MRFF | MATERIALS RECOVERY FOR THE FUTURE

FLEXIBLE PACKAGING SORTATION AT MATERIALS RECOVERY FACILITIES

RESEARCH REPORT

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RRS also acknowledges the external reviewers who volunteered to review this report, including subject matter experts and sustainable materials management practitioners from both private and public sectors.

The work was performed by RRS as an independent contractor. The findings and conclusions are strictly those of RRS. RRS makes no statements nor supports any conclusions other than those presented in this report.

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EXECUTIVE SUMMARY

This research report on Flexible Packaging Sortation at Materials Recovery Facilities (MRFs) was prepared by Resource Recycling Systems (RRS) on behalf of the Materials Recovery for the Future (MRFF) project. The purpose of the report is to provide a transparent account of the research objectives, methodology and results to those working to accelerate solutions that improve the recovery of flexible packaging.

The report examines whether flexible packaging that is predominantly plastic and currently not recycled in the MRF could be separated effectively in the North American residential single stream recycling system. The results of RRS' preliminary modeling identified several pathways to increase the recovery of flexibles based on the past work of other pilot projects. The overarching goal was to find the most cost-effective pathway to separate and create a flexible packaging commodity bale for reprocessing or conversion to energy.

In the first year of the research program completed August 2016 the objectives were to:

- Test the potential of existing automated MRF sorting technologies, particularly optical sorters and separation screens, to improve separation of prevalent flexible plastic packaging forms (e.g., pouches, chip bags, films, food storage bags, pet food bags, etc.) in the existing post-consumer municipal solid waste stream that consumers may, at some point, separate for single stream collection.
- Define the recovery system of the future through identification of additional technologies required for plastics reprocessing to ensure the mechanical recycling of resins that currently have end markets.

MRFF Research Partners recognize this program will be a multi-year effort and seek to engage peers in the packaging value chain to advance the best solutions. Analyzing the economics of recycling flexible packaging is just as important as proving the technical capacity to separate and process this material. This work is critical to qualifying flexible packaging as a component of MRF flow and subsequent market recyclability - which is the long term vision of the group. A multi-prong strategy is presented to generally describe this additional work.

The research methodology for this phase of the program involved conducting a flow study, performing a comprehensive set of tests at MRF equipment labs to tune key sortation equipment and a series of tests in select MRFs with optical sorting capability on their sorting lines. The tests seeded a representative mix of pre-consumer flexible plastic packaging in a form that mimicked actual conditions into a standard single stream material mix at three MRFs in the US and Canada: IMS Recycling, San Diego, CA; Emterra Environmental,Surrey, BC; and Emterra Environmental, Regina, SK.

The results of how the flexible plastic packaging flowed in the baseline test are reported. The majority of the flexible plastic packaging, 88% by weight, flowed with the fiber streams, consistent with the hypothesis for the test. The focus of subsequent testing was on capturing this majority flow of flexible plastic packaging in the fiber stream. Equipment lab testing identified a theoretical maximum for unmodified optical sorter efficiency, and MRF testing in the Emterra Environmental facilities was able to achieve a level near that.

Throughout the course of the research program, improvements were made over the baseline in the metrics tested through 1) reduced loading on the optical sorters, 2) increased sorter belt width, and 3) adjusted targeted optical sorter programming. It is important to note the age of equipment also varied between tests, and that no conclusions are made or implied about the effectiveness of equipment from different manufacturers.

The target flexible plastic packaging product still contained a large amount of paper, but over the two MRF tests the product purity was improved from 28% to 46% flexible plastic packaging. Finally, the increased capture to the target product meant less flexible plastic packaging remaining in paper products, demonstrating the potential to reduce contamination of fiber bales if flexible plastic packaging is accepted in MRFs.

Results by weight are shown in Table 1. In the final round of testing (MRF Test 2) the total amount of flexible plastic packaging present in the fiber was reduced from 6.6% to 2% by weight in one pass by the optical sorter, which meets the Institute of Scrap Recycling Industries (ISRI) specification threshold for non-paper plastics material in the standard Grade 56 and Grade 58 residential paper grades coming from a MRF. It was even further reduced in subsequent passes.

The research shows that existing optical sorter and MRF equipment technology can be used to sort flexible plastic packaging at promising levels of efficiency. With some targeted adjustments of the equipment, identification and sorting of the seeded flexible plastic packaging improved dramatically. It is expected that this existing technology can be optimized so that fiber product quality is concurrently improved.

Disc screen wrap was minimal and was not seen as a major issue for the flexible plastic packaging targeted in this study for the formats that were tested and in the facilities where testing occurred. The research team recognizes that flexible plastic packaging, especially larger plastic film items, is a problem in many single stream MRFs. The research team observed that improvements in the screen technologies are reducing the wrapping on shafts. However, this will remain a concern for most MRFs that do not have the most modern screen technology in place and upgrades to these screens will be needed to effectively sort these materials.

The report also provides next steps on how members of the value chain can work to create a stable supply, and demand for, recycled flexible plastic packaging feedstock. Five work streams for further research are identified:

1. Further Equipment Testing: Further improve sorting through MRF equipment testing in a controlled environment, with a focus on optical sorters and design of air flow control to optimize the separation of fiber from flexible plastic packaging. To augment the capabilities of optical sorting, additional technologies will need to be pursued to achieve lowest cost solutions. These may include vacuum systems, film grabbers, air drum separators and other evolving technologies. These technologies allow for capture on both the fiber and container lines.

2. End Market Assessment: While an increasing amount of plastic film is being returned to packaging products, the majority of this consumption is in bulk extruded and molded products such as plastic lumber. While the

Table 1: Results Summary

	Optical sorter efficiency: % of FPP correctly sorted by optical sorter(s)	FPP that flowed with fiber: % of FPP entering MRF system that flowed with the fiber	Purity of FPP end product: % of designated flexible product consisting of FPP	Contamination of paper products: % of paper bale that consisted of FPP
Baseline Test	43%	88%	Not tested	3.3%
Equipment Lab Testing	91%	N/A	Not tested	Not tested
MRF Test 1	71%	83%	28%	2.4%
MRF Test 2	89% (via three passes)	N/A*	46%	0.6%

* MRF Test 2 involved seeding test material directly into fiber portion of single stream feedstock
FPP: Flexible Plastic Packaging

majority of flexible plastic packaging at this time is constructed of a single resin that could be sorted and recycled by common methods, much of the flexible plastic packaging stream will not be marketable to the existing plastic film market because it is made up of multi-layer, multi-resin construction. While a number of small scale processors are able to blend and mold these mixed resin materials into durable products, no large scale consumers with this capability have been identified to date. Additionally, a number of conversion technologies are evolving that may be able to utilize much of this material. Research is needed to estimate the market for end products produced with these technologies. While some end market technologies have been explored extensively, others are in early research stages. End market assessment will provide a comprehensive evaluation of the full range of end markets.

3. MRF Processing Economic Analysis: An up-to-date MRF net system cost analysis that considers the economics of installing new equipment to sort flexible packaging, and its subsequent impact on revenues, costs, disposal, and quality of paper after sortation, needs to be undertaken to economically justify long-term change in MRFs, and provide useful information to municipalities who may want to add flexible packaging to the curbside mix.

4. Secondary Processing Economic Analysis: The MRF sorted flexible plastic packaging mix will require preparation by secondary markets to achieve full recovery. Greater understanding of the technical feasibility, environmental impacts and economic value of flexible plastic packaging secondary processing to meet end market feedstock requirements is needed. The costs of further sorting, cleaning and converting cleaned flexible plastic packaging to various products will inform proper investment. Conducting feasibility analysis of the preparation for each market is needed to project net system costs that establish a business case, and prove an end form with value can be developed. Conducting trial testing with the most promising end markets will be necessary to confirm the feedstock is suitable for larger scaled applications.

5. Community MRF Demonstration Pilot: Once the new design is successfully achieved in a controlled setting and end market trails completed, a demonstration test for curbside collection testing with a willing community MRF partner can be performed. A cost-benefit analysis of capital costs, operating costs and secondary processing and market value will also be needed at this point.

VISION, PARTNERS, & PURPOSE

Materials Recovery for the Future (MRFF) is a research collaboration that brings together leading brands, manufacturers, packaging companies, trade associations and other key members of the value chain committed to finding solutions for improved recovery of flexible packaging that is not widely recycled in the current system.

The focus of MRFF research this year was to examine whether flexible packaging that is predominantly plastic could be processed in the single stream recycling system. Flexible packaging includes formats such as bags, wraps, pouches, and films that are produced from a variety of substrates in both single and multi-layer formats. Approximately 90% of flexible packaging by weight is produced from plastic resins according to the most recent market study from the Flexible Packaging Association (Flexible Packaging Industry Segment Profile Analysis, FPA 2013), and some of these flexible plastic formats contain foil and paper as well. The remainder of flexible packaging is predominantly paper bags.

Resource efficiency, along with its low cost per unit, have helped spur flexible plastic packaging's rapid growth in the marketplace, and it has evolved to displace many types of packaging formats, including those that are traditionally recycled. However, in North America, flexible plastic packaging is not accepted in most of the current post-consumer curbside recycling infrastructure, and this represents a significant long-term risk for product manufacturers that use this packaging for their products, as well as producers of this packaging. For example, some types of flexible plastic packaging have been regulated or banned in areas of North America and across the European Union, and it is also the subject of a variety of global environmental campaigns. This represents a challenge to its continued growth.

MRFF collaborators have come together in a voluntary effort to define a research agenda

MRFF

VISION

All flexible packaging goes into the recycle bin and the recovery industry captures value from it

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- Widespread consumer access
- Highest and best value of materials
- Net financial benefits
- LCA positive impact
- Healthy workplace

Figure 1: Materials Recovery for the Future Vision

that will find beneficial secondary uses for this packaging material through exploration of the most sustainable (i.e., economic, environmental and socially beneficial) recycling and recovery options. There are sustainability benefits associated with use of plastics in flexible packaging that derive from its light weight, which reduces cost and the carbon footprint associated with use, while providing product protection that results in improved food safety and significant reduction in product waste. One recent study prepared by Trucost found the environmental costs due to climate change, human health and ecosystems, in particular oceans, would increase by a factor of 4.2 if existing consumer plastic packaging was replaced with functionally equivalent alternate materials (Plastics and Sustainability, July 2016).

The research agenda for the first year of MRFF was aimed at understanding how flexible plastic packaging flows with other recyclables that are processed at material recovery facilities (MRFs), and whether and how this packaging can be effectively sorted for recovery on a broad scale. This packaging is already being introduced at MRFs today and being removed at some of the more modern MRFs in an effort to improve operation performance and reduce contamination of paper products. This represents a practical opportunity to examine whether the existing sorting technology could be adapted to capture this material stream to create a product bale.

The purpose of this report is to share the learnings from this first year of research, and provide suggested next steps for those interested in further evaluation of the research questions and economic analyses that remain to achieve curbside recycling of flexible plastic packaging at scale.

1. RESEARCH PARTNERS

1.1. MANUFACTURERS, BRAND OWNERS AND TRADE ASSOCIATIONS

MRFF is hosted and managed by the Foundation for Chemistry Research and Initiatives, a 501(c)(3) tax-exempt organization established by the American Chemistry Council (ACC). The research program is being developed and conducted by Resource Recycling Systems (RRS), in collaboration with packaging and sustainability experts who serve as research partners and provide financial support and/or materials for testing. The 2016 MRFF Research Partners are listed in Figure 2.

1.2. TECHNOLOGY SOLUTION PARTNERS

The research program significantly benefited from collaboration with the recycling industry. In the first year, it involved a comprehensive equipment assessment and resulted in collaboration with five material recovery equipment manufacturers, who provided the project team with expertise and access to their lab testing facilities. These Technology Solution Partners included Titech/Tomra, MSS/CP Group, National Recovery Technologies (NRT)/Bulk Handling Systems (BHS), Pellenc Selective Technologies (ST), and Steinert (RTT).

