# The Bioplastics Sorting Project

CalRecycle
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Final Grant Report of Technical Findings
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# Acknowledgments

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# Executive Summary

The Future 500 Bioplastics Sorting Project was a multi-year research effort that included stakeholder input, an analysis of discarded plastics lost to landfills in the state, and development of an optical sorting system to test removal of bioplastics from several waste streams. The project expanded its original focus on separating polylactic acid (PLA) bottles from the polyethylene terephthalate (PET) recycling stream to additionally explore the feasibility of sorting and collecting other bioplastic products (such as clamshells and cups) for recycling and to test the efficiency of sorting multiple plastics from one another. PLA products have been problematic for PET recyclers because they often look identical to PET products, so they cannot be visually separated, and due to differences in their chemical characteristics, the two resins cannot be recycled together. So they must be separated optically.

This technical report provides the results of multiple sorting trials completed in 2011 and 2012. The trials were designed to answer four primary questions:

1. Can the optical sorting system effectively separate PLA bottles from PET bottles, so that clean PET would continue to be available to PET reclaimers?
2. Can the optical sorting system effectively separate PLA from other materials, so that PLA products could be recovered for recycling?
3. Can the optical sorting system effectively separate other (non-bottle) PLA products, especially cups and food service items, from a mixed plastics stream?
4. Can the optical sorting system effectively separate various other types of plastics from each other, from a pre-sorted mixed plastics stream?

While the project examined the effectiveness of the sorting system, it was not designed to address the costs or other economic factors critical to deployment of advanced optical sorting at California facilities.

## *Methodology*

To perform the sorting tests necessary to answer these questions, Future 500 released a Request for Proposal for the design and construction of a mobile optical sorting system. A contract was awarded to Pellenc Selective Technologies, which hired Titus Maintenance to help build the system. Between June 2011 and November 2011, the equipment was tested on samples from five separate streams of materials from eight materials recovery facilities (MRFs), including:

1. **Sorted PET:** PET bottles that had been positively sorted from a MRF container line (i.e. separated from other materials by hand and/or machine into a dedicated PET bin). This stream was fed into the mobile system and processed by the optical technology to remove non-PET materials, especially PLA, that inadvertently had been separated into the PET bin by the MRF.
2. **Sorted HDPE:** HDPE containers positively sorted from a MRF container line. These were run through the optical sorting machinery to recover PLA and PET bottles that inadvertently had been sorted as HDPE, and to remove paper and other plastics from the HDPE.

3. **Sorted Mixed Plastics:** Mixed plastics (resin codes 3-7) separated from other materials by the MRFs either positively or negatively (i.e. allowed to fall into a bin after PET and HDPE had been removed). This stream was run through the optical sorting machinery to recover any PET and HDPE missed when the material was sorted initially, and to remove loose paper.
4. **Unsorted Mixed Containers:** Containers separated from fiber at the MRFs and transferred to a container sort-line for further separation. These containers were run through the optical sorting machinery to separate PET, PLA, and HDPE from all other material types.
5. **MRF Processing Residuals:** Contaminants and any containers remaining after desirable materials had been positively sorted at the MRFs from the mixed container stream. These residuals were run through the optical sorting machinery to recover PET, PLA, and HDPE that had been missed in the first sort.

Data from the eight MRFs were aggregated to protect the confidentiality of individual facilities. (The team also tested residual materials from three Southern California reclaimers, but these data are not reported for confidentiality reasons due to the small number of facilities.)

When grant funds originally were awarded to Future 500, PLA bottles increasingly were entering the California marketplace and it appeared the trend was growing. The 2011 tests were designed with the assumption there would be sufficient numbers of PLA containers in the samples to confirm the ability of the optical sorting machinery to separate PLA from PET and other plastics. However, the testing revealed insufficient PLA in the sampled material to fully test the capabilities of the system. In response, the project team "seeded" additional samples in June and July 2012 with known quantities of PLA bottles, cups, and clamshells.

## *Sorting Results*

Collectively, the trials demonstrated:

- The Pellenc/Titus optical sorting system is capable of removing many types of contaminants from PET loads previously sorted at the MRF, increasing the quality of marketed PET. More than 8 percent of the materials in loads sorted by the MRFs as "clean" PET bottles were found to be other than PET (other plastics and other material types).
- The optical system is capable of separating PLA bottles only, or bottles, cups, and clamshells from all other mixed containers recovered at a MRF. Separating PLA will allow it to be reprocessed into new PLA products, when appropriate facilities are in place. The results from Sample 7 showed that when the machinery is set to separate only PLA from "other" materials, it can achieve a 99.6 percent recovery rate, although additional trials with the same setting were not conducted. More favorable results were achieved when the incoming materials were sorted into two fractions rather than sorted into three fractions.
- The optical system is capable of separating multiple plastic resins from each other to produce higher-value marketable materials from mixed plastic containers inadequately sorted at the MRF.
- The optical system is capable of recovering high value plastics (notably PET and HDPE) from the mixed plastics stream as currently sorted for sale by the MRFs, potentially offering an additional revenue stream for recovery facilities.

## *Conclusions and Recommendations*

The bioplastics sorting project demonstrated the Pellenc/Titus mobile optical sorting system can add value to recovered plastics by removing contaminants and redirecting traditional and non-traditional materials to their appropriate markets. Overall recovery rates for PET and HDPE could be increased by appropriate use of this technology. A system of this type also could be used to positively sort PLA for recycling, addressing a major challenge as bioplastic packaging grows in market share.

Additionally, reprocessing the mixed plastics stream (resin codes 3-7) through optical scanners can make more high-value materials available to markets, and may provide additional revenue to MRF operators. Although a complete cost-benefit analysis was beyond the scope of this project, it is possible the revenue from the sale of additional PET and HDPE recovered would pay for the cost of this secondary processing.

Recovery rates can be increased by running materials through the sort system more than once, or by running loads through a second sorting machine. Realistically, sorting more than once is not likely to happen at most MRFs due to throughput and economic constraints. But it may be advantageous for reclaimers to install such an optical sorting system because they already have to re-sort the PET they purchase to ensure it meets their quality requirements. In the process, reclaimers lose desirable material, and revenue, in their residuals.

While the sorting trials demonstrate the *potential* for improved recovery of materials, more research is needed to narrow the factors that affect actual performance in day-to-day operations. The project team's collective experience in the industry suggests multiple variables can affect both recovery rates and the quality of materials produced when deploying an optical system. The equipment must be properly calibrated and/or conditions modified to achieve optimal results. Variables include:

- The loading of the system feed belts
- The number of sorts being performed each time the machine is run
- The composition of incoming materials
- The amount of the material to be separated as a percent of the total amount of material processed
- Splitting of incoming material into two or three fractions
- How effectively the materials were initially processed
- Space constraints at the processing facility
- Cost of labor

Stakeholder engagement was a fundamental component of this project. From the start, Future 500 communicated with groups and companies with a vested stake in improving recovery of bioplastics and recycling in California in general. The project team held a stakeholders meeting in October 2012 to discuss the sorting results and to solicit technical and policy recommendations. While some stakeholders, especially those processing PET, feel that PLA cannot be sorted out effectively despite improved technology, the participants nevertheless suggested a number of policy mechanisms to explore in legislation or by other means, including various ways to incentivize improved sorting and higher recovery. Among them:

- Several regional “intermediate” processing facilities located throughout the state may be the most cost-effective way to process mixed materials through an optical sorting system.
- The state should consider re-implementing a plastics "Quality Incentive Payment" (QIP) for facilities which market materials that meet certain quality standards. The bar would need to be set high enough so California processors could capture the incentive payment to better compete with foreign buyers, but low enough to make it achievable.
- Currently the “glass-cleaning regulation” (Public Resources Code §2425h) allows CRV claims on glass material with greater than 10 percent contamination, if the processor cleans the glass to ASTM specifications for glass container manufacture. A similar approach could be applied to PET and HDPE, creating an incentive to improve sorting methods.
- MRF performance standards could be established to reduce contamination in recovered plastics shipped to market.
- Higher CRV processing payments would help pull smaller-volume bottles and containers from the waste stream and provide revenue for improved recovery.
- The Plastic Market Development Payment (PMDP) program, which pays California processors and manufacturers a premium for using recycled plastics in-state, could be expanded.
- Stricter enforcement of the Rigid Plastic Packaging Container (RPPC) regulations may help ensure cleaner streams and improved plastic recovery; some participants stated the HDPE reclaiming industry in California became established largely because of such policies.
- Design for Recyclability (DfR) guidelines would help assure end-of-life considerations as part of initial packaging design. DfR could be tied to the CRV program, so manufacturers’ CRV payments would be higher if the containers don’t meet the recyclability guidelines.
- California could increase minimum recycled-content requirements for selected resins.

By itself, enhanced optical sorting will not address the many challenges facing recyclers and processing facilities as new materials enter the marketplace. But the project demonstrated the feasibility of technology, when used under the right conditions, to increase both the effectiveness of the state’s recovery infrastructure and the quality of recycled feedstocks supplied to manufacturers fabricating new products and packaging. Innovative technologies like those demonstrated here will become increasingly critical tools as California advances toward its 75 percent recycling rate goal.

# Project Overview

The Future 500 Bioplastics Project was funded by CalRecycle (formerly the California Department of Conservation, Division of Recycling) in a Market Development and Expansion Grant (#5008-502), using unclaimed beverage container deposits held by the state. The purpose of the grant was to determine whether an optical sorter could be constructed that would be able to effectively separate polylactic acid (PLA) resin bottles from polyethylene terephthalate (PET) resin bottles. PLA products have been problematic for PET recyclers because they often look identical to PET products, so they cannot be visually separated, and due to differences in their chemical characteristics, the two resins cannot be recycled together. So they must be separated optically.

The original focus of the project was to help ensure that if bioplastic bottles were introduced into the marketplace in significant quantities, those bottles would not contaminate the clean PET stream, and would not negatively impact the recycling of PET bottles. This meant that a means of separating PLA from PET that did not rely on visual inspection of the PLA containers from the PET containers was needed.

As a corollary to this effort, it was important to determine if clean PLA bottles could be recovered for recycling, since PLA is technically recyclable if it is recovered in sufficient quantities to bring down the unit costs for handling. (A company called BIOCOR was created in 2010 to manage the recovery and recycling of PLA throughout California, but its current operations are uncertain.)

In addition to the original purpose, two additional goals were developed during the term of this grant. The first was to test whether the sorter could be used to facilitate the recovery of additional PLA material types, especially cups and food service items, from a mixed plastics stream.

Second, the optical sorting machinery was used to identify whether the optical sorter could be used to help separate other types of plastics from each other in a mixed plastics stream.

# Study Goals

This research project was designed to answer four primary questions:

1. Can the optical sorting system effectively separate PLA bottles from PET bottles, so that clean PET would continue to be available to PET reclaimers?
2. Can the optical sorting system effectively separate PLA from other materials, so that PLA products could be recovered for recycling?
3. Can the optical sorting system effectively separate other (non-bottle) PLA products, especially cups and food service items, from a mixed plastics stream?
4. Can the optical sorting system effectively separate various other types of plastics from each other, from a pre-sorted mixed plastics stream?

# System Design

Following the award of this grant, a Request for Proposals (RFP) was prepared by Future 500 for the development of an optical sorting system. The primary requirement was that the machinery be capable of identifying PLA and physically separating PLA from whatever “other” materials were in the load being sorted. Additionally, the RFP required that the optical sorting machinery be mobile—that is, mounted on a trailer. The plan was to move the sorter from processing facility to processing facility. A wide range of materials then could be tested over the range of conditions that would represent the real world needs of the materials processing industry.

The RFP also required that the optical sorter be designed with capacity to process 3-5 tons per hour of input materials, the quantities that would commonly be generated at a large materials recovery facility (MRF) in California.

The only proposal received was from Pellenc Selective Technologies. After careful review, the Pellenc proposal was deemed to be fully responsive to the RFP. Pellenc provided the optical scanner, and Titus Services constructed the materials delivery system for the sorter (Figure 1).

The first step in processing the materials is to load them into a feed hopper. Pellenc realized that it was important to remove small particles and lightweight materials before the containers were presented to the optical scanner, so the machine includes a two stage pre-sort system. The materials are first pre-screened to remove the fines (< 2” particles), and the lightweight fraction (mostly shredded paper and film plastics) is vacuumed off.

The remaining materials continue on to a horizontal conveyor and pass under the optical scanner. To achieve the best quality of sort, less than 30 percent of the surface of the horizontal scanner delivery conveyor should be covered at any time. The high speed of the conveyor (belt speed of 9 feet per second) still allows processing of a large quantity of materials (3-4 tons per hour).

The requirement for the system to be mobile resulted in three unanticipated constraints:

1. The in-feed hopper and discharge bins were too small to allow the machine to be run as it would in a commercial facility;
2. Even so, it still required two trailers (instead of one) to hold all of the equipment; and
3. The optical sorter had to be recalibrated every time the trailer was moved.

Adjustments were made to the sorting system throughout the trials to improve quality of the sorted materials. Lessons learned at each test were applied to later tests, and results became more accurate.

Figure 1 depicts the mobile system as originally designed.

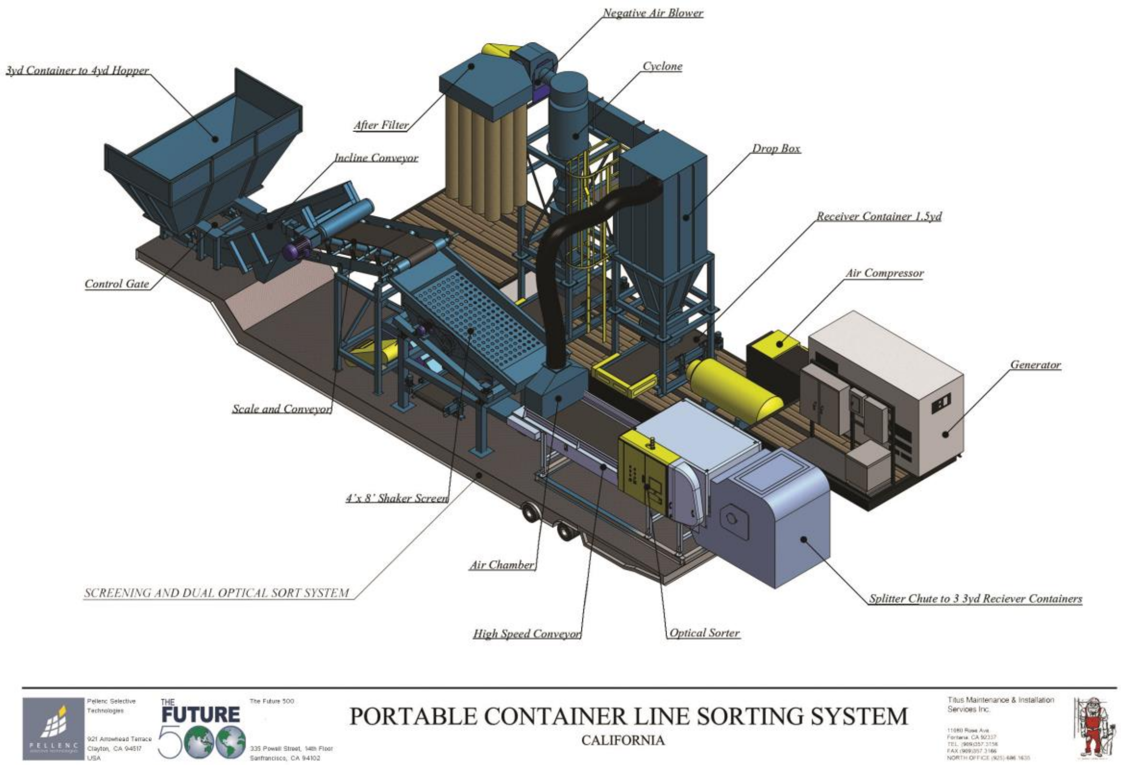


**Figure 1 - The Optical Sorting Equipment**

The optical scanning unit is a Pellenc Mistral Model M12-15T. The scanner reads the near-infra-red (NIR) signature of each container to identify its composition. The scanner scans the entire container, not just a single point, so it can properly identify containers even when they have labels or caps attached that are different material types, and can be "trained" to scan for different material types (plastic resins) and shapes (such as cups and clamshells as well as bottles).

Materials being sorted are fed from the pre-sorter onto a 46-inch-wide conveyor belt. A sensor in the scanning unit analyzes the material on the belt and inputs that information into a computer that determines how the material will be sorted (Figure 2).

**Figure 2 - The Optical Scanner**

Based on the scan, a computer sends a signal to a series of air jets. As each container comes off the end of the flat conveyor, it can be subjected to a blast of air pushing it up, blowing it down, or it can be allowed to continue on unimpeded (Figure 3).

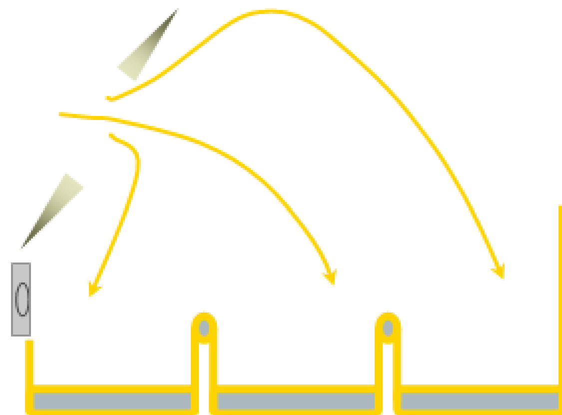

Figure 3 - Air Separations

Pellenc claims three features unique to its technology:

1. It uses reflected light rather than transmitted light.
2. It uses an advanced, patented spectrometer.
3. The distance from the optical reading to the air jets is very short, so there is less chance for a round container to move before being sorted.

Sorting problems may arise when the individual pieces are large and irregularly shaped, or when materials are stacked on the belt so that the scanner does not have a clear view of each item. Also, the round, unflattened bottles behave differently to bursts of air than do flattened bottles, so when individual containers are blown up or down they may bump into other containers, sending them where they are not supposed to go, and resulting in inaccurate sorting.

Since optical sorting devices currently in use are not able to accurately sort 100 percent of the PET in normal MRF operating conditions, processed materials may be run through the same equipment a second time, or through another optical sorter, to achieve a higher degree of separation.

The term “effectively separates” can be defined in both economic and technical terms. In economic terms the question is whether the cost of operating the system can be recovered from the higher market revenues achieved. (A cost-benefit analysis was beyond the scope of this project.) In technical terms, the question is whether an optical system can produce cleaner material for market than the systems commonly in use today. The answer to both questions can be yes, but there are many variables to consider.

One key element in the ability of reclaimers and their customers to use recovered PET in the production of new products is the amount and composition of contaminant materials. Most contaminants in PET loads (such as natural and colored high-density polyethylene (HDPE) containers) can be easily distinguished from PET. However, many PLA bottles are designed to have the same shape and color as PET, so they cannot easily be identified visually by workers. Checking the resin code on each bottle would be too time-consuming to be practical on an industrial scale.

If the non-PET bottles were shaped differently, or colorized, staff at the reclaimers would be able to quickly identify them as not being PET and the problem would be resolved. However, because the reclaimers do not control the marketplace, an alternative solution must be developed.

The alternative selected for this study was to test whether an optical sorting system, specifically designed with bioplastics in mind, could increase our ability to separate PET bottles from non-PET bottles.

Additionally, the effectiveness of the optical sorting system could be demonstrated if MRF operators were able to recover significant quantities of high-value plastic resins from materials that the MRF systems had sorted as lower-value mixed plastics. The recovery of high-value PET and HDPE from mixed plastics might be cost-effective, so that reprocessing materials may pay for itself and additional materials would be available for use in manufacturing new products in California.

# Testing Protocol

Two sets of tests were conducted during the project. The first testing set covered the period from June through November 2011, the second from June to July 2012. In the first set, materials from the Allan Company facilities in San Diego, Baldwin Park, and Glendale; the Burrtec facilities in Fontana and Riverside; the Sun Valley Paper Stock facility in Los Angeles; and the Republic Services facilities in Richmond and San Jose were processed through the optical system. The second round of tests were conducted at the Titus Services facility in Fontana.

The first set of optical sorter tests targeted five separate streams of materials from the MRF operations. Samples were obtained from each of the five streams after the materials had been sorted for market. None of these materials were baled. The optical sorter was tested on the following five streams:

1. **Sorted PET:** PET bottles that had been positively sorted from a MRF container line (i.e. separated from other materials by hand and/or machine into a dedicated PET bin). This stream was fed into the mobile system and processed by the optical technology to remove non-PET materials, especially PLA, that inadvertently had been separated into the PET bin by the MRF.
2. **Sorted HDPE:** HDPE containers positively sorted from a MRF container line. These were run through the optical sorting machinery to recover PLA and PET bottles that inadvertently had been sorted as HDPE, and to remove paper and other plastics from the HDPE.
3. **Sorted Mixed Plastics:** Mixed plastics (resin codes 3-7) separated from other materials by the MRFs either positively or negatively (i.e. allowed to fall into a bin after PET and HDPE had been removed). This stream was run through the optical sorting machinery to recover any PET and HDPE missed when the material was sorted initially, and to remove loose paper.
4. **Unsorted Mixed Containers:** Containers separated from fiber at the MRFs and transferred to a container sort-line for further separation. These containers were run through the optical sorting machinery to separate PET, PLA, and HDPE from all other material types.
5. **MRF Processing Residuals:** Contaminants and any containers remaining after desirable materials had been positively sorted at the MRFs from the mixed container stream. These residuals were run through the optical sorting machinery to recover PET, PLA, and HDPE that had been missed in the first sort.

The second set of tests only evaluated on the ability of the optical sorter to remove the PLA that was introduced into the samples from PET feedstocks. These tests did not test resorting of processed MRF materials.

# Testing Results

## *2011 Sorting Trials*

Six tests were conducted on the five materials streams from eight different MRFs. The tests were run on similar materials on different days of the week at these different MRFs to ensure that the widest possible range of materials were tested.

The data shown in the following tables are aggregate numbers for the total tests from the eight facilities. To maintain the confidentiality of the information gathered, and because the individual samples represent different program elements from community to community, detailed data by facility is not provided.

### Sorted PET

Material that had been positively sorted at the processing facilities into the PET bottle stream was reprocessed through the optical sorter. As shown in Table 1, an average of only 92 percent of the materials sorted to be PET was actually PET, about 3 percent was other types of plastic, 3 percent was either fines or lightweight materials, and the remaining 2 percent was “other” materials. Of the 6,325 pounds of material sorted to be PET, the optical sorter separated out only 19 PLA bottles (less than 3 pounds).

**Table 1: Sorted PET**

| Material | Pounds | % of Total |
|---|---|---|
| **<2 inches (Shaker screen)** | 151.5 | 2.4% |
| **Light Paper (Vacuum system)** | 30.3 | 0.5% |
| **PET** | 5,780.1 | 91.4% |
| **Metal and PLA** | 42.0 | 0.7% |
| **Other Plastics** | 202.7 | 3.2% |
| | | 98.1%* |

### Sorted HDPE

Materials that had been positively sorted as HDPE from other materials in the mixed container stream were processed to recover any PLA from that stream, and also to remove other material types that had been incorrectly sorted into the HDPE. As shown in Table 2, only 90 percent of the material processed to be HDPE was actually HDPE, about 1.5 percent was fines or lightweight materials, and about 7 percent was other plastic. Two PLA bottles were identified amid the 5,710 pounds of materials that had been sorted to be HDPE.

* Totals may not equal 100 percent due to rounding as well as yield loss in the sorting process.

### Table 2: Sorted HDPE

| Material | Pounds | % of Total |
|---|---|---|
| **<2 inches (Shaker screen)** | 66 | 1.2% |
| **Light Paper (Vacuum system)** | 16 | 0.3% |
| **HDPE** | 5,131 | 89.9% |
| **Metal and PLA** | 26 | 0.5% |
| **Other Plastics** | 414 | 7.3% |
| | | 99.0% |

### Sorted Mixed Plastics

Mixed plastics from the selected loads were resorted with the optical sorting machinery to remove any PET and HDPE that had been missed in the initial sort. As shown in Table 3, more than 40 percent of the materials in these samples were PET and HDPE (although the breakdown between PET and HDPE was not recorded), less than 30 percent of the total materials sorted was actually "other plastics," 2 percent was metal, and about 25 percent was trash. Of the 2,646 pounds sorted as mixed plastics, the optical sorter found 31 PLA bottles (about 4 pounds).

### Table 3: Sorted Mixed Plastics

| Material | Pounds | % of Total |
|---|---|---|
| **<2 inches (Shaker screen)** | 53 | 2.0% |
| **Light Paper (Vacuum system)** | 18 | 0.7% |
| **PET & HDPE** | 1,092 | 41.3% |
| **Other Plastics** | 767 | 28.9% |
| **Metal and PLA** | 13 | 0.5% |
| **Trash** | 653 | 24.7% |
| | | 98.0% |

### Unsorted Mixed Containers

Materials that had been separated from the fiber in the early stages of processing at the MRFs are sent to the mixed container sort line, where PET, HDPE, aluminum and steel are sorted from mixed "other plastics." As shown in Table 4, almost half of the materials on the mixed container sort line were fines, and only 5 percent of the materials on that line were plastic containers. A total of 10 PLA containers were identified in the unsorted mixed container line, all from one MRF. Of the plastics in the unsorted mixed plastics container line samples, the optical scanner identified PET as 36 percent of the plastics, HDPE as 30 percent, and "other plastic" containers as 34 percent in these loads.

**Table 4: Unsorted Mixed Containers**

| Material | Pounds | % of Total |
|---|---|---|
| **<2 inches (Shaker screen)** | 5961 | 44.3% |
| **Light Paper (Vacuum system)** | 550 | 4.1% |
| **PET & HDPE** | 669 | 5.0% |
| **Other Plastics** | 650 | 4.8% |
| **Metal and PLA** | 3276 | 24.4% |
| **Trash** | 2258 | 16.8% |
| | | 99.3% |

### MRF Processing Residuals

From 13,452 pounds of residuals from the MRFs that were processed through the optical sorter, only 18 PLA bottles (less than 3 pounds) were recovered. The total amount of plastic and metal containers in the residuals was less than 10 percent by weight.

### 2011 Testing Notes

During the 2011 MRF tests, a total of 6,325 pounds of materials that had been processed for sale as PET were processed through the optical sorter. From this total 6,207 pounds of materials were recovered, for a 2 percent yield loss, which is assumed to be liquid and dirt. Of the remaining materials, 92 percent was PET; 3 percent was fines and lightweight paper removed in the pre-sort; and 4 percent was other plastic and metal. From this entire sample, a total of only 19 PLA bottles (less than 3 pounds, or less than 0.05 percent) were recovered.

When CalRecycle originally awarded grant funds to Future 500, PLA bottles increasingly were entering the California marketplace and it appeared the trend was growing. The initial 2011 tests were designed with the assumption there would be sufficient numbers of PLA containers in the samples to confirm the ability of the optical sorting machinery to separate PLA from PET and other plastics. However, the testing revealed insufficient PLA in the sampled material to fully test the capabilities of the system. PLA bottles that were successfully separated from “other” materials by the optical sorting machinery were noted, but the trials did not provide sufficient information on whether some PLA might have inadvertently ended up in the “other” materials fractions. Further, the data provided to Future 500 about the sorting described how well the PLA was sorted from each stream, but did not fully identify how well the other materials were sorted from each other.

In response, the project team “seeded” additional samples in June and July 2012 with known quantities of PLA bottles, clamshells and cups before being sorted through the optical scanner, and tracked their recovery. The Cascadia Consulting Group was hired to monitor the testing and develop a report on the additional trials.

## *June 2012 Testing*

A total of nine samples from multiple MRFs were processed in 2012 to get clear data on the ability of the optical sorter to recover PLA from various materials streams. PLA bottles were added to the feedstock material for each of the three samples in the June 2012 testing (referred to as Performance Test 1 in the Cascadia Report); and various PLA products were added to each of the six samples that were tested in July 2012 (referred to as Performance Test 2 in the Cascadia Report). Each run of materials through the system could be sorted three ways: two positive sorts, where the air jets send the targeted materials either up or down, and a negative sort, where the materials continue unimpeded into a third bin (see Figure 3).

In the Performance Test 1 series, 50 PLA bottles were added to each sample of mixed plastics, before the loads were run through the optical scanner. Each sample was separated into three fractions in the First Run, and certain fractions were reprocessed in a Second Run to capture additional targeted materials. The results of these tests are provided in Table 5 and in the discussion that follows.

**Table 5: Performance Testing Series 1[†]**

| Seeded Material | Sample | First Run | Second Run | | Results (% of original 50 bottles) |
|---|---|---|---|---|---|
| **PLA Bottles** | Sample 1 | PLA+PET (+) | PLA+PET fraction | PLA (+) | 24.0% in PLA fraction |
| | | Paper (+) | | PET (+) | 10.0% in PET fraction |
| | | Other (-) | | Other (-) | 66.0% in Other fraction |
| | Sample 2 | PLA (+) | N/A | | 67.7% in PLA fraction |
| | | PET (+) | | | 11.1% in PET fraction |
| | | Other (-) | | | 21.2% in Other fraction |
| | Sample 3 | HDPE (+) | "Other" fraction | PLA (+) | 65.0% in PLA fraction |
| | | PET (+) | | PP (+) | 18.0% in PET fraction |
| | | Other (-) | | Other (-) | 16.0% in Other fraction |

In the first run of Sample 1, PLA and PET were separated as one fraction, paper as a second fraction, and "other" materials as the third fraction. Paper in the load can interfere with the scanner's ability to properly sort materials. The paper limits the ability of the sensors to see materials that are covered, and sheets of paper interfere with the ability of the air jets to move the containers to the desired sort bin. Because of the amount of paper in the load, only 17 of the 50 seeded PLA bottles were properly sorted into the PLA/PET fraction. Next, the PLA/PET fraction was resorted, and 12 of the 17 PLA bottles ended up in the PLA-only fraction. Thus, the system positively sorted only 24.0 percent of the original 50 PLA bottles in Sample 1.

† A positive sort is indicated with a + symbol, and a negative sort is indicated with a – symbol.

In Sample 2, PLA bottles were sorted as one fraction, PET bottles as another fraction, and “other” materials as the third fraction. None of the fractions were resorted. The scanner correctly sorted 34 of the 50 PLA bottles (68 percent) into the PLA stream, 5 bottles were ejected with the PET, and 11 PLA bottles ended up in the “other” fraction.

In the first run of Sample 3, HDPE was sorted as one fraction, PET was separated as the second fraction, and all “other” materials were the third fraction. This resulted in 9 of the 50 PLA bottles (18 percent) ending up in the PET fraction with the remaining 41 bottles sorted into the “other” fraction. In the second run, the “other” materials were positively sorted into polypropylene (PP) and PLA fractions, with a negative sort for “other” materials. In this run, 33 of the 41 remaining PLA bottles ended up in the PLA fraction, with the final eight PLA bottles (16 percent) ejected along with the “other” materials. Thus, the system positively sorted 65 percent of the original 50 PLA bottles into a final PLA-only fraction.

Between each of the three sample runs, the machine operators made adjustments to the optical scanner to improve the quality of the results.

Based on general observations of the optical sorting machinery in action, it appears that the poor results in the June 2012 series of tests were due to the two positive-sort feature with the air jets pushing some containers upward and others downward; the irregular shape (some flattened, some round) of the containers caused them to not always respond the same way and causing some to bump into others, and thus end up in the wrong compartment. It is likely that this low recovery rate in Sample 1 was related to the interference resulting from a positive sort for paper.

None of the Sample 1-3 tests were considered to have demonstrated the capabilities of the optical sorter to achieve the project goals, so additional testing was scheduled.

### *July 2012 Testing*

Based on the June 2012 test observations, much larger quantities of PLA were added to the July 2012 samples, and some of the sorts were to be run as two-way (positive/negative) sorts instead of three-way sorts. Observations were to be made of where all of the PLA ended up, instead of only tracking the positive sort PLA stream.

The final six samples, (referred to as Performance Test 2 in the Cascadia Report) were run in July 2012. In Samples 4-6, much larger numbers of PLA bottles were added to three samples to be processed.

- Sample 4: 163 bottles were added
- Sample 5: 163 bottles were added
- Sample 6: 159 bottles were added

*[NOTE: it is likely that the four PLA bottles missing from Sample 6 were lost into the “other materials” fraction sorted in Sample 5]*

In Samples 7 through 9, in addition to PLA bottles, PLA cups and PLA clamshells were added to the feedstock materials. Samples 7 through 9 were seeded as follows:

- Sample 7: 120 bottles, 61 cups, 47 clamshells; total 228 pieces
- Sample 8: 125 bottles, 69 cups, 55 clamshells; total 249 pieces
- Sample 9: 124 bottles, 70 cups, 59 clamshells; total 253 pieces

Four of the six sample runs in these two series were two-way sorts, instead of the three-way sorts, to determine whether better results and cleaner streams of materials could be achieved with this methodology. The results of the July 2012 tests are provided in Table 6.

**Table 6: Performance Testing Series 2**

<table>
<tr><th>Seeded Material</th><th>Sample</th><th>First Run</th><th colspan="2">Second Run</th><th>Results (% of original total seeded PLA items)</th></tr>
<tr><td rowspan="7">PLA Bottles</td><td rowspan="2">Sample 4</td><td>PLA+PET (+)</td><td colspan="2" rowspan="2">N/A</td><td rowspan="2">97.5% in PLA fraction</td></tr>
<tr><td>Other (-)</td></tr>
<tr><td rowspan="2">Sample 5</td><td>PET (+)</td><td rowspan="2">“Other” fraction</td><td>PLA (+)</td><td>87.7% in PLA fraction</td></tr>
<tr><td>Other (-)</td><td>Other (-)</td><td>8.6% in PET fraction</td></tr>
<tr><td rowspan="3">Sample 6</td><td>PLA (+)</td><td colspan="2" rowspan="3">N/A</td><td>88.7% in PLA fraction</td></tr>
<tr><td>PET (+)</td><td>2.5% in PET fraction</td></tr>
<tr><td>Other (-)</td><td>8.8% in Other</td></tr>
<tr><td rowspan="7">PLA bottles, cups, and clamshells</td><td rowspan="2">Sample 7</td><td>PLA (+)</td><td colspan="2" rowspan="2">N/A</td><td rowspan="2">99.6% in PLA fraction</td></tr>
<tr><td>Other (-)</td></tr>
<tr><td rowspan="2">Sample 8</td><td>PET (+)</td><td rowspan="2">“Other” fraction</td><td>PLA (+)</td><td>87.6% in PLA fraction</td></tr>
<tr><td>Other (-)</td><td>Other (-)</td><td>12.4% in PET fraction</td></tr>
<tr><td rowspan="3">Sample 9</td><td>PLA (+)</td><td colspan="2" rowspan="3">N/A</td><td>92.5% in PLA fraction</td></tr>
<tr><td>PET (+)</td><td>0.9% in PET fraction</td></tr>
<tr><td>Other (-)</td><td>6.6% in Other</td></tr>
</table>

Sample 4 was sorted into two fractions, PLA and “other” materials, and properly recovered 97.5 percent (159 of 163) of the PLA bottles in the sample. The other 2.5 percent (4 of 163) of the PLA bottles were sorted into the “other” materials fraction.

Sample 5 was first sorted to separate PET bottles from all “other” materials, and then the “other” fraction was sorted to separate PLA from all remaining “other” materials. About 88 percent (144 of 163 bottles) of the PLA was correctly sorted into the PLA fraction in the first run, with about 9 percent (14 of 163 bottles) sorted into the PET fraction. The remaining 5 PLA bottles were sorted into the “other” materials fraction in the second run.

Sample 6 was sorted only once, into PLA, PET and “other” fractions. In this sample, about 89 percent (138 of 159) of the PLA bottles were correctly sorted into the PLA fraction, less that 3 percent wound up in the PET fraction, with the remainder ending up in the “other” fraction.

While Sample 5 and Sample 6 both correctly recovered about the same percentage of the available PLA bottles, by first sorting only for PET and “other” in the first run, more of the PLA bottles ended up in the PET stream from Sample 5.

Sample 7 was sorted into only two fractions, to separate PLA bottles, cups, and clamshells from “other” materials, and 99.6 percent of the total PLA products were correctly sorted. This sort achieved the best results of all of the tests that were run.

Sample 8 was sorted into two fractions to separate PET from “other” materials in the first run, and then the “other” materials fraction was sorted to separate PLA from “other” materials. The first run resulted in 12 percent of the total PLA bottles, cups, and clamshells sorted into the PET fraction. In the second run, the sorter correctly separated all of the remaining PLA bottles, cups, and clamshells into the PLA fraction. Thus, in Sample 8 about 88 percent of PLA items were sorted into the correct fraction.

Sample 9 was sorted once to separate out PLA, PET and “other” fractions. More than 92 percent of the PLA bottles, cups, and clamshells were correctly sorted into PLA stream, while less than 1 percent ended up in the PET fraction; about 7 percent of the remaining PLA was sorted into the “other” fraction.

### 2012 Testing Notes

When PLA is present in any of the product forms tested, the optical scanner can identify it in the mix of plastics. Under the most favorable operating conditions, a sorting accuracy rate of 99.6 percent was achieved in one run, although additional runs with the same settings were not conducted. Less favorable results were achieved when the incoming materials were sorted into three fractions than when they were sorted two ways.

Although it was not done as part of the testing protocols, it seems likely that if the materials recovered as PET in Samples 5, 6, 8 and 9 had been run through the scanner again, most if not all of the PLA would have been separated from the PET.

While not formally part of this project, CalRecycle supplied the team with some prototype bottles for sorting made from a polymer in the polyhydroxyalkanoate (PHA) family. This bioplastic exhibits a scanner “signature” similar to PLA. To test whether the optical system could separately distinguish PHA, the team introduced the bottles into the system for one run in 2012, for general information only. Anecdotally it appears the Pellenc system would be able to separate this bioplastic as well, though a rigorous analysis was not conducted.

## *PET Reclaimer Residuals*

In addition to the testing of samples provided by MRFs from around the state, Pellenc and Titus tested the sorter on samples provided by three Southern California PET reclaimers to determine whether contaminants could be removed from the "clean" PET that the reclaimers had purchased, and to determine if additional PET could be recovered from the reclaimers' residuals stream.

In June 2012 the optical sorter was tested on "clean" PET and processing residuals from the Global PET facility in Perris; and in August 2012 the sorter was tested on PET processing residuals from the CarbonLite PET recycling facility in Riverside and the Repet facility in Chino to see if they would be able to recover additional PET from the residuals without reintroducing PLA bottles into the PET recycling stream.

PLA and other contaminants (including HDPE, a contaminant in PET processing) were successfully separated from the PET, and some additional recyclable materials were recovered from the reclaimer residuals. However, detailed data from those sorts are not available to the authors of this report because of confidentiality agreements between the reclaimers and the sorter operators.

# Optical Sorting Effectiveness

The four questions laid out in the “Study Goals” section above were answered by this research project.

1. *Can the optical sorting system effectively separate PLA bottles from PET bottles, so that clean PET would continue to be available to PET reclaimers?*

Discussion

The primary purpose of the bioplastics project was to determine if optical sorting could be expected to provide some certainty that, if PLA bottles were introduced into the marketplace in significant quantities, MRF operators would still be able to produce clean PET for recycling.

In the first phase of testing, samples of PET that had been recovered from the mixed container sort lines from eight MRFs around the state were reprocessed. On average, more than 8 percent of the processed materials were found to not be PET and were removed from the samples.

Conclusion

The optical scanner was able to remove non-PET materials, including PLA, from “clean” PET bottles, producing a higher value PET for recycling.

2. *Can the optical sorting system effectively separate PLA from other materials, so that PLA products could be recovered for recycling?*

Discussion

The results from Sample 7 showed that when the machinery is set to separate only PLA from “other” materials, it can achieve a 99.6 percent recovery rate. Less favorable results were achieved when the incoming materials are sorted into three fractions.

Conclusion

Based on limited test results, the optical system is capable of separating PLA bottles only, or a variety of PLA products (including bottles, cups, and clamshells) from all other mixed containers at MRFs. Separating PLA will allow it to be recovered for further processing into new PLA products, when dedicated facilities are in place. However, some stakeholders doubted whether this high recovery rate could be achieved consistently over time. This study did not attempt to measure the economic feasibility of consistently achieving a high separation rate.

3. *Can the optical sorting system effectively separate other (non-bottle) PLA products, especially cups and food service items, from a mixed plastics stream?*

Discussion

The 2011 computer sensor records show almost no PLA passed under the scanner, indicating that the optical sorter did not fail to separate PLA. In 2012, known quantities of PLA containers, cups, and clamshells were added to the samples being tested.

The sorter successfully separated non-PET materials, including PLA, from PET and separated PET and HDPE from loads of mixed plastics.

Additionally, as seen in the test results for Sample 7 run in July 2012, more than 99 percent of the 120 PLA bottles, 61 cups, and 47 clamshells (a total of 228 pieces) