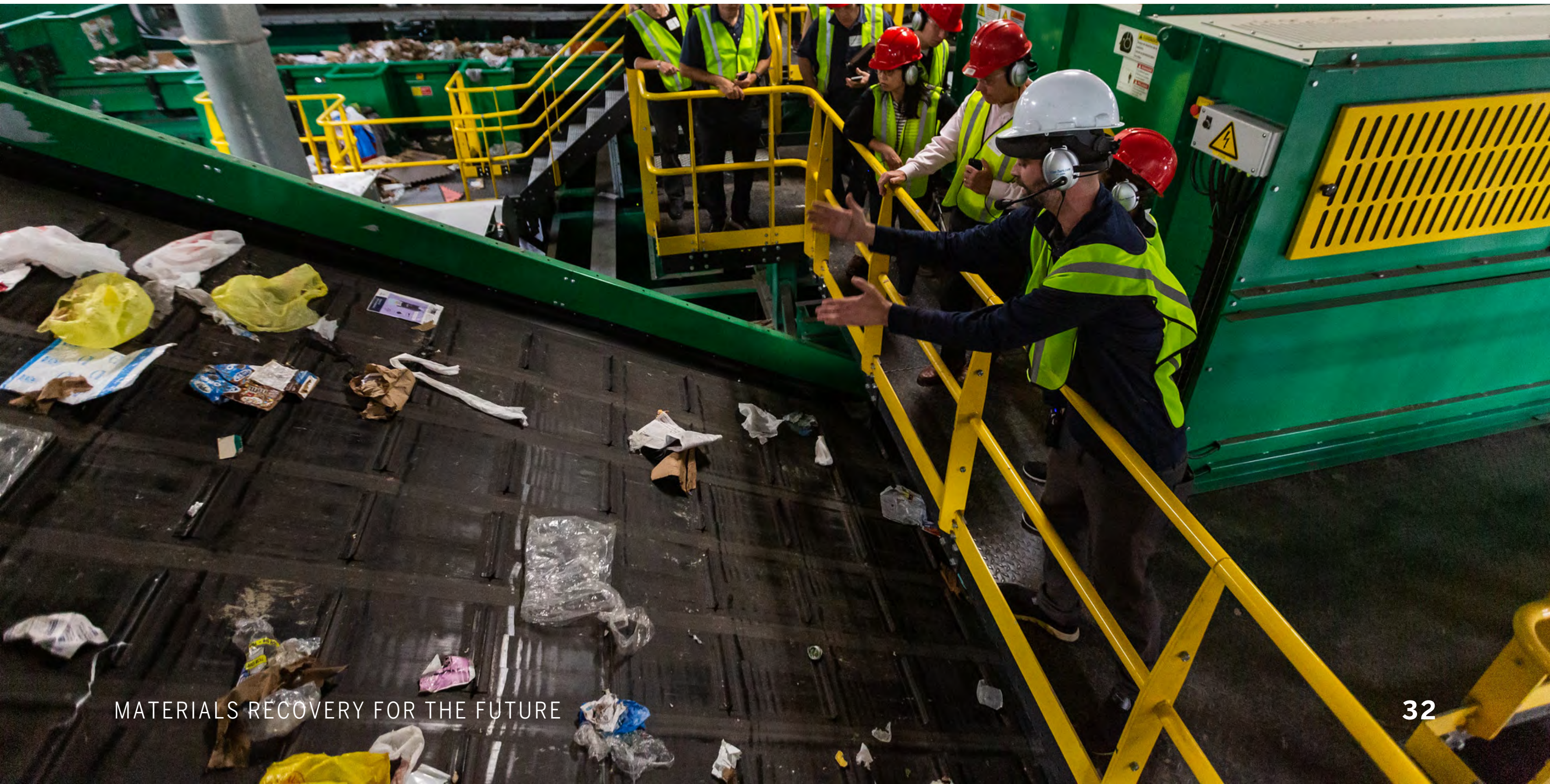
Steve Sikra, former Director of Sustainability at Procter & Gamble & MRFF Chair, presenting to community representatives at Customer Showcase event

CONCLUSIONS

In the first year of operation the TotalRecycle FPP Pilot team, with support from J.P. Mascaro & Sons corporate, the RRS Project Team and MRFF sponsors, made significant progress in demonstrating how to efficiently sort flexible plastic packaging, providing multiple learnings as the first proof-of concept pilot facility to accept curbside cart material. Of the five performance goals set for the pilot, four goals were met and improvement towards the final goal – a 90% recovery rate for FPP in feedstock – is expected as optical sorter adjustments continue and scheduled equipment upgrades are completed. The selected automated equipment featuring optical sorters, air separation, and other peripherals successfully sorted flexible packaging over the pilot period, with an immediate benefit of cleaner paper bales that have enhanced marketability.

FPP was successfully collected via municipal single stream curbside carts in areas served by the MRF that had the appropriate lidded collection carts to participate. The process was easy and well received by residents in the pilot communities. The updated RRS pro forma modeling costs and benefits to add FPP to curbside collection shows costs continue to be on par with other curbside recyclables such as polypropylene.

Once the TotalRecycle rFlex bale supply became consistently available in November 2019, a ninety day period of accelerated end market testing began with an expanded team of plastics processing experts joining the RRS Project Team to peer review and collectively identify over a dozen priority end market product opportunities. The opportunities include the most immediate go-to-market potential in building envelope and exterior environment products; additional distribution, rail and trucking/store interior products; and longer term consumer products and packaging. These products are currently in various stages of development or commercialization. The majority require investment and/or product contracts to successfully meet the growing demand from brand owners for PCR content products. The continued engagement of this experienced rFlex recycling work group—applying their knowledge of material science, processing technologies, and market scale economics—has the potential to unlock domestic recycling capacity in one to five years with the proper leveraged investment strategy.



RECOMMENDATIONS

The research and peer review performed to date by Materials Recovery for the Future have established a body of scientific evidence and identified a scalable path for capturing FPP through optical sortation on fiber sort lines of large automated MRFs. The research indicates that recycled FPP feedstock has potential to be a high performing substitute material for virgin materials such as petroleum, wood, gypsum, and concrete. However, more work is required to optimize and process the rFlex bale to produce products to scale the learnings in this report.

SHORT-TERM PILOT COMPLETION

MRFF project sponsors came together to complete a proof-of-concept pilot. RRS recommends the following actions to complete a successful demonstration of FPP recycling:

1. Refine Sorting: Synchronize rFlex bale production — both quality and quantity — with plastic end market requirements for the limited purposes of this pilot demonstration project. Perform monthly monitoring for a period once the TotalRecycle rFlex 2020 upgrades are complete. Perform a repeat RFID flow test to measure the system's capture efficiency, and further evaluate packaging categories that were outliers captured at a significantly lower rate than the rest of the mix. Optimize the rFlex bale for end markets, and continue to engage the rFlex Recycling Work Group to define pre-processing requirements and an investment strategy once end market testing is completed and the bale performance is improved.
2. The REMADE Institute has partnered with MRFF to award U.S. Department of Energy funding to refine the rFlex bale and develop a life cycle inventory of the major end market product pathways, evaluating energy use and greenhouse gas emissions as compared to virgin materials. Proceeding with this work will support rFlex bale synchronization described above.
3. Recycling is successful when the MRF is able to both sort and create a product to sell to a reclaimer. As individual companies, committing to purchase rFlex products will create demand for rFlex.
   a. Join the APR Demand Champions program, or as part of the ongoing commitment for current members, consider directing commitments to rFlex PCR products. Public commitments help raise awareness among stakeholders and catalyze end market development. Target plans to procure a new roof system with rFlex over the next 12 months, and will share the learnings from the test store with other property teams and suppliers from peer companies as they become available.
   b. As individual companies, investigate the rFlex product opportunities identified in this report with property teams or suppliers to utilize roof cover board and other commercially tested products in both retail and retail supply chain environments. Target Stores has agreed to share the learnings from their 2020 test store with other property teams and suppliers from peer companies.

SCALING THE PILOT LEARNINGS

Longer term, it is important to recognize recycling is not just a matter of recovering recyclable material; it's a total economic system. At the time of publication, the cost of collecting and processing FPP outweighs its value as a commodity that can be sold back to industry. Unless industry end users (product manufacturers, retailer and e-commerce), public works end users (government agencies) and consumers buy recycled products, the markets for the material put out at the curb or into store drop-off receptacles will remain anemic.

Today's FPP value chain is linear, as the vast majority of material (over 96%) is not recycled in the U.S. market. The FPP Value Chain involves the key actors noted in Figure 17. Product manufacturers include packaging companies and the consumer packaged goods companies that use this packaging for their product.

An RRS 2019 survey of MRFF brand owners and retailers showed the majority would like to achieve circular economy goals through curbside recycling of FPP within five years. In addition to many MRFF

Figure 17: Flexible Plastic Packaging Value Chain

sponsors, a large number of companies have made similar public commitments to recyclable packaging and PCR content through the Ellen MacArthur Foundation.

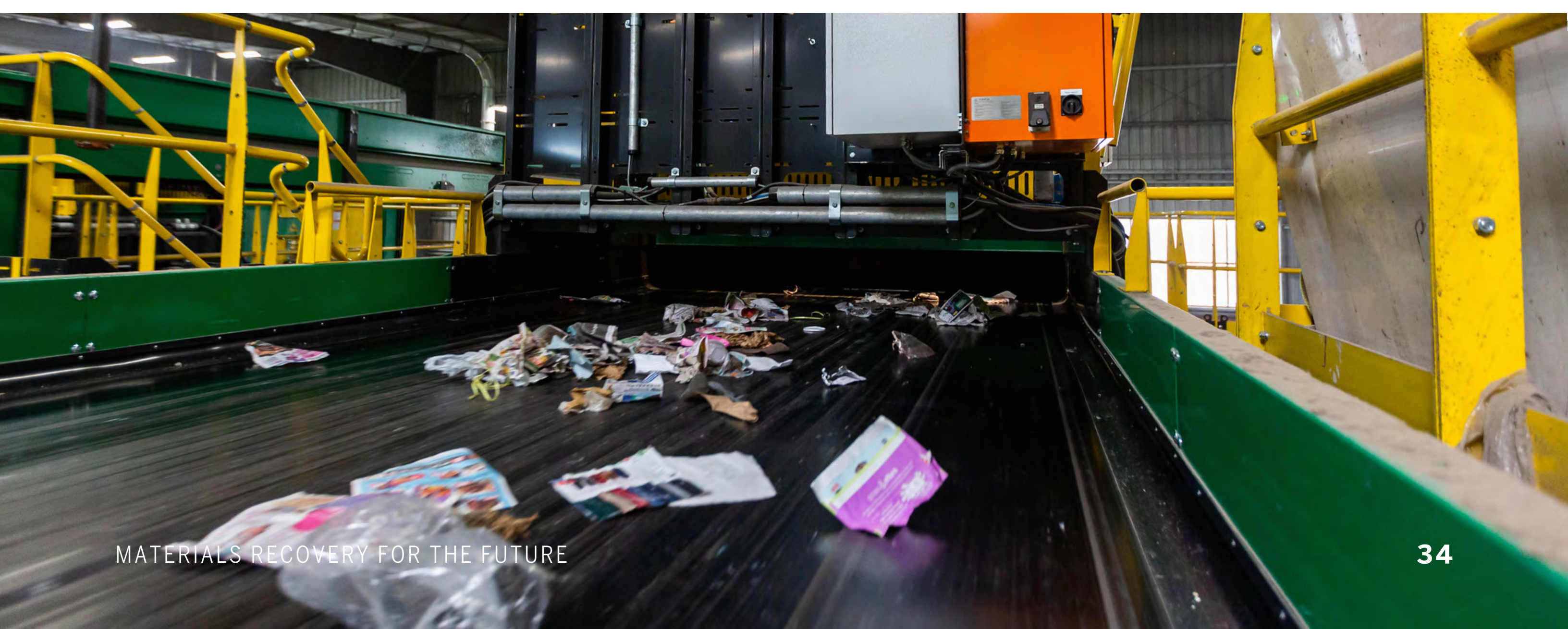
RRS developed the following recommendations to achieve the five-year curbside recycling target. Success will require ongoing development of the supply chain while simultaneously scaling access through a series of targeted investments in MRF processing upgrades to create a circular FPP value chain.

1. Build Demand for rFlex

In the non-regulated, economically driven U.S. system, manufacturers of rFlex PCR will require investment and long-term customer contracts to justify expansion. The customer is the catalyst in manufacturing economies.

Currently, there is established, steadily growing demand for green building products among industry and public works end users. This makes quicker wins of investment in and contracts for the PCR building envelope products identified in this research. Waste Management Inc.'s investment in Continuus Materials is a prime example of the type of investment necessary.

The product manufacturing, retail, and e-commerce industries that use FPP collectively utilize millions of square feet of retail space – stores, distribution centers, plants, and warehouses. Local public works agencies complete millions of square feet of infrastructure projects requiring retention walls, irrigation pipes, and other building materials every year. rFlex polymer-based products offer superior technical performance and durability depending on the building products they replace. Procurement departments should evaluate not only whether specification of PCR supports achievement of the company's sustainability goals, but also whether the use of PCR offers superior durability and performance.



FPP packaging value chain members, from resin manufacturers to retail/e-commerce end users, can choose to take two actions to achieve the desired recycling target in current market conditions: either invest in, or become a customer for, rFlex PCR products.

Figure 18 illustrates a closed loop model for the flexible plastic recycling value chain. Every member of this value chain has a role to play to support development of domestic reclaimers and rFlex product manufacturers. In this model, product manufacturers expand to represent the priority product opportunities researched in Table 7 that can use post-consumer FPP. Mechanical recycling is preferable for this feedstock as it requires fewer steps and less cost to reprocess. Chemical (or advanced) recycling technologies may be useful where collection and/or sortation does not yield a mechanically recyclable feedstock.

Figure 18: A circular model for FPP recycling in the U.S.

End Market Investment Strategy

- The most technically feasible, short term product opportunities are high volume, non-structural building products. Existing demand pull for green building products and LEED point credits make investment in these markets the most promising, particularly if sited near early adopter MRFs that provide supply.
- Dry washing is a low-cost, intermediate step that is a key infrastructure hurdle for investment to allow more efficient rFlex processing and unlock a wide array of end market applications for rFlex plastics. Investigating strategies around developing this capacity domestically is an important next step. For the current anticipated supply from TotalRecycle, 3000 tons annually, pre-processing is a straightforward bridge solution until supply grows.

2. Supply

A top MRF industry priority today is supplying better quality paper bales to customer mills. In the MRF, two-dimensional FPP often flows with two-dimensional paper, clogging screens and contaminating paper bales. This means that MRFs currently performing upgrades are focused on cleaning up paper: sorting FPP out on the fiber lines to improve bale quality, and landfilling FPP as markets are not available. Those upgrading MRFs are an excellent target for implementing FPP recovery as piloted by the MRFF program, leveraging industry value chain co-investment from Closed Loop Partners, the Alliance to End Plastic Waste, and other recycling investment groups. Funds may also potentially emerge from national recycling infrastructure legislation, however that is unlikely to appear in time to achieve current plastic recovery targets.

How much investment is needed? In 2017, RRS estimated the capital investment cost based on the TotalRecycle Pilot RFP to be $300-500M to retrofit and upgrade all large automated U.S. facilities (approximately 100) with optical sorters and peripherals required to sort rFlex ($3-5M per MRF). Given equipment costs have increased over the past three years, a starting budget today for planning purposes may need to be larger to retrofit large MRFs. This investment would yield recovery of 1.2 billion pounds of rFlex.

The most cost-effective way to scale TotalRecycle Pilot learnings is through co-investment in new build MRFs with owners and operators that aim to process today's typical ton of recyclables in modern MRFs with better quality products. New build systems are typically more cost-effective than retrofits, and these MRFs present another excellent target for industry value chain co-investment. Advancing use of digital watermarking technologies also offers promise for the circular packaging recovery system of the future.

As demand pull is created, MRFs will be incented to produce rFlex bales to sell to end market product manufacture customers in their region. To create a stable supply of rFlex necessary to scale pre-processing and PCR resin manufacturing discussed in the preceding recommendation, bale specifications must be set.

RRS expects flexible plastic bales may follow a similar pattern to the development of paper bales, so there will be different grade specifications driven by the requirements of different end market production processes. Whether these grades are attainable at the MRF or are met post-MRF remains to be seen. This approach is economically advantageous to MRF owners, providing flexibility to respond to spot markets and regional needs. Based on this research, two potential bales are:

- rFlex mixed bale grade – low value flexible plastics (85%) and mixed paper (up to 15%)
- FPP plastic bale grade – rich in polyolefins, paper at de minimis levels, 2% or less along with other potential contaminants such as PET containers. PVC and metals at each less than 0.5% each.

Where consumers and residents expect robust curbside recycling and want to recycle FPP, municipal recycling collection authorities can use the pro forma model presented in Appendix B to evaluate adding FPP processing capability to their MRF along with other single stream recyclable costs. All residential recycling services have net costs. Planning for these costs helps MRFs buffer the ups and downs associated with commodity values.

3. Municipal Collection

Large capacity covered carts are a recycling best practice and critical to efficient automated sorting of loose material in a MRF. As the scaling of FPP recycling proceeds, more carts will be needed to recycle this material along with other materials currently accepted for collection. The Recycling Partnership has found that nationally, only 44% of the single-family population with curbside recycling have a cart.[4] The RRS gap analysis showed that in the region served by the pilot facility an investment of over $11 M will be needed to fully allow all households to recycle FPP curbside. Investment is needed to fill this gap. Making this investment in carts would also allow increased collection of other recyclable materials, including cardboard, paper, and aluminum.

In summary, through focused and sustained supply chain facilitation, success can be achieved through the above interventions, carefully coordinated in an industry-led strategy for scaling MRF FPP recovery. RRS believes the five-year target is achievable through strong, sustained industry leadership that creates demand while building supply to complete the circular flexible packaging recovery value chain. Strategic co-investments in equipment, a focused strategy on end market development to include investment where necessary, commitment to more rFlex PCR supplier contracts, and a municipal access strategy as executed by other recycling collective action programs such as Carton Council show what can be accomplished in the U.S. market.

The authors of this report hope the MRFF proof-of-concept research process can be utilized to the mutual benefit of those who share sustainable material management goals. We've provided a summary table of recycling grants and tools for those who seeking to carry this work forward in Appendix C.

4. The Recycling Partnership. (2017). The 2016 State of Curbside Report. Retrieved from https://recyclingpartnership.org/wp-content/uploads/2018/05/state-of-recycling-report-Jan2017.pdf

APPENDIX A

PACKAGE FLOW TEST RESULTS

This appendix includes detailed results at the package level for each RFID test period. A variety of packages were used in each test, ranging in dimensions from 2.5 x 4 inches up to 14 x 24 inches.

April 2019 Test

Table 9: Equipment Efficiency Analysis, April 2019

PACKAGE	FIBER SCREENS EFFICIENCY	OS 1-3 EFFICIENCY	OS 4 EFFICIENCY	FLEX/RIGID SEPARATOR EFFICIENCY
Large Standup Pouch	98%	66%	68%	92%
Medium Standup Pouch	92%	60%	68%	80%
Large Chip Bag	96%	62%	81%	91%
Cereal Bag	98%	82%	84%	92%
Small Chip Bag	91%	46%	75%	92%
Bread Bag	99%	84%	81%	99%
Shrink Wrap	93%	75%	85%	92%
Small Storage Bag	91%	48%	71%	97%
Spouted Pouch	62%	37%	95%	80%
Retail Carry Bag	96%	89%	82%	94%
Large Storage Bag	95%	72%	80%	99%
Composition Adjusted Average	95%	75%	81%	93%

The equipment efficiency metric allows the components of the sortation system to be directly compared. The fiber screens were the top-performing part of the system during the April 2019 test, while Optical Sorters (OS) 1-3 were found to have a lower level of performance. The performance of the first three optical sorters was found to vary by package type. Large, highly flexible packages like retail carry bags were ejected at levels comparable to that seen in lab testing, while smaller packages did not fare as well. Losses to Optical Sorter 4, the clean-up system, varied as well. Finally, the flex/rigid separator performed well in the testing, effectively retaining 93% of material that made it to that point.

Overall, 55% of packages were recovered into the target bale during the April 2019 test. Of the remaining 45%, 5% were lost at the fiber screens; 23% at OS 1-3 due to failure to be recognized and ejected; 13% at OS 4 as collateral ejects with the mixed paper recovery; and 4% at the flex/rigid separator.

Table 10: Package Flow Analysis, April 2019

PACKAGE	LOSSES TO FIBER SCREEN MISSES	LOSSES TO MISSED FIBER LINE EJECTION (OS 1-3)	LOSSES TO MIXED PAPER EJECTION (OS 4)	LOSSES TO FLEX/ RIGID SEPARATOR	RECOVERY RATE
Large Standup Pouch	2%	33%	21%	3%	41%
Medium Standup Pouch	8%	37%	17%	7%	30%
Large Chip Bag	4%	37%	11%	4%	43%
Cereal Bag	2%	18%	13%	6%	62%
Small Chip Bag	9%	49%	10%	3%	29%
Bread Bag	1%	16%	16%	1%	67%
Shrink Wrap	7%	23%	10%	5%	55%
Small Storage Bag	9%	47%	13%	1%	30%
Spouted Pouch	38%	39%	1%	4%	17%
Retail Carry Bag	4%	10%	15%	4%	67%
Large Storage Bag	5%	26%	14%	1%	55%
Composition Adjusted Average	5%	23%	13%	4%	55%

The flow of packages within the system in the April 2019 test resulted in an overall capture rate ranging from a high of 67% recovery for retail carry bags and bread bags to a low of 17% for spouted pouches. None of the packages performed at the target levels established in the RFP process.

August 2019 Test

The results of this adjusted system are shown at the equipment level in Table 11 below. In the August 2019 test, fiber screens remained the top-performing piece of equipment. The first three optical sorters now performed at 90% efficiency, while OS 4 showed only 65% efficiency due to its greater level of aggressiveness on paper. The flex/rigid separator was 86% efficient across the stream as a whole.

Table 11: Equipment Efficiency Analysis, August 2019

PACKAGE	FIBER SCREENS EFFICIENCY	OS 1 - 3 EFFICIENCY	OS 4 EFFICIENCY	FLEX/RIGID SEPARATOR EFFICIENCY
Small Chip Bag	97%	83%	76%	67%
Large Chip Bag	97%	91%	75%	73%
Medium Standup Pouch	96%	85%	81%	64%
Spouted Pouch	88%	79%	88%	44%
Juice Pouch no Straw	94%	81%	88%	62%
Juice Pouch with Straw	91%	76%	81%	59%
Shrink Wrap	90%	87%	51%	89%
Small Storage Bag	92%	71%	73%	95%
Large Standup Pouch	97%	95%	81%	73%
Bread Bag	97%	90%	58%	93%
Cereal Bag	97%	91%	81%	75%
Retail Carry Bag	94%	93%	46%	94%
Composition Adjusted Average	95%	88%	64%	83%

As shown in Table 12 below, the recovery rate was 71% across the entire stream of packaging for the August 2019 test, ranging from a high of 80% for bread bags to a low of 34% for spouted pouches. The highest losses were seen at OS 4, but an estimated 90% of these packages were recovered at Q/C into the FPP stream, meaning that only approximately 3% of this material actually ended up in the mixed paper stream. Once the Q/C is factored in, the greatest losses occurred as missed ejections at the first three optical sorters, followed by losses to the flex/rigid separator.

Table 12: Package Flow Analysis, August 2019

PACKAGE	LOSSES TO FIBER SCREEN MISSES	LOSSES TO MISSED FIBER LINE EJECTION (OS 1-3)	LOSSES TO MIXED PAPER	LOSSES TO FLEX/RIGID SEPARATOR	RECOVERY RATE
Small Chip Bag	3%	17%	2%	20%	58%
Large Chip Bag	3%	9%	2%	16%	70%
Medium Standup Pouch	4%	14%	2%	24%	57%
Spouted Pouch	12%	19%	1%	34%	34%
Juice Pouch no Straw	6%	18%	1%	25%	50%
Juice Pouch with Straw	9%	22%	1%	22%	46%
Shrink Wrap	10%	11%	4%	4%	70%
Small Storage Bag	8%	27%	2%	2%	61%
Large Standup Pouch	3%	5%	2%	20%	70%
Bread Bag	3%	10%	4%	3%	80%
Cereal Bag	3%	9%	2%	18%	69%
Retail Carry Bag	6%	7%	5%	3%	80%
Composition Adjusted Average	5%	11%	3%	10%	71%

February 2020 Test

Table 13: Equipment Efficiency Analysis, February 2020

PACKAGE	FIBER SCREENS EFFICIENCY	OS 1 - 3 EFFICIENCY	OS 4 EFFICIENCY	FLEX/RIGID SEPARATOR EFFICIENCY
Small Chip Bag	95%	45%	49%	83%
Large Chip Bag	99%	71%	52%	92%
Medium Standup Pouch	93%	59%	26%	47%
Spouted Pouch	29%	35%	100%	13%
Juice Pouch with Straw	63%	25%	78%	81%
Shrink Wrap	100%	92%	45%	96%
Large Storage Bag	99%	87%	42%	87%
Large Standup Pouch	100%	73%	74%	58%
Bread Bag	99%	89%	47%	99%
Cereal Bag	95%	82%	57%	79%
Retail Carry Bag	100%	94%	49%	100%
Composition Adjusted Average	98%	85%	50%	92%

As shown in Table 14 below, the recovery rate in the February 2020 test was 74% across the entire stream of packaging, ranging from a high of 90% for bread bags to a low of 1% for spouted pouches. Screen maintenance issues during the test period had an outsize impact on the recovery of very small packages such as the spouted pouches.

Table 14: Package Flow Analysis, February 2020

PACKAGE	LOSSES TO FIBER SCREEN MISSES	LOSSES TO MISSED FIBER LINE EJECTION (OS 1-3)	LOSSES TO MIXED PAPER	LOSSES TO FLEX/RIGID SEPARATOR	RECOVERY RATE
Small Chip Bag	5%	52%	4%	4%	36%
Large Chip Bag	1%	29%	3%	3%	64%
Medium Standup Pouch	7%	38%	1%	7%	43%
Spouted Pouch	71%	20%	0%	8%	1%
Juice Pouch with Straw	37%	47%	0%	3%	13%
Shrink Wrap	0%	8%	2%	1%	85%
Small Storage Bag	1%	12%	3%	5%	76%
Large Standup Pouch	0%	27%	1%	24%	46%
Bread Bag	1%	11%	4%	0%	84%
Cereal Bag	5%	18%	2%	10%	65%
Retail Carry Bag	0%	6%	5%	0%	90%
Composition Adjusted Average	2%	15%	3%	6%	74%

APPENDIX B

PRO-FORMA FINANCIAL MODEL FOR ADDING FPP

The financial pro-forma model provides an estimate of the costs, benefits, and net cost to a MRF to add flexible plastic packaging to their incoming material stream. RRS developed the pro-forma so that it can be adjusted to model this scenario for any MRF in the U.S. The key variable inputs to the model include operational characteristics of the MRF being modeled, such as inbound and outbound tonnage, staffing, operations and maintenance; as well as key financial variables, such as landfill tipping fees in the region, material sales revenue per ton, and capital and operating expenditures.

The results of the model are highly sensitive to two variables:

- landfill tipping fees
- revenue per ton from sales of the recovered flexible packaging.

The sample MRF Summary that follows demonstrates a realistic scenario for a large single stream MRF in a region of the U.S. similar to that of the Pilot Facility, with higher than average landfill tipping fees. Revenue per ton is estimated at $10/ton of FPP reflecting the baseline assumptions of the MRFF pilot program. In a scenario where the MRF receives no revenue for the sale of FPP, the cost to process increases to $2.41/ton of total recyclables processed. The breakeven point at which the revenue for the sale of FPP would offset additional costs to process was found to be roughly equivalent to the current market value of sorted polypropylene (PP #5). Additional revenue from the sale of paper, owing to the higher quality found to be produced in the pilot, is a potential benefit that has not been quantified in these calculations.

Addition of Flexible Packaging

		FACILITY BASELINE	CHANGES FROM ADDITION OF FP	FACILITY TOTALS WITH FP ADDED
Total Inbound Tonnage	A)	123,300	1,500	125,000
	B)		2% Increase	
Outbound Tonnage				
Fiber Tonnage	C)	67,000	0	67,000
Container Tonnage	D)	44,000	0	44,000
FP Tonnage	E)	0	2,000	2,000
Residue	F)	12,000	(400)	11,600
Building Area	G)	70,000	0	70,000
Number of Employees	H)	65	(3)	62
Capital Cost	I)	$19.1 M	$3.7 M	$22.8 M

REVENUE SUMMARY - BASELINE		AMOUNT	NOTES
Annualized Capital Cost	J)	$1.46 M	
Annual Operating Cost	K)	$5.07 M	
Annual Revenue from Material Sales (net of residue tipping fee)	L)	$5.1 M	
Annual Net Revenue (Cost)	M)	-$1.4 M	Line L - (Line J + Line K)
Capital + Operating Cost/Ton	N)	$53	(Line J + Line K) / Line A
Average Revenue Per Ton (net of residue tipping fee)	O)	$42	Line L / Line A
Net Revenue (Cost) Per Ton of Recyclables Processed	P)	($11)	Line V - Line U

REVENUE SUMMARY - WITH FP		AMOUNT	NOTES
Annualized Capital Cost	Q)	$1.8 M	Includes annualized addition of $2.835 M (Line I) in capital equipment
Annual Operating Cost	R)	$5.04 M	Includes savings from reduced sorter labor and added costs from higher throughput
Annual Revenue from Material Sales (net of residue tipping fee)	S)	$5.2 M	Includes estimated revenue of $10/ton on sorted FP and reduction in residue tip fees from FP not disposed as residue
Annual Net Revenue (Cost)	T)	($1.7 M)	Line S - (Line Q + Line R)
Capital + Operating Cost/Ton	U)	$55	(Line Q + Line R) / Line A
Average Revenue Per Ton (net of residue tipping fee)	V)	$41	Line S / Line A
Net Revenue (Cost) Per Ton of Recyclables Processed	W)	-$14	Line V - Line U
Net Benefit (Cost) Per Ton of Recyclables Processed to MRF with FP Added	X)	($2.25)	

APPENDIX C

SELECTED RECYCLING PROGRAM RESOURCES

The following table lists some of the organizations, programs, and resources supporting recycling programs and infrastructure in the U.S.

RESOURCE	DESCRIPTION
Alliance to End Plastic Waste	The Alliance to End Plastic Waste is made up of over 40 companies making investments to help end plastic waste in the environment.
Association of Plastic Recyclers Recycling Demand Champions	APR Recycling Demand Champions commit to purchase post-consumer resin (PCR), and thereby play a prominent role in expanding the market for mixed residential plastics.
CalRecycle	The California Department of Resources Recycling and Recovery (CalRecycle) offers funding opportunities authorized by legislation to assist public and private entities in the safe and effective management of the waste stream.
Closed Loop Partners	New York based investment firm comprised of venture capital, growth equity, private equity and project finance as well as an innovation center focused on building the circular economy.
Colorado Department of Public Health and Environment	Recycling Resources Economic Opportunity (RREO) Program provides funding that promotes economic development through the management of materials that would otherwise be landfilled.
Keep America Beautiful	A leading national nonprofit, Keep America Beautiful inspires and educates people to take action every day to improve and beautify their community environment by ending littering, improving recycling and beautifying our communities.
Michigan Department of Environment, Great Lakes, and Energy	Recycling Grants: Funding is available annually through the Renew Michigan Fund to support projects that contribute to Michigan's environment through enhanced materials management.
Pennsylvania Recycling Markets Center	The Pennsylvania Recycling Markets Center is a leader in developing and expanding recycling markets in Pennsylvania. In a competitive global marketplace, the RMC is the keystone clearinghouse of environmental, economic development, and manufacturing resources for end use support of recycled commodities and products.
The Recycling Partnership	The Recycling Partnership catalyzes improvements through leveraged seed grants, partnerships, and its extensive reach to spark commitment, investment, and standards across the system.
U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy	Plastic Innovation Challenge: a comprehensive program to accelerate innovations in energy-efficient plastics recycling technologies.