1.3. MRF PARTNERS

Finally, and equally important to the research effort, a select group of MRF operators in North America were selected to provide expertise plus make their facilities available for use in full-scale baseline and MRF material flow testing, including:

- IMS Recycling (San Diego, CA, US)
- Emterra Environmental (Surrey, BC, Canada)
- Emterra Environmental (Regina, SK, Canada)

Hundreds of MRFs were screened for participation in the research program. IMS Recycling and Emterra were selected because they operate single stream MRFs with an equipment configuration that was well suited for the test methodology described later in this report. They already had optical sorters in a configuration that was conducive to the desired testing.

Figure 2: 2016 Research Partners

Figure 3: Technology Solution Partners

2. PROJECT BACKGROUND – FRAMING THE CHALLENGE OF FLEXIBLE PLASTIC PACKAGING RECOVERY

The MRFF Research Program was guided by data regarding the volumes of flexible packaging entering the waste stream, previous pilot studies, the potential pathways to collect and process this material at the MRF, and the engineering, economic, and societal challenges around doing so. This data formed the basis for the development of the experimental design. Where data did not exist, estimates and assumptions were made based on past related studies. RRS then identified and evaluated a set of MRF system costs at a high level to help the industry experts participating in the project collectively select the most economical pathway for recovery. Key assumptions and research questions related to collecting and processing the flexible plastic packaging material for recovery at scale are discussed in the following section.

2.1. TONNAGE OF FLEXIBLE PLASTIC PACKAGING AVAILABLE FOR COLLECTION

According to the Flexible Packaging Association (FPA), 8.7 million tons of flexible packaging was produced in the US in 2013, and thus potentially available for recycling or energy recovery. There has been significant growth since then each year in the flexible packaging market, and this is expected to continue, further highlighting the importance of recovery of this material.

However, not all of this material produced is practically available for collection and recovery. For example, for the most part, trash bags of various types, medical and hazardous waste packaging, and a portion of the packaging used for food may be too contaminated to practically clean for any type of recovery. RRS estimated that 3% by weight of the total incoming residential stream would be flexible plastic packaging if recycling programs intentionally began accepting this material and residents placed this material into their recycling containers at a similar proportion to their capture of other plastics (30-35%). 3% flexible plastic packaging by weight was used for the cost analysis and as the target for seeding during testing. Because of the variations in the amount of flexible plastic packaging already in the waste stream, seed amounts varied by test location in order to reach a uniform 3%.

Recent efforts to recover flexible plastic packaging also helped to characterize the waste stream and form assumptions for the preliminary MRF system cost analysis in 2014. The Dow Citrus Heights Energy Bag pilot collected three tons of flexible packaging via bagged collection within carts over three months for energy recovery was reviewed and proved useful for characterization of material types. The results from the UK-based Waste & Resources Action Programme (WRAP), which collected 17 lbs/household/year of plastic film in a curbside pilot program in the UK, was also reviewed to inform our analysis.

2.2. POTENTIAL PATHWAYS FOR RECOVERY OF FLEXIBLE PLASTIC PACKAGING

There are several potential recovery pathways that flexible plastic packaging can follow from consumer to end market. This section discusses the rationale for researching the selected pathway, and Figure 4 illustrates both the selected pathway and alternatives considered during scoping of the research project.

For residential curbside collection, the cost of providing standard bags to consumers to consolidate the material was compared with the costs for a loose flexible plastic packaging collection program. At the MRF, manual hand sorting of flexibles was compared to the use of optical sorters. Finally, the costs of secondary processing required to achieve marketable grades of resins for manufacturing or fuel/chemical recycling at a plastics recycling facility (PRF) were estimated and considered.

The preliminary cost analysis indicated the loose automated collection pathway has the potential to be considerably more scalable and cost effective than bagged collection, particularly in larger MRFs. The primary advantage of the "loose in cart" approach is that it puts the ease of recycling flexible plastic packaging on par with that of other recyclables. However, the approach also poses important issues for further research. For example, the cost of MRF equipment upgrades to process loose flexible plastic packaging stream could vary widely given the variability in existing systems today.

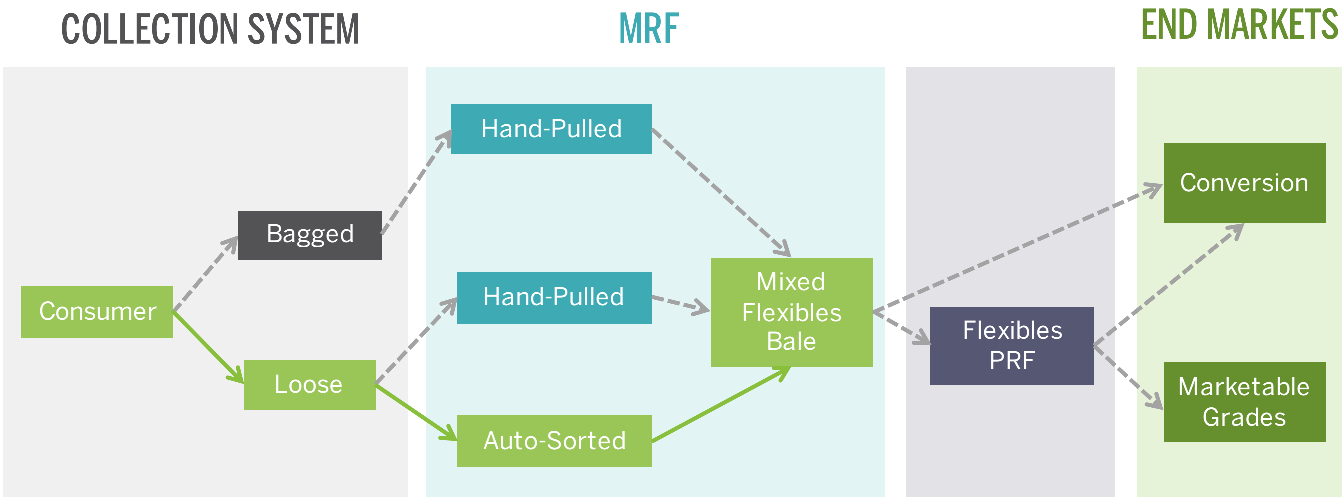


Figure 4: Potential Pathways for Flexible Plastic Packaging

Further challenges with the other approaches were also identified. Purchase and delivery of collection bags to consumers significantly increases the cost per ton to recycle the material. In order to sort the captured flexible plastic packaging, the bags must be opened. Most methods for opening the bags risk reducing the size of the pieces to be sorted, which likely increases the sorting costs. There were also issues associated with contamination, as many MRFs use metering drums to provide an even flow of material from the feed hopper into the sorting system which could break open or tear the bags depending on their configuration. Handpicked sorting was not cost effective. At a reasonable speed of work (50 picks/minute), a 25 ton/hour MRF receiving an input consisting of 3% flexible plastic packaging by weight would need more than 30 additional workers and individual sort stations to handle this material. In contrast, if two optical sorters were added to the paper line to accomplish the sorting, only two additional workers would be needed for quality control.

Additional alternatives and their costs were considered but eliminated before selecting the loose automated sorting pathway using optical sorters for further research.

- Transferring the cost of a bagged program to residents by requiring residents to purchase standardized bags. This approach was considered a significant deterrent to participation in the program.
- Reducing the cost of a bagged collection program by allowing residents to reuse existing shopping or grocery bags to bag other flexible plastic packaging. While this approach reduces the collection cost, sorters in the MRF are then presented with the problem of distinguishing bags containing flexible plastic packaging from bags that might contain disposable waste items such as diapers or kitty litter. These problems are expected to result in higher sorting costs, a contaminated flexible plastic packaging product or losing much of the flexible plastic packaging to residue, which would result in too large of an economic trade-off.

3. RESEARCH AGENDA

For the first year of the research program, August 2015 - August 2016, the objectives established were to:

- Test the potential of existing automated MRF sorting technologies, particularly separation screens and optical sorters, to improve separation of prevalent flexible plastic packaging forms (e.g., pouches, chip bags, films, food storage bags, pet food bags, etc.) in the existing post-consumer municipal solid waste stream.
- Define the recovery system of the future through identification of additional technologies required for plastics reprocessing to ensure the mechanical recycling of resins that currently have end markets.

Beyond this first year research focus to answer whether existing MRF equipment technologies could be adapted to sort flexibles at full-scale, the MRFF Research Partners recognized that more work would be needed to achieve their vision. The multi-prong strategy that appears in Figure 5 was developed to describe this additional work.

As part of the work needed, new technologies will be explored to create a high value commodity and market demand for this new source of flexible plastic packaging feedstock. Research will be conducted to define reprocessing cost and feasibility, and develop product bales for end markets. The costs to upgrade MRFs, including consideration of throughput adjustments, estimation of capital and operational costs to upgrade, plus the potential purity and consistency requirements for end markets will be determined. MRFF Research Partners are continually seeking outreach opportunities to discuss new findings along this quest in the interest of engaging more partners to accelerate the solution.

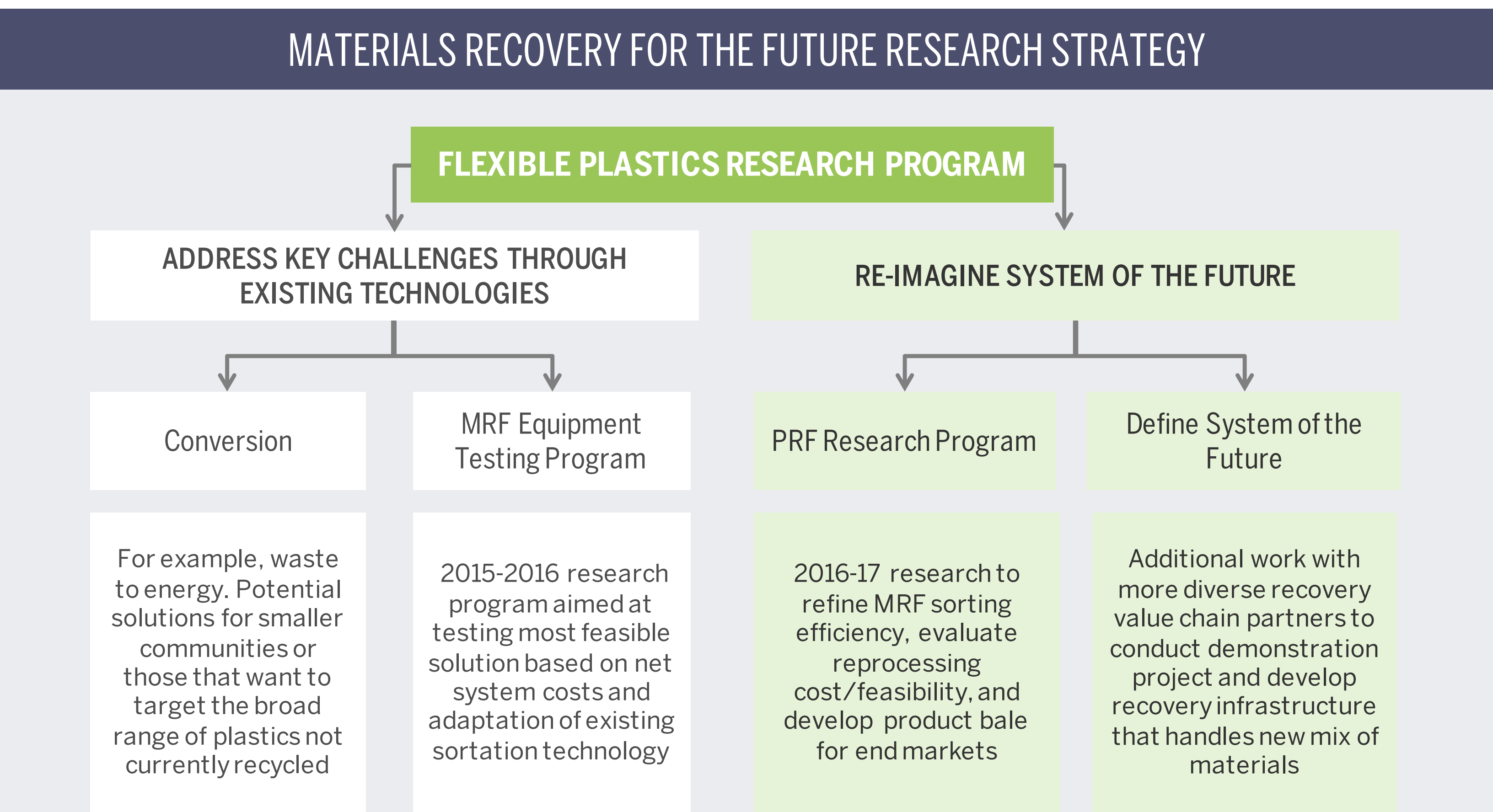
4. TEST LOCATIONS AND TIMETABLE

4.1. MRF SELECTION

The three MRFs selected for baseline and MRF performance testing were chosen based on several aspects of their equipment configuration that made them well suited for measuring the potential to sort flexible plastic packaging. As each MRF is uniquely configured with many different combinations of equipment, building design, and recovery capabilities, the MRFs used in testing had to be individually selected by reviewing numerous potential test locations in North America. RRS sought MRFs with optical sorters on their fiber lines, hypothesizing that the majority of flexible plastic packaging would flow with the fiber stream, and that optical sorting would provide the best option to recover the flexible plastic packaging from the fiber stream. These factors resulted in choosing the following test sites:

- Baseline Test at IMS Recycling/CP Group, San Diego, CA, US
- MRF Test 1 at Emterra, Surrey, BC, Canada
- MRF Test 2 at Emterra, Regina, SK, Canada

Figure 5: MRFF Research Strategy



The IMS Recycling/CP Group MRF in San Diego, California was selected as the location for the baseline test to provide initial results that further testing would be compared against. IMS Recycling is a typical type of mid-life single stream MRF serving the city of San Diego. The single stream material at IMS Recycling is reflective of beverage container deposit states in general, with smaller than average bottle and container flow due to the regulated deposit system there.

Emterra's MRF in Surrey, British Columbia was an optimal test site for MRF Test 1 due to the optical sorting on the fiber lines fed directly from primary screens. The Surrey MRF is an advanced-design, single stream MRF serving Multi-Material British Columbia (MMBC) and the Vancouver/Surrey region of British Columbia. While this MRF is of a more modern design than most US MRFs, it processes a stream of materials similar to that received by many US single stream MRFs. The single stream material is reflective of deposit states in general (due to the beverage container deposit system used in British Columbia), with smaller than average bottle and container flow due to the more aggressive deposit system there.

MRF Test 2 was conducted at the Emterra Regina, Saskatchewan MRF. The Emterra Regina MRF is a single stream MRF serving Regina and surrounding Saskatchewan. It has a similar sorting sequence to many newer US single stream MRFs. Its attractiveness for testing for the MRFF project was driven by the ability to send a mix of fiber and flexible plastic packaging to a series of three optical sorters through minor and easily reversible modifications to the equipment.

4.2. EQUIPMENT MANUFACTURER TESTING

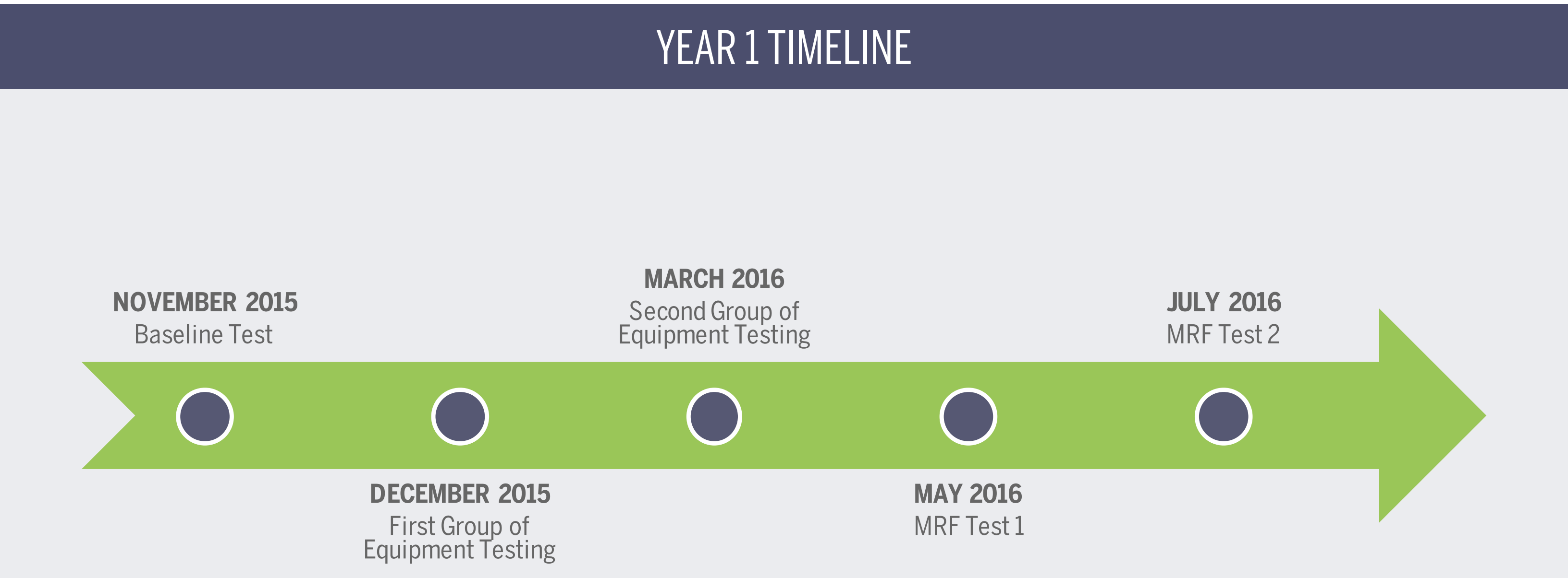
The research team identified and screened ten optical sorter manufacturers with optical sorters in US MRFs. The four with the largest presence in US MRFs appear to be Titech/Tomra, MSS/CP Group, NRT/BHS and Pellenc ST. Green Machine, Machinex, Redwave (Binder), Steinert (RTT), Sherbrooke OEM (Vizion), and Sesotec (S+S) are more recent and/or smaller entries into the US market.

Pellenc and Steinert were identified because they have developed optical sorters specifically adapted to sorting paper and plastic film. Additional manufacturers were selected based on their large installed base or their presence at the MRFs under consideration for test locations. These included MSS/CP Group, Titech/Tomra, and NRT/BHS.

4.3. TIMETABLE

The testing took place over the course of a year, as shown in Figure 6.

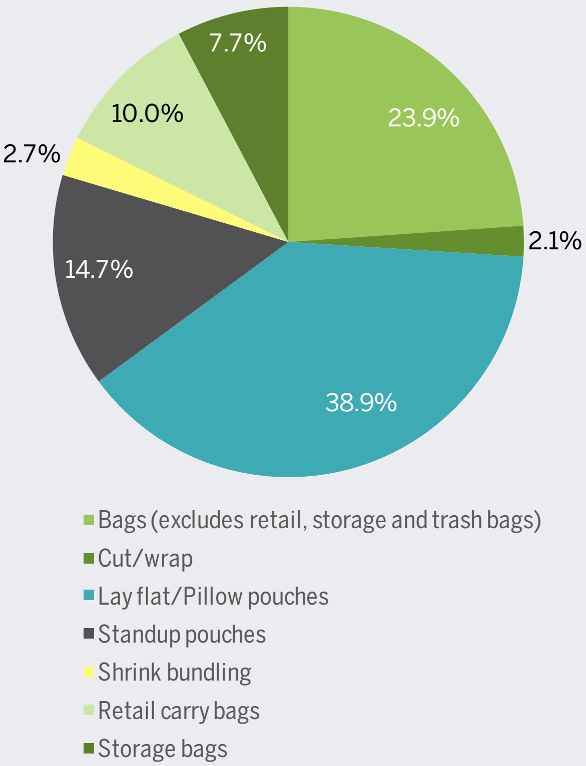
Figure 6: Year 1 Timeline



5. DEFINING THE PACKAGING MIXTURE TO BE TESTED

The goal of the research program was to test the ability of MRFs to sort a representative mix of flexible plastic packaging – comparable in terms of package quantities, types, forms, and sizes to that which would be received at the MRF if flexible plastic packaging were accepted in residential collection programs. A hypothetical material mix was constructed using packaging categories and corresponding quantities developed by the FPA. The sponsoring Research Partners contributed these package types for testing according to the quantities determined in the material mix. While the hypothetical mix had to be adjusted somewhat based on the quantities received from each sponsor, it remained representative of what is seen nationally in terms of flexible plastic packaging produced and discarded. Figure 7 shows the percent of each plastic packaging type by weight in the test material mix.

Figure 7: Test Material Mix



RRS tested packaging sizes down to 2.5" x 4" lay flat pouch. Smaller sizes were expected to have high loss rates to residue. Therefore, small packaging categories such as candy bar wrappers were excluded from this phase of research. While this small packaging is very large in piece count, they represent a small weight percentage of flexible plastic packaging as a whole.

6. RESEARCH METHODOLOGY

6.1. OVERVIEW

Flexible plastic packaging is produced in a range of single resin, multi-resin, and/or multi-layer formats for consumer packaged goods. Some European MRFs were built with optical sorters on the fiber line to allow the recovery of plastic film for recycling but no studies were identified that tested separation of the typical range of flexible plastic packaging in a comparable single stream environment to the US. The MRFF research program was thus designed to test the effectiveness of existing technology, in particular disc screens, to direct flexible plastic packaging to the 2D paper line and subsequently, the efficiency of optical sorters to remove flexible plastic packaging from paper.

6.1.1. BASELINE TEST

Testing began with a baseline MRF assessment. The baseline set out to quantify where flexible plastic packaging materials would flow in an unmodified MRF setting. The hypothesis was that flexible plastic packaging would flow with the fiber, due to its two dimensional nature. The test was performed using existing equipment configurations with only minor adjustments to the optical sorters. Consistent with the hypothesis, flexible plastic packaging materials were found to generally flow within the paper stream. Sorting and equipment issues were identified and learnings were used to inform targeted tests on equipment and improvements during future MRF tests to increase the capture of flexible plastic packaging and reduce contamination of the fiber stream.

6.1.2. EQUIPMENT LAB TESTING

Observations about optical sorter capacities from the baseline assessment were used to design targeted equipment trials in manufacturer test laboratories to test the limitations of optical sortation equipment in a controlled environment and identify settings that would lead to increased flexible plastic packaging material recovery. Solutions around airflow control and material spread were identified.

6.1.3. MRF TESTS 1 AND 2

Two rounds of testing were conducted incorporating key findings about equipment configurations and settings from the baseline and equipment tests. The research team selected two active MRFs that had advantageous configurations for the recovery of flexible plastic packaging utilizing existing equipment. The goal was to see whether optical sorters programmed to target flexible plastic packaging could potentially perform at a reasonable level of efficiency in a MRF system, and lend insight into whether existing MRF equipment could be modified to increase recovery of flexible plastic packaging material. The first test repeated procedures of the baseline test using optical sorters specifically programmed to target flexible plastic packaging amongst a single stream material feedstock, and the second test followed similar procedures but was focused only on separating flexible plastic packaging from fiber.

Throughout the testing, disc screen wrap was minimal and was not seen as a major issue for the flexible plastic packaging targeted in this study at the MRFs tested. The research team recognizes that flexible plastic packaging, especially larger plastic film items, is a problem in most single stream MRFs. Screen manufacturers continue to design screens with reduced wrapping problems through the use of larger diameter shafts, spacers and improved disc designs. The research team anticipates that this problem will be much reduced in future MRF designs.

6.2. STUDY GOALS

Each round of testing aimed to advance on previous research with several primary test goals identified, as shown in Table 2.

Table 2:Study Goals

TEST PHASE	STUDY GOALS
Baseline Test	• Learn where flexible plastic packaging will end up in the MRF • Establish a baseline number for what portion of the flexible plastic packaging introduced to the in-feed of the MRF may be potentially captured to a target flexible bale • Start to develop an understanding of what sort processes might need to be modified to allow good recovery of flexible plastic packaging at MRFs
Equipment Test	• Determine if a specific flexible plastic packaging form, resin content or ink/coatings cause recognition problems • Determine if certain forms are difficult to eject
MRF Test 1	• Learn where flexible plastic packaging will end up in the MRF • Estimate what portion of the flexible plastic packaging introduced to the in-feed of the MRF may be potentially captured to a targeted flexible plastic packaging product • Improve understanding of what sort processes might need to be modified to allow good recovery of flexible plastic packaging at MRFs • Observe and record impacts on the fiber product bales
MRF Test 2	• Explore to what degree flexible plastic packaging can be removed from fiber with current technology optical sorters utilizing a multiple pass approach • Explore to what degree the fiber content in sorted flexible plastic packaging can be minimized by adjusting optical sorter programming • Increase understanding of what improvements in optical sorters may be needed for a MRF providing continuous separation of flexible plastic packaging

6.3. BASELINE TEST PROCEDURES

In the Baseline Test, seeded flexible plastic packaging was mixed with 50 tons (45.4 tonnes) of base feedstock of single stream recyclables and then introduced into the MRF. It was anticipated that the feedstock would already contain 1% flexible plastic packaging by weight, so an additional 2% was seeded to bring the level up to the study target of 3%. RRS then determined how the seed material flowed through the facility and at what major points it exited.

6.4. EQUIPMENT TESTING METHODOLOGY

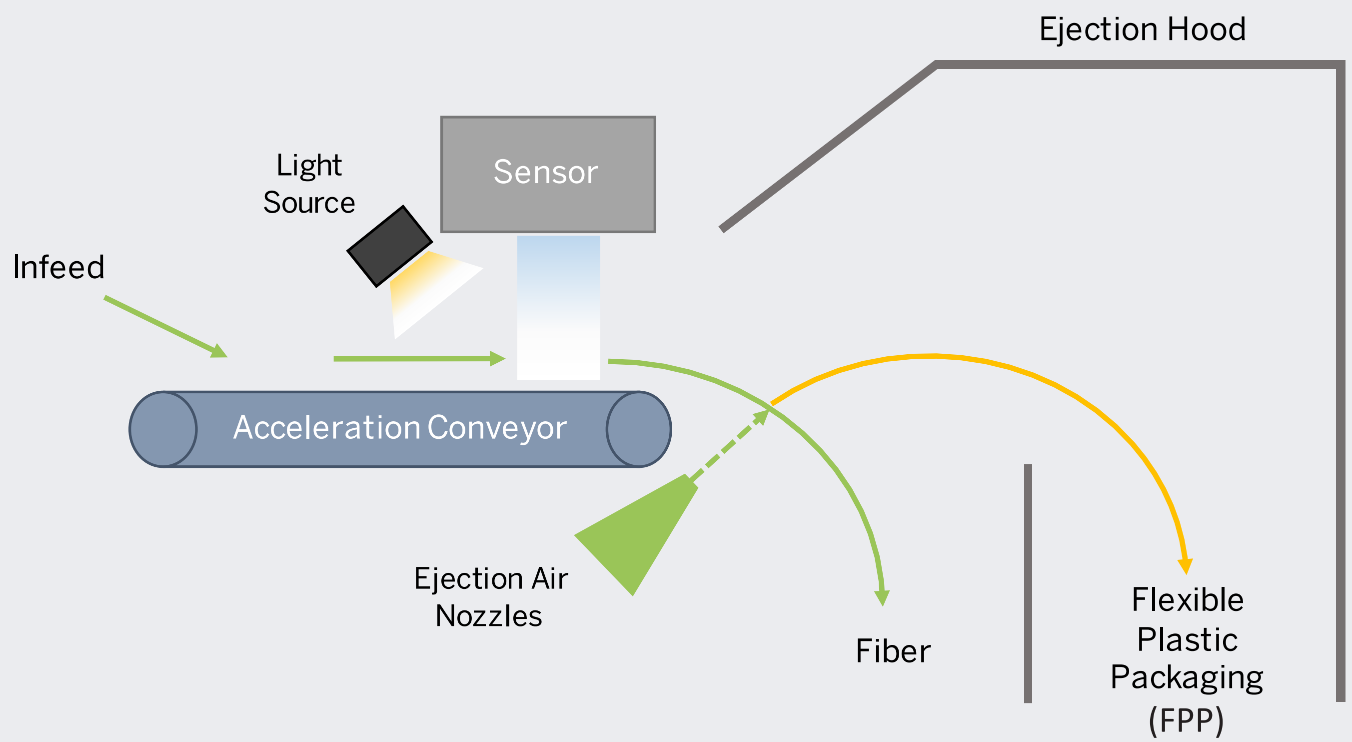
Optical sorter testing was performed at five manufacturer test facilities to obtain data representative of the majority of optical sorters currently in use in US MRFs and to start explorations of optical sorter features that might be needed to achieve high level recovery.

Figure 8 is a schematic of an optical sorter. The stream to be sorted is first fed on to an acceleration conveyor where the material is identified by the near infra-red (NIR) sensor. The sensor identifies the material type, size and location on the belt. As the target material reaches the end of the conveyer and starts to come off of the belt the ejection air nozzles fire at the determined location and for the calculated duration to eject the desired material. The ejected material then falls down on to the proper discharge conveyor, thus separating the one stream into two sorted streams.

6.4.1. EQUIPMENT TESTING ACTIVITIES

Before testing started, equipment manufacturers were allowed to individually test each type of flexible plastic packaging supplied and adjust recognition programs as needed. After this initial setup the project team created a test mixture consisting of five pieces of each type of flexible plastic packaging. This mixture was then run through the optical sorting test setup and the results were recorded. Testing first with only the flexible plastic packaging allowed the team to identify if certain materials presented problems for either identification, ejection or both. After the isolated flexible plastic packaging test was completed, paper was mixed with the flexible plastic packaging mixture to create the new sample stream. The desired ratio of flexible plastic packaging to paper for this new stream was 10% flexible

Figure 8: Optical Sorter Schematic



plastic packaging and 90% paper by weight. 10% flexible plastic packaging by weight is seen as the upper limit of what would be expected to show up in the paper stream of a typical US MRF if this material were collected curbside. To maintain the minimum number of flexible plastic packaging pieces for each test concessions were made to reduce the amount of paper added when the testing setup was unable to handle the quantity of the desired mix. This limitation was the result of the test setup configuration, specifically: the width of the optical sorter, the method of spreading the material onto the acceleration conveyor and the speed of the acceleration conveyor. The total amount of test material that could be loaded into the test loop without excessive burden depth was also limited by the lengths and widths of the conveyors that made up the test loop. The reduction of added paper had the effect of increasing the ratio of flexible plastic packaging to paper, which was viewed as an acceptable variation because it presented a more challenging condition for the optical sorter than the desired 10% flexible plastic packaging by weight. This new test stream was then run through the test setup and the results were recorded. Throughout the test, equipment manufacturers were encouraged to modify the optical sorting software to achieve the best results possible. At each test site a video camera was used to record the testing. The recorded video was used to examine the cause of ejection problems.

6.5. MRF TEST 1 PROCEDURES

The procedures for MRF Test 1 were identical to the baseline test with the exception that the testing was performed in two separate runs of 11 tons (10 tonnes) each. A seeding of 2.5% flexible plastic packaging by weight was added to the feed stock, which was estimated to already contain 0.5% flexible plastic packaging. MRF sort preparation consisted of fine tuning the optical sorters to target flexible plastic packaging prior to the test runs. After a test run was complete, all product and residuals were labeled, weighed and set aside. Once both test runs were complete, samples of processed material and residual were selected for sorting. Samples of fiber, residuals and other products containing seed materials were sorted and weighed, documenting how much of each type of seed material and other flexible plastic packaging ended up in each product or residual stream. The presence of seed materials in container products and old corrugated containers (OCC) was assessed by inspection, and a determination was made if sorting of these products was needed to quantify seed material present.

6.5.1. MRF TEST 1 VARIATIONS

Because MRFs in North America are not designed to handle the quantities of flexible plastic packaging generated curbside, the throughput of the test MRFs had to be decreased to reduce overloading of the existing disc screens and optical sorters. The Surrey MRF normally runs at 22 to 24.3 tons/hour (20 to 22 tonnes/hour). RRS anticipated that a feed rate of 11 tons/hour (10 tonnes/hour) is the maximum rate that might succeed in preventing overload of the optical sorters with the added flexible plastic packaging. In order to increase the throughput rate back up to normal levels, the flow to optical sorters will need to be optimized through sorter improvements, proper sizing, and through the splitting of the stream if needed.

6.6. MRF TEST 2 PROCEDURES

MRF Test 2 was conducted at an Emterra Regina MRF. The facility was attractive for testing because a simple modification made it possible to send a mix of fiber and flexible plastic packaging to a series of three optical sorters. The removal of two shafts in the old newspaper (ONP) screen allowed for this configuration. The testing was focused only on separating flexible plastic packaging from fiber (e.g., paper products).

The procedures for MRF Test 2 were very similar to the procedures for the baseline test and the first MRF test with the exception that three test runs of 750 kg (826.7 lbs) each were conducted.

6.6.1. MRF TEST 2 VARIATIONS

Single stream content of 3% flexible plastic packaging by weight was used to reflect flexible plastic packaging that might be delivered to a single stream MRF in the near future. Based on single stream recyclables being around 50% paper (excluding OCC) by weight and assuming all of the flexible plastic packaging can be directed to the fiber stream, it was concluded that the fiber stream used for testing at Regina should be 6% flexible plastic packaging by weight. The Regina MRF normally processes single stream recyclables at 11 to 13.2 tons/hour (10 to 12 tonnes/hour) but because all of the fiber was directed over to the container line during testing, which has a series of two-meter-wide optical sorters, the flow rate was limited to avoid overloading the optical sorters. A throughput of 4.4 tons/hour (4 tonnes/hour) was selected to closely replicate the optical sorter load seen in MRF Test 1.

6.7. MATERIALS ADDED TO THE STREAM

The tests were conducted by sending a representative mix of flexible plastic packaging through the respective MRFs and pieces of equipment. In the Baseline Test and MRF Test 1, the flexible plastic packaging was mixed with single stream recyclables, while in MRF Test 2 the flexible plastic packaging was mixed solely with pre-sorted newspaper. In the equipment tests the flexible plastic packaging was run on its own and with a test quantity of paper. The materials seeded into the system as well as variations for each test are shown below:

Table 3: Materials Added and Test Variations

TEST MATERIAL DESCRIPTION	MATERIAL MIX	BASELINE TEST	MRF TEST 1	MRF TEST 2
Material Seeded into MRF	Percent	Weight (lbs)	Weight (lbs)	Weight (lbs)
Bags (excludes retail, storage, trash)	23.9%	478.9	135.3	25.3
Cut/Wrap	2.1%	42.3	11.9	2.2
Lay Flat/Pillow Pouches	38.9%	778.1	219.9	41.1
Standup Pouches	14.7%	294.3	83.2	15.5
Shrink Bundling	2.7%	54.3	15.4	2.9
Retail Carry Bags	10.0%	199.2	56.3	10.5
Storage Bags	7.6%	152.9	43.2	8.1
Total	100.0%	2000 lbs	565.2 lbs	105.6 lbs
Base Feedstock Mixed with Seed Material		Single Stream Recyclables	Single Stream Recyclables	ONP (Old Newspaper)
Weight of Base Feedstock		50 tons	11 tons	826.7 lbs
Seed Material as % of Total Stream		2%	2.5%	3%*
Estimated Flexible Plastic Packaging in Feed Stock		1%	0.5%	0%
Seed Material as % of Fiber Stream		4%*	5%*	6%
Test Throughput		16.7 tons/hr	11 tons/hr	4.4 tons/hr

*Calculated based on 50% fiber (excluding OCC) by weight in single stream feedstock

7. MATERIAL FLOW – WHERE DOES FLEXIBLE PLASTIC PACKAGING FLOW IN A MRF?

7.1. BASELINE TEST

7.1.1. MATERIAL FLOW

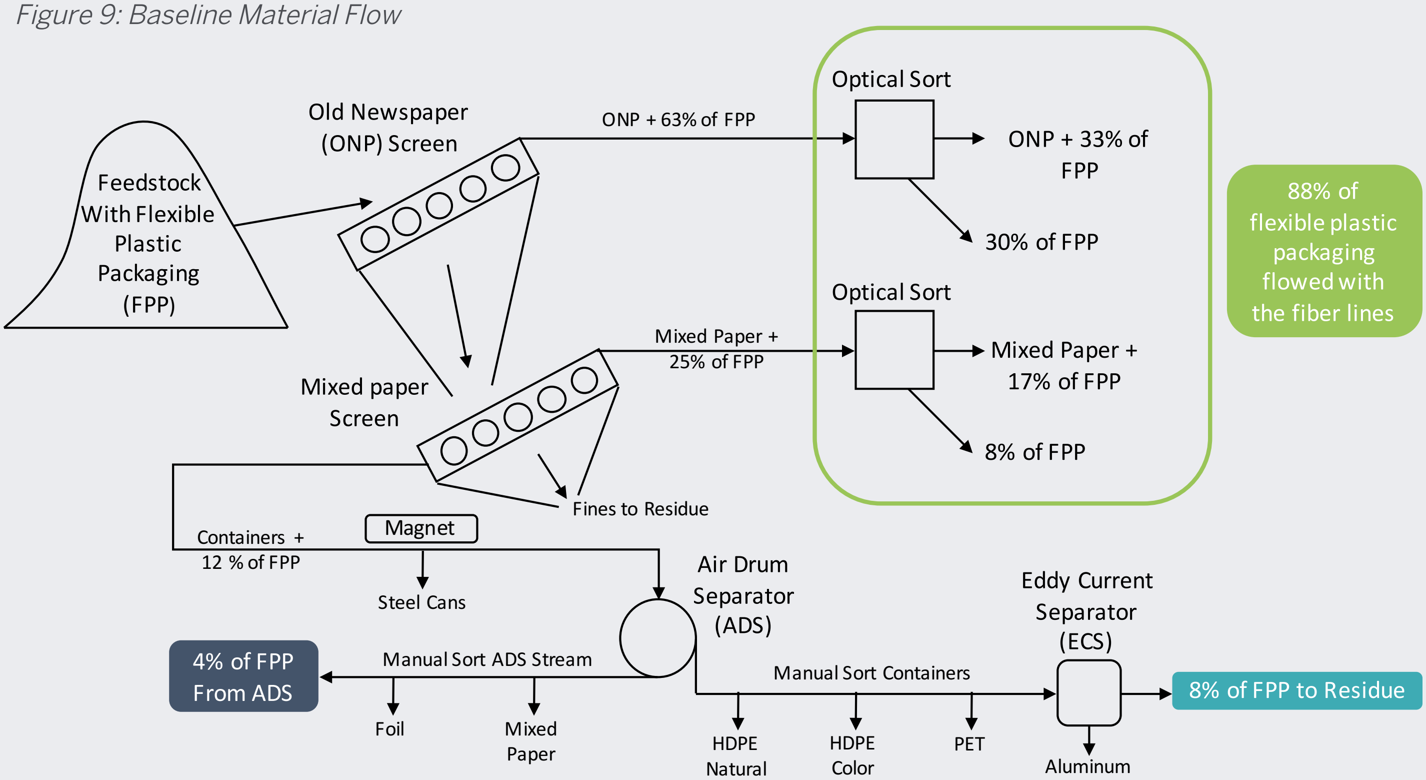
Figure 9 shows the results of how the flexible plastic packaging flowed in the baseline test. It can be seen that the majority (88% by weight) of the flexible plastic packaging flowed with the fiber streams (ONP and mixed paper), consistent with the hypothesis for the test.

The test stream (single stream feedstock plus flexible plastic packaging) was first fed into the system and through the presort where it then encountered the ONP screen. The overs (the portion of material that continues over the screen) from this screen continued on to the first optical sorter and the unders (the portion that falls through the screen or rolls off the bottom of the screen) flowed to the mixed paper screen. The overs from the mixed paper screen went to the second optical sorter and the unders continued on to the container line. Both optical sorters were programmed to fire on flexible plastic packaging. The material that flowed past both paper screens to the container line first encountered an overhead magnet and then an air drum separator (ADS). The ADS separated the 3D containers from any flat material that remained. On the 3D side of the ADS the plastic containers were manually sorted by type and the aluminum was separated out by an eddy current separator with the remaining stream being sent to residue. On the flat side of the ADS material was manually sorted into mixed paper and foil, the remainder was the ADS output.

7.1.2. OPTICAL SORTER EFFICIENCY

The next area of focus for the baseline test was the efficiency of the optical sorters. Optical sorter efficiency is measured as the ratio of sorted flexible plastic packaging to missed flexible plastic packaging. Figure 10 shows a comparison of the efficiency for the ONP optical sorter, the mixed paper optical sorter and the test average.

Figure 9: Baseline Material Flow



The baseline test was able to successfully sort 43% by weight of the seeded flexible plastic packaging that made it to the optical sorters. It was observed that the optical sorters were overloaded and that increased optical sorting capacity in the form of additional or larger optical sorters would likely improve the sorter efficiency. It is important to point out that in this test the MRF was run at normal throughput rates. Because the flexible plastic packaging that was added to the stream has a large surface area, some overloading of the optical sorters was anticipated.

7.2. EQUIPMENT TESTING

The next phase of testing was concentrated on exploring the capabilities of optical sorting to separate flexible plastic packaging from fiber. Testing in manufacturer's test labs allowed for a controlled environment where the sorting machines could be properly programed and calibrated to target test materials.

7.2.1. OPTICAL SORTER EFFICIENCY

Figure 11 shows the results of the equipment lab testing. Over 90% by weight of the seeded flexible plastic packaging was successfully separated from the fiber by the optical sorters after calibration. The value for the individual sorters ranged from 85% to 97%.

This represents a major increase over the baseline test sorting efficiency and proves that optical sorting is capable of sorting flexible plastic packaging from fiber at a high level under suitable conditions. This testing also shed light on ways to adjust airflow control and material spread to improve the efficiency of optical sorting.

7.2.2. AIRFLOW CONTROL

There were two areas identified where airflow played a major role in the successful sortation of flexible plastic packaging from paper during lab testing. The first area is the air above the conveyor belt. If this air is flowing at the same speed and in the same direction as the belt, the flexible plastic packaging is less likely to tumble or shift between identification and ejection. If it is not flowing at the same speed or in the same direction, the optical sorter may eject the wrong item.

The second area identified where proper airflow was important was inside of the ejection hood. The ejection hood is the area after the end of the belt where the ejected material and non-ejected material fall on to separate conveyors. It was observed that often flexible plastic packaging items were successfully identified and ejected only to end up floating back down on to the wrong discharge conveyor because of the unstable airflow inside the

Figure 10: Baseline Optical Sorter Efficiency

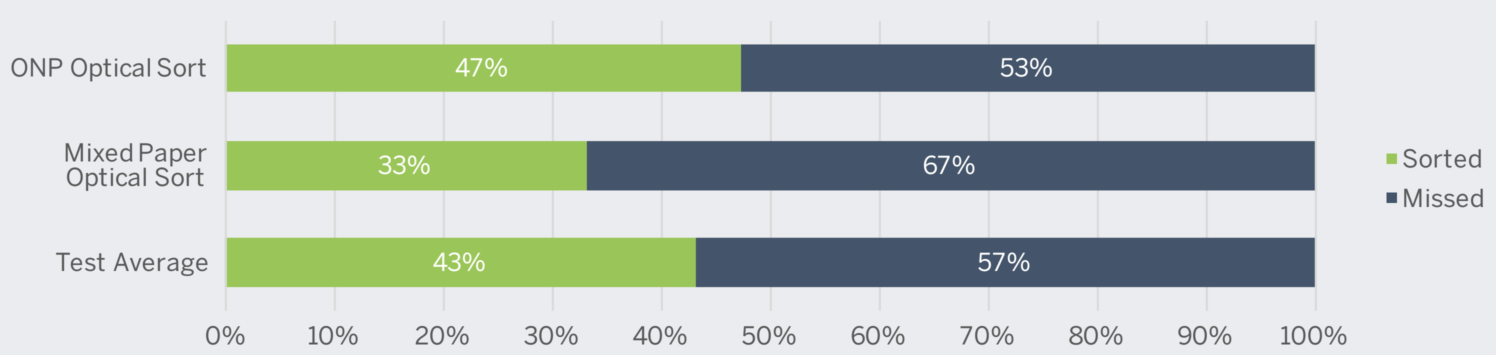
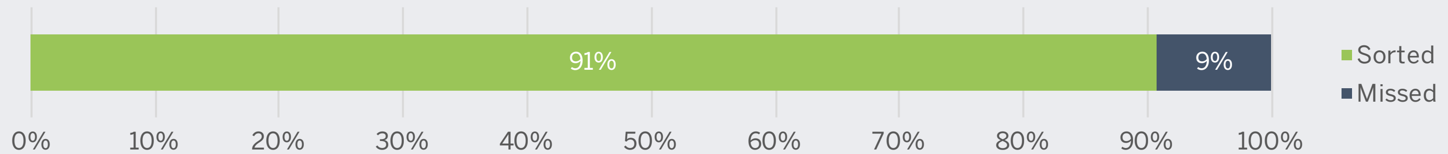


Figure 11: Equipment Test Optical Sorter Efficiency



chamber. This issue can be addressed by either an air capture system or an airflow system (secondary jets or vacuums) that creates a current to ensure that ejected items end up on the correct discharge conveyor.

Various solutions to address this issue were suggested by different equipment manufacturers. These included the following:

1. Vent the back of the ejection hood to minimize turbulence caused by ejection air
2. Draw air from the back or top of the ejection hood to minimize turbulence
3. Create sufficient suction at the back of the ejection hood to suck the flexible plastic packaging to a storage bunker. This method provides the option to suck up only flexible plastic packaging, while ejected plastic containers fall to the existing discharge conveyor, allowing for a three-way split.

The first two options were observed in action with option #2 being more effective than option #1 in the observed configurations. Option #3 has been implemented by one manufacturer in one or more installation but was not available during testing. Additional testing would be necessary to verify the initial observation of these options.

RRS anticipates that if airflow over the belt is implemented with airflow control in the ejection hood, in order to avoid blowing light items that were not ejected over the divider, some air must also be directed downward on the front side of the divider. And to avoid creating new instabilities in the ejection hood area, all of the airflows will need to be balanced and the hood will need to be sculpted to minimize turbulence. These hypotheses should be verified through future testing of various prototypes.

7.2.3. MATERIAL SPREAD

Based on discussions with optical sorter manufacturers and observations from testing, the importance of material spread became very apparent. If the material stream is spread out evenly on the optical sorter acceleration belt, identification and ejection is improved because there is less overlap, and target materials are easily seen as individual objects and identified by the sensor. Ejection is also improved because of reduced overlap. With less overlap there is less paper that gets ejected with the flexible plastic packaging, and there is a better likelihood that the ejected flexible plastic packaging ends up on the correct discharge conveyor because of reduced interference with paper. There are several ways to improve the material spread on the optical sorter acceleration belt:

- Have the disc screens feed straight on to the optical sorter conveyors. This technique was suggested by many of the optical sorter manufacturers as the best option because if the screen width is the same as the acceleration conveyor width, the material would be spread out in one layer without the need for additional equipment.
- Increasing the acceleration conveyor belt speed also helps to spread out material and this can be effective if the increased air resistance and/or turbulence over the belt does not cause materials to move around on the belt surface relative to the belt's motion and the optical sorter processors are fast enough to recognize and eject target objects.

7.3. MRF TEST 1

Using the information and test results gathered in the baseline test and equipment testing, MRF Test 1 was designed to determine what the expected level of flexible plastic packaging recovery might be for a MRF using optical sorters to clean up fiber. With two wide optical sorters in parallel, there was significant capacity to capture the flexible plastic packaging from the fiber stream. In its unmodified configuration this MRF was one of the best test sites in North America for this work. It can be seen in Figure 12 that the research hypothesis again proved correct. 83% of the flexible plastic packaging by weight flowed with the fiber stream.

Feedstock was fed into the system where it first encountered the OCC screen. The unders from the OCC screen fell on to a glass breaker, and the material that flowed over the glass breaker was sent to the ONP screen. The overs from the ONP screen flowed directly on the acceleration conveyor of the optical sorter, and the unders continued on to the container line. It was noted that the configuration of having the ONP screen feed directly on to the optical sorter acceleration conveyor was desirable and facilitated material spread. The container line started with an optical sorter set to recover mixed paper and then flowed to a hand sort and then to a density separator. The density separator removed any additional mixed paper from the container stream and then the container stream was collected in a storage bunker.

There were three major differences present in MRF Test 1 that were not present in the baseline test:

1. The optical sorter program was calibrated to target all plastics
2. The fiber disc screens fed directly on to the acceleration belt of the optical sorter
3. Optical sorter width increased from roughly 4m of total belt width to 5.6m

These differences were sought out and influenced by the baseline test, the equipment testing and discussions with manufacturers about ways to increase optical sorter efficiency.

7.3.1. OPTICAL SORTER EFFICIENCY

Figure 13 shows how efficient the optical sorter was at sorting the flexible plastic packaging from the ONP stream when programmed to specifically target flexible plastic packaging.

71% efficiency is a significant increase from the baseline test at 43%. The targeted optical sorter program, the increased material spread resulting from limiting MRF throughput and feeding directly from the ONP screen onto the optical sorter acceleration conveyor, and the increased optical sorting capacity all factored into this improvement.

7.3.2. COMPOSITION OF FLEXIBLE PLASTIC PACKAGING PRODUCT (BALE)

The composition of the ejected flexible plastic packaging product (the material bale) is a key factor in understanding how well the optical sorter is working. High contamination of the flexible plastic packaging product was observed;

Figure 12: MRF Test 1 Material Flow

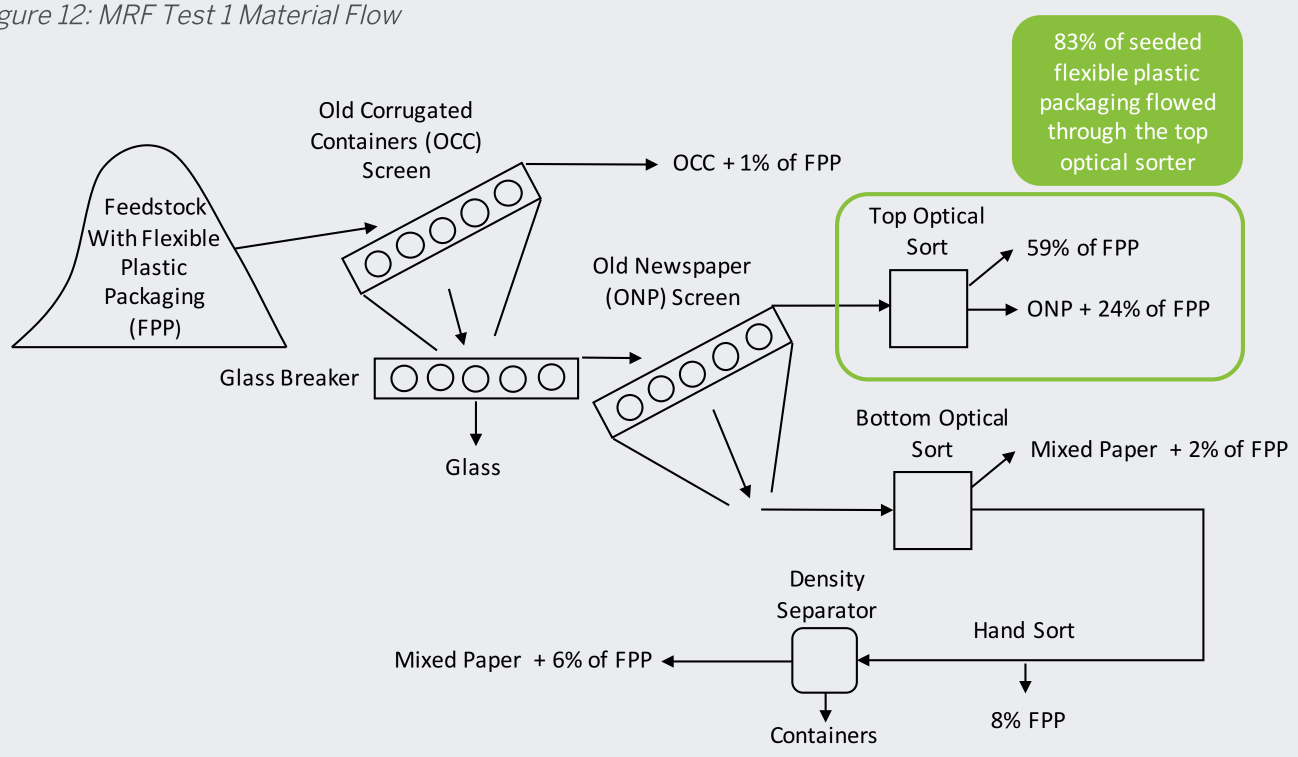


Figure 13: MRF Test 1 Optical Sorter Efficiency

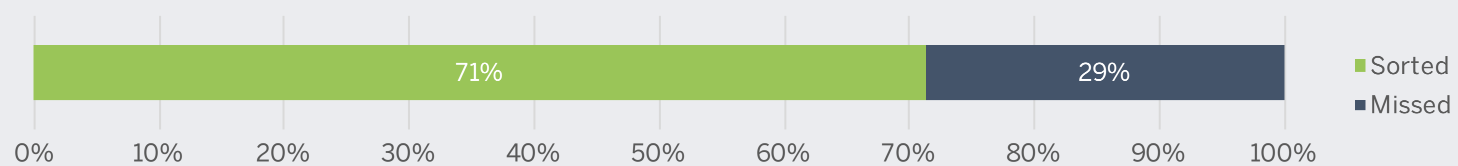


Figure 14 shows that approximately 50% of the sorted material was fiber by weight.

One reason for the high contamination is that the optical sorting program was set to aggressively eject flexible plastic packaging, which brought fiber with it. Further testing was clearly needed to optimize the balance between capturing flexible plastic packaging and minimizing the collateral capture of fiber.

7.4. MRF TEST 2

MRF Test 2 objectives were set based on the results of MRF Test 1: 1) to establish whether multiple passes of optical sorting could improve separation of the seed material from the fiber stream, and 2) to determine if an increase in product purity could be achieved without a major reduction in the efficiency of the optical sorting.

Figure 15 is a simplified material flow diagram for MRF Test 2. The test mix for MRF Test 2 was simplified to only include seeded flexible plastic packaging and ONP product that had already been run through the system. The test material first flowed to the OCC screen where the overs were the OCC product, and the unders continued to the fines screen. Fines and glass were removed from the material stream and the rest was sent to the ONP screen. The ONP screen was modified by removing two shafts of the screen so that all of the material would flow to the container line. On the container line the material encountered three consecutive optical sorters set to fire on containers and flexible plastic packaging.

Figure 16 shows that 6% of the seeded flexible plastic packaging by weight went to the OCC product. This consisted of only the largest flexible plastic packaging and can be readily of effectively recovered manually. MRF Test 1 had 1% flow with OCC and MRF test 2 had 6%, this may have been because screen designs were different - different manufacturers with different disc designs and different shaft rotation speeds. Of the remaining 94% of seeded flexible plastic packaging that flowed to the optical sorters, 64% was ejected at

Figure 14: MRF Test 1 Flexible Plastic Packaging Product Composition

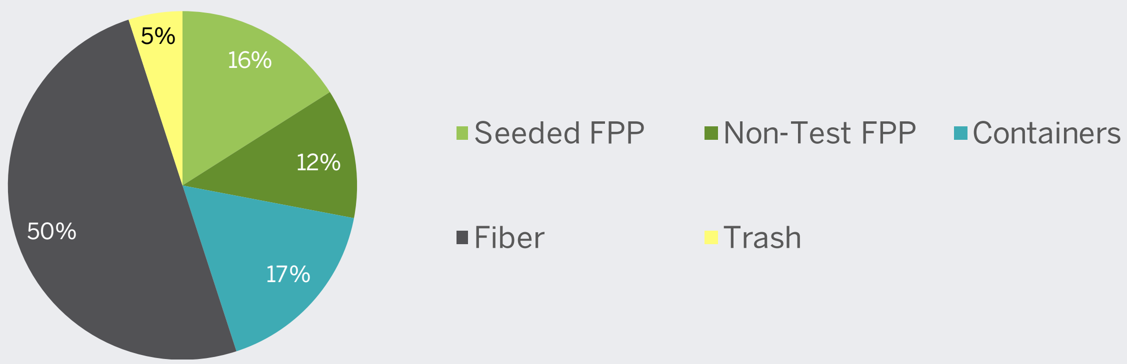
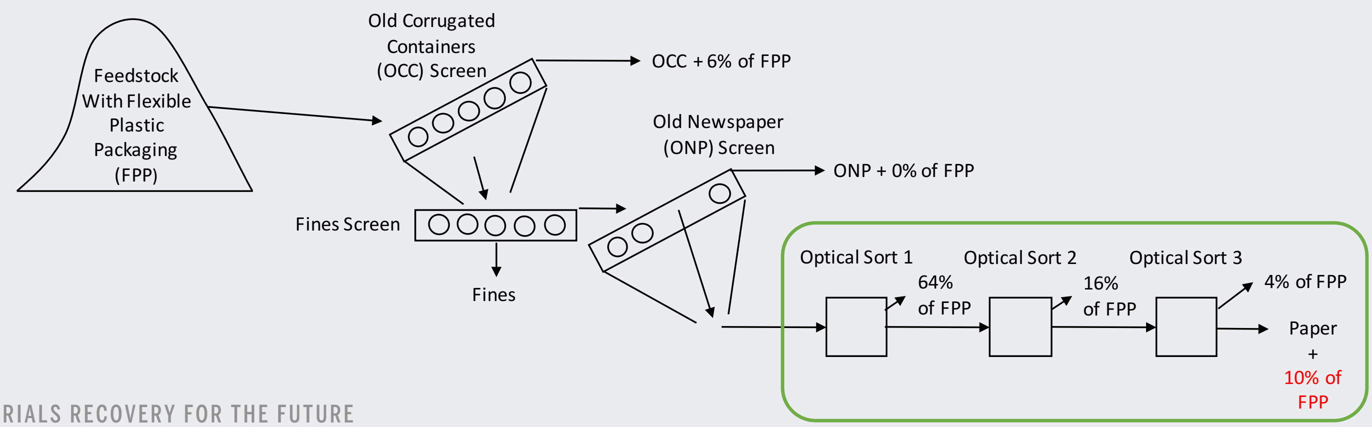


Figure 15: MRF Test 2 Material Flow



the first sorter, 16% was ejected at the second sorter and 4% was ejected at the last sorter. 10% of the seed flexible plastic packaging went into the paper product.

7.4.1. MULTIPLE PASS SORTER EFFICIENCY

Figure 17 below displays the optical sorting efficiencies of the second MRF test system as a whole after each optical sorter.

68% efficiency was achieved at the first optical sort, which is consistent with the results seen in MRF Test 1. After the second optical sort, 85% of the seeded flexible plastic packaging by weight that went through the first two optical sorters was removed. And finally, the system of three optical sorters was able to remove 89% of the seeded flexible plastic packaging that flowed through it. The diminishing effectiveness of successive optical sorters is a result of two factors, one being that there is less flexible plastic packaging to recover at each sort and the other being that the material that does make it to further sorts is more challenging to sort.

7.4.2. COMPOSITION OF THE FLEXIBLE PLASTIC PACKAGING PRODUCT

For MRF Test 2, adjustments were made to the optical sorting program to reduce the aggressiveness of the air jet firing area with the intention of reducing the amount of fiber in the flexible plastic packaging product. There was an improved result: the 50% fiber found in the flexible plastic packaging product in MRF Test 1 was reduced to 37% fiber by weight in MRF Test 2.

7.5. COMPARISON OF BASELINE TO MRF TESTS

7.5.1. OPTICAL SORTER EFFICIENCY

Figure 19 provides comparison of the optical sorting efficiency of the baseline test, MRF Test 1 and MRF Test 2.

There was a significant increase in sorter efficiency between the baseline test and MRF Test 1. This is due to the targeted optical sorter program, the increased material spread and the increased optical sorting capacity. The optical sorting efficiency of

Figure 16: MRF Test 2 Material Flow Diagram

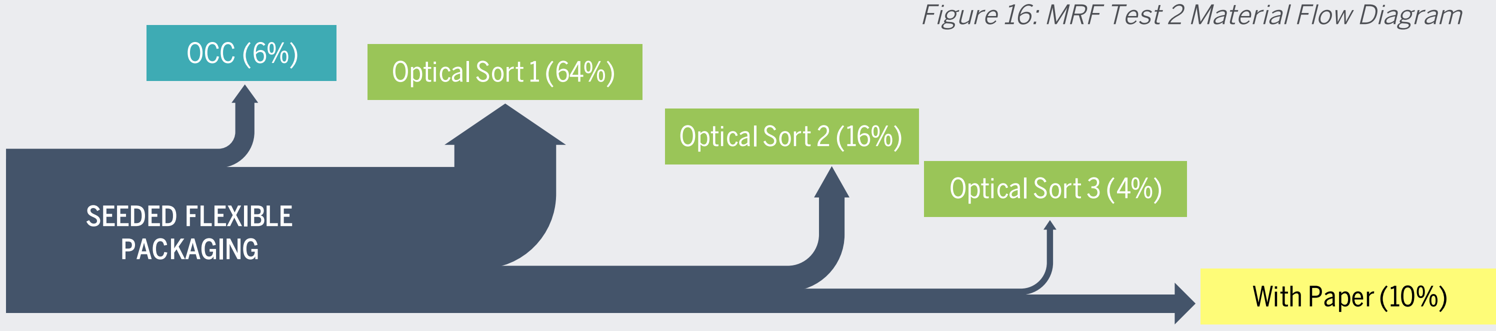


Figure 17: Multiple Pass Optical Sorter Efficiency

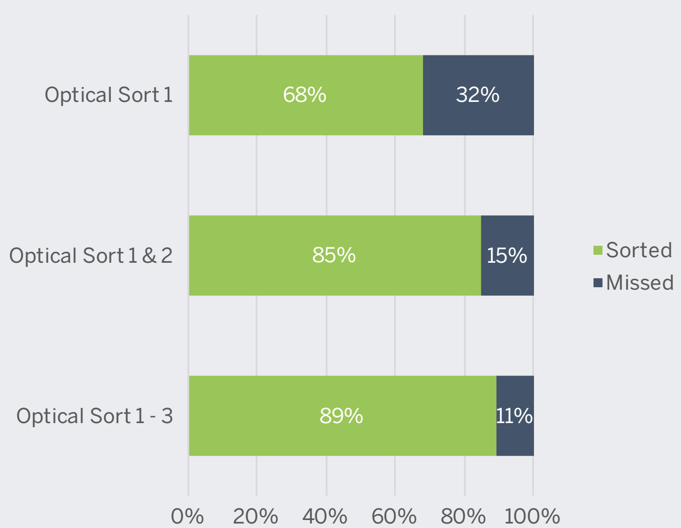
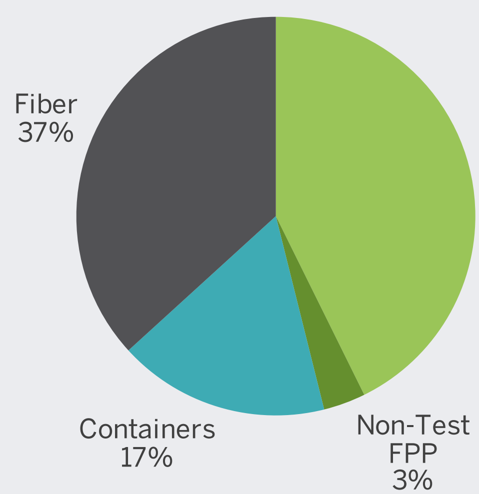


Figure 18: MRF Test 2 Flexible Plastic Packaging Product Composition



MRF Test 2: Optical Sort 1 is comparable to the efficiency seen in MRF Test 1, validating these results and demonstrating that this level of sorting efficiency can be expected at other MRFs.

Comparing the three levels of sorting in MRF Test 2 it can be seen that a high level of recovery is possible with multiple optical sort passes. As mentioned before, there is a diminishing return as more sorters are added in series because the amount of flexible plastic packaging in the stream decreases after each pass and the proportion of challenging pieces of flexible plastic packaging is increased.

More effort is needed to optimize the sorting efficiency of optical sorters for this application before the number of sorts required to produce a suitable flexible plastic packaging product while maintaining fiber product quality is known. During all testing, a portion of the identified flexible plastic packaging was either missed during ejection because of movement in the optical sorter acceleration belt, or material was included in the wrong output after ejection because of turbulent airflow in the ejection hood and the 2D-nature of flexible plastic packaging. Airflow could be designed differently that would increase efficiency in the future. To augment the capabilities of optical sorting, additional technologies will need to be pursued to achieve lowest cost solutions. These may include vacuum systems, film grabbers, air drum separators and other evolving technologies. These technologies allow for capture on both the fiber and container lines.

7.5.2. COMPOSITION OF FLEXIBLE PLASTIC PACKAGING PRODUCT

Figure 20 compares the compositions of the flexible plastic packaging product by weight from the two MRF tests. MRF Test 1 contains only 28% flexible plastic packaging (seeded and non-test) and is heavily contaminated with 50% fiber, while MRF Test 2 product improved to 46% recovered flexible plastic packaging and 37% fiber.

It should be noted that the test stream for MRF Test 2 included seeded flexible plastic packaging with a paper product that had been previously sorted by the MRF, this paper product still included containers and some non-test flexible plastic packaging. These materials were targeted for ejection with the seeded flexible plastic packaging. Many factors go into accounting for the reduction of fiber and increase of flexible plastic packaging, but the main factor was the modified optical sorting programming. In MRF Test 1, the optical sorter was programmed to fire the air jets on an area about the same size as the identified object. While this configuration increases the likelihood of properly ejecting the target object,

Figure 19: Optical Sorter Efficiency Comparison

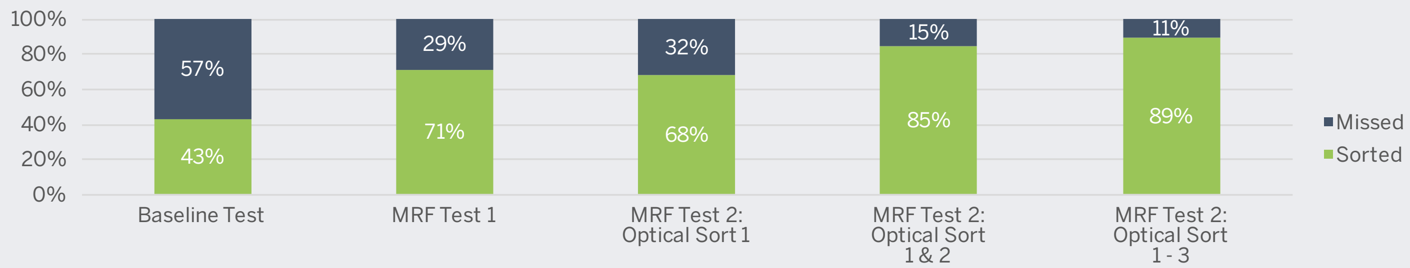
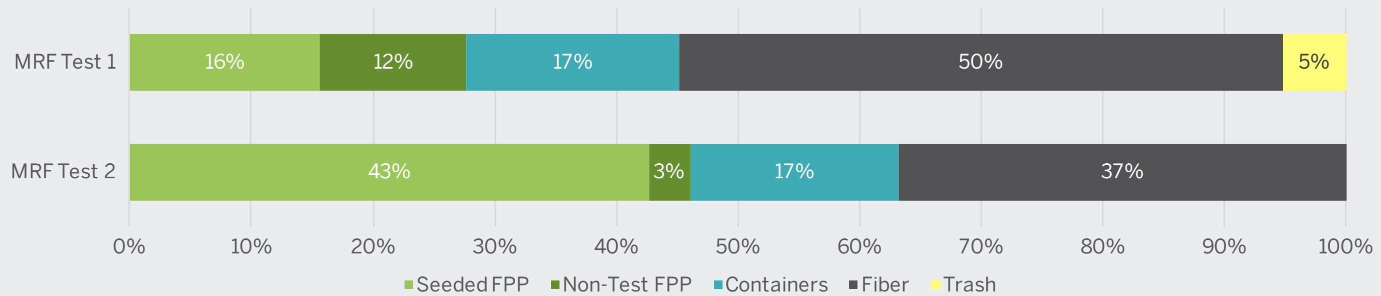


Figure 20: Composition of Flexible Plastic Packaging Product



there is also an increased chance of a piece of material near or slightly overlapping the target piece being ejected as well. In MRF Test 2 the optical sorter was set to fire on a smaller area on the target piece of material and thus there was less collateral fiber ejected with the flexible plastic packaging. This concentrated firing had a major effect on increasing the flexible product purity without negatively effecting the efficiency of the optical sorter. This result is a positive trend and shows the need for further testing to determine the optimal balance between flexible plastic packaging product purity and optical sorting efficiency.

8. MRF PRODUCTS - WHAT WAS THE IMPACT OF ADDING THE FLEXIBLE PLASTIC PACKAGING?

8.1. IMPACT ON OTHER PRODUCTS

8.1.1. MRF TEST 1

Figure 21 displays the fiber stream composition results by weight for MRF Test 1. After the optical sorters, fiber stream contamination was reduced from a total of 8.4% flexible plastic packaging to just 2.4%, which corresponds to 97.6% fiber purity.

Flexible plastic packaging was seeded to 2.5% by weight of the entire input stream. By the time it reached the optical sorters where containers had already been sorted out, flexible plastic packaging constituted 5% of the stream, which was predominantly otherwise fiber. Furthermore, about 3.4% of the stream at that point consisted of naturally-occurring levels of non-test flexible plastic packaging, so a total of 8.4% of the fiber stream was made up of flexible plastic packaging. A contamination level of 2.4% is close to meeting the two Institute of Scrap Recycling Industries (ISRI) bale specifications which govern MRF fiber, #56 Sorted Residential Papers (SRP) and #54 Mixed Paper (MP), for which the amount of prohibitive material (e.g., flexible plastic packaging) is 2%. A level below 2% by weight for flexible plastic packaging is desired to allow for other prohibitive material as well.

8.1.2. MRF TEST 2

MRF Test 2 was seeded to approximately 6% flexible plastic packaging by weight and there was no concentrating of the flexible plastic packaging proportion in the fiber stream because the configuration of this test was such that all of the feedstock would flow to the optical sorters. There still was a small amount of non-test flexible plastic packaging present at a level of 0.4%. Figure 22 shows how well the multiple optical sorts of MRF Test 2 reduced the contamination of the fiber stream.

Figure 21: MRF Test 1 Fiber Stream Contamination

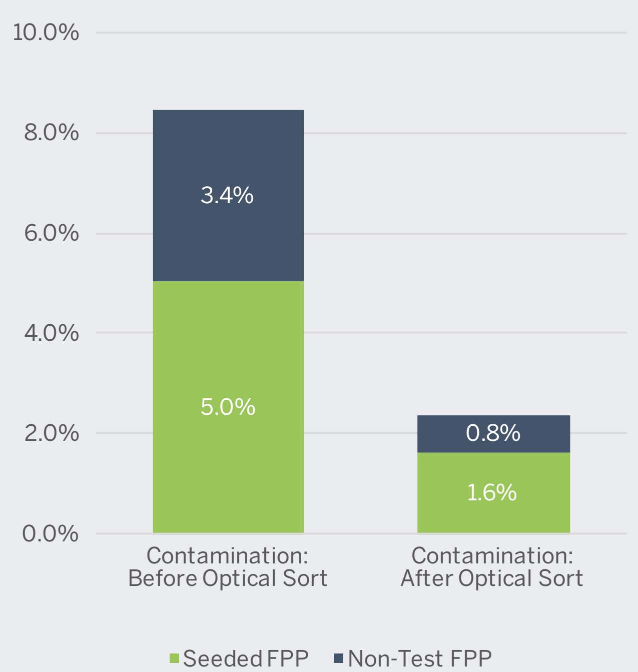
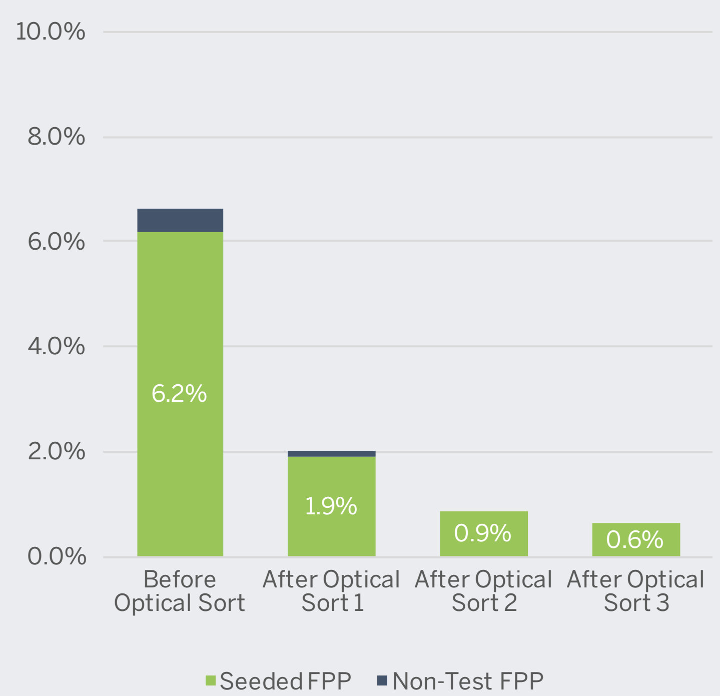


Figure 22: MRF Test 2 Fiber Stream Contamination



Optical Sort 1 was able to reduce the total amount of flexible plastic packaging present in the fiber from 6.6% to 2% by weight, which meets the ISRI specification threshold for non-paper plastics material in the standard Grade 56 and Grade 58 residential paper grades coming from a MRF. Optical Sort 2 was able to further reduce the concentration to 0.9%. Finally, Optical Sort 3 left the fiber stream at 99.4% fiber and 0.6% flexible plastic packaging. This result shows that optical sorting can produce very pure bales of fiber even when the stream contains a sizable amount of flexible plastic packaging.

9. SUMMARY OF FINDINGS ON MATERIAL FLOW

Throughout the course of the research program, improvements were made over the baseline in the metrics tested through reduced loading on the optical sorters, increased sorter belt width and targeted optical sorter programming. The age of equipment also varied between tests with the baseline test being 10 - 12 years old and MRF tests having newer equipment. Lab testing identified a "theoretical maximum" for unmodified optical sorter efficiency and the subsequent testing was able to achieve a level near that in a real-world MRF setting. The majority of flexible plastic packaging flowed with the fiber line, consistent with the project hypothesis. The target flexible plastic packaging product still contained a large amount of paper, but over the two MRF tests the product purity was improved from 28% to 46% flexible plastic packaging, an encouraging trend. Finally, the increased capture to the target product meant less flexible plastic remaining in paper products, demonstrating the potential to reduce contamination of fiber bales. A summary of results by weight is shown in Table 4.

10. FACTORS INFLUENCING MATERIAL FLOW

Table 5 is a summary of the factors that influence flexible plastic packaging recovery. The results in this table are preliminary and most of the conclusions were derived from observations. Further testing will be needed to quantify factors that merit concrete MRF equipment and/or packaging design changes.

Optical sorters produced by different manufacturers varied in their ability to identify and eject certain materials. This is not to say that all tested optical sorters were fitted with the same options, or that one manufacturer's design was consistently better than the others tested. The following were observed to be challenging to most of the optical sorters tested:

- Highly glossy surfaces were more difficult to recognize. The manufacturers explained this as a problem of specular reflection overwhelming the sensor with broad spectrum reflected light.
- Black and very dark objects generally do not reflect enough light back to the optical sensors for reliable identification. Part of the variation between optical sorters is the actual spectrum that they are capable of reading.
- Very thin packaging such as retail carry bags and shrink wrap with little structural stiffness tended to move around in the optical sorter acceleration conveyor belt as approaching the optic reader. This resulted in failed ejections because these items did not cross the ejection jets at the time and place that the optical sorter predicted they should. Other lightweight packaging such as food storage bags with closures were stiffer and were not significantly moved by air above the conveyor belt allowing them to eject well.

Table 4: Material Flow Summary

	Optical sorter efficiency: % of FPP correctly sorted by optical sorter(s)	Flexible plastic packaging that flowed with fiber: % of FPP entering MRF system that flowed to the fiber	Purity of flexible plastic packaging end product: % of designated flexible product consisting of FPP	Contamination of paper products: % of paper bale that consisted of FPP
Baseline Test	43%	88%	Not tested	3.3%
Equipment Lab Testing	91%	N/A	Not tested	Not tested
MRF Test 1	71%	83%	28%	2.4%
MRF Test 2	89% (via three passes)	N/A*	46%	0.6%

* MRF Test 2 involved seeding test material directly into fiber portion of single stream feedstock

Table 5: Material Flow Factors

FACTOR	IMPACT ON RECOVERY	SOLUTION
Size	32% of FPP < 55 sq. inches flowed with containers and only 11% of FPP ≥ 55 sq. inches flowed with containers	A minimum of two stages of mechanical separation before the optical sorters
Form	Packaging that was unevenly weighted tended to tumble rather than lift when ejected by optical sorters	Some optical sorters did much better than others at this task. Additional experimentation is needed to understand optimum ejection timing and what other factors can better control trajectory
	Very lightweight packaging floated around on the acceleration conveyor and causes ejection issues	Airflow control over the belt and in the ejection hood
Structure	Lightweight packaging with closures that increase their stiffness such as food storage bags were not affected as much by turbulence above the conveyor belt	N/A
Color	Black packaging was less likely to be recovered	Reduced use of black pigments in packaging may help. Also some optical sorters were better at recognizing dark objects probably because of choice of light spectrum utilized
Dimensionality	Flexible plastic packaging and paper are both flat and have a tendency to overlap which can impede the air jets and the optical sensor	More sophisticated recognition and airflow control
Finish/Glossiness	Very shiny packaging reflected back too much broad spectrum light to the optical sensor and drowned out the resin identification signature spectrum	Reduce glossiness of packaging

IN CONCLUSION: A PATH FORWARD

The research shows that existing optical sorter and MRF equipment technology can be used to sort flexible plastic packaging at promising levels of efficiency. With some targeted adjustments of the equipment, identification and sorting of the seeded flexible plastic packaging improved dramatically. Although the film quality levels generated were not yet optimal, it is expected that this technology can be optimized so that fiber product quality is concurrently improved.

This section of the report utilizes the learnings from this first year of research to provide next steps on how members of the value chain can work to create a stable supply, and demand for, recycled flexible plastic packaging feedstock. RRS provides suggested work streams for further research that we believe are the most useful and relevant for those interested in working in a positive manner to achieve curbside recycling of this material. The work streams are interrelated and are envisioned to be done concurrently and not in sequence. At the same time, RRS does not intentionally make specific recommendations regarding who or how this work should be done or proceed.

1. Further Equipment Testing: Improve sorting of flexible plastic packaging through MRF equipment testing in a controlled environment. There is a need to focus on optical sorters and design of air flow control to optimize the separation of fiber from flexible plastic packaging. Improvements may also be possible through optimizing aim, pressure and port size of the ejectors, or by using airflow capture for either the flexible plastic packaging or the paper. Some recognition improvement may be possible through working with equipment manufacturers to assure the optimum portion of the spectrum for recognizing flexible plastic packaging is utilized. Developing a community of practice to share knowledge among equipment manufacturers, operators and brands seeking next life solutions for this material will accelerate equipment development to achieve greater sort efficiencies. Once the new design is successfully achieved in a controlled setting, a robust engagement of key stakeholders in the recycling industry and broader recycling community could help identify a MRF demonstration site for curbside collection testing in a community.

2. End Market Assessment: While an increasing amount of plastic film is being returned to packaging products, the majority of this consumption is in bulk extruded and molded products such as plastic lumber. Much of the flexible plastic packaging stream will not be marketable to the existing plastic film market because it is made up of multi-layer, multi-resin construction. While a number of small scale processors are able to blend and mold these mixed resin materials into durable products, no large scale consumer with this capability has been identified to date. And more importantly, no research has been performed that estimates the market for end products produced with these technologies. While some end market technologies have been explored extensively, others are in early research stages. End market assessment will provide a comprehensive evaluation of the full range of potential end markets.

3. MRF Processing Economic Analysis: An updated net system cost analysis that considers the economics of installing new equipment to sort flexible packaging, and its subsequent impact on revenues, costs, disposal, and quality of paper after sortation, needs to be undertaken to economically justify long-term change in MRFs, and provide useful information to municipalities who may want to add flexible packaging to the curbside mix.

4. Secondary Processing Economic Analysis: The MRF sorted flexible plastic packaging mix will require preparation by secondary markets to achieve full recovery. Greater understanding of the technical feasibility, environmental impacts and economic value of flexible plastic packaging secondary processing (e.g., PRF reprocessing) to meet end market feedstock requirements is needed. The costs of further sorting, cleaning and converting cleaned flexible plastic packaging to various products will inform proper investment and will be one input to the MRF processing economic analysis described in work stream 3 above. Conducting feasibility analysis of the preparation for each market would provide understanding and cost data to project net system costs that establish a business case, and prove an end form with value can be developed. Conducting trial testing with the most promising end markets will be necessary to confirm the feedstock is suitable for larger scaled applications.

Promising enabling technologies for further research include:

- Resin compatibilizers. Adding these to new packaging may improve the ability to recycle more of the flexible plastic packaging with plastic film. Similar additives possibly could be added when blending some laminated flexible plastic packaging to improve usability in a range of existing end markets.
- Chemical and physical delamination processes.
- Chemical recovery processes that allow reclamation of monomers and precursors that can be refined and used to make new polymers.
- Conversion technologies will remain an alternative for some elements of the stream to allow recovery of useful chemicals and energy.

5. Community MRF Demonstration Pilot: Implement a MRF demonstration project with a willing community MRF partner. This is the last step that would provide a brick and mortar demonstration site in a community that is eager to add more material to their carts. Once the cost-benefit analysis of capital costs, operating costs and secondary processing and market value is complete, private-public partnerships could pave the way for success of a market-based solution. The MRF would install the necessary equipment upgrades and provide a data set that could be evaluated by others to incent addition of the material.

GLOSSARY

Air Drum Separator (ADS): A separation device that separates light flexible materials from rigid and 3D objects. Materials fall on a rotating perforated drum with suction from the inside. Light flexible materials such as paper and film cling to the drum until blown off on the back side. Rigid materials are not held to the drum and fall off the front side.

Bags (excludes retail, storage, trash): Bags used to collate and merchandise multiple items (e.g. bread bags, diaper bags, produce bags, textile bags, etc.).

Conversion technology: Processes used to covert plastics to energy, synthetic oil and gases or recover monomer and precursors for new resin.

Delamination: The process of separating a multi-layered material into separate layers.

Flexible Packaging (FP): Packaging produced from paper, plastic, film, aluminum foil, or a combination designed to be flexible. Includes bags, envelopes, wraps, labels, rollstock, etc.

Flexible Plastic Packaging (FPP): Packaging produced from plastic that is designed to be flexible. Includes bags, pouches, liners, wraps, and other flexible plastic products.

MRF: A materials recovery facility takes feedstocks of collected recyclables and processes them into marketable commodities.

OCC: Old corrugated containers.

ONP: Old newspaper.

Optical Sorter Efficiency: The percentage of targeted material that went through the optical sorter and was successfully sorted.

Overs: The portion of material that continues over a disc screen or does not fall through the openings in a sizing screen.

PRF: A plastics recovery facility further processes plastics from a MRF into higher value products. These processes include separating by resin type, increasing bale purity, washing and sizing to flakes and producing densified resin forms such as pellets.

Residue: The non-marketable material that is left over after MRF processing.

Resin: Any of various synthetic products that have some of the properties of natural resins but are different chemically and are used in plastics.

Resin compatibilizer: An additive that aids in the mixing of different plastic resins.

Storage bags: Bags used for the storage of household goods.

Unders: The portion of material that falls through or rolls off the bottom of a disc screen or through the openings in other sizing screens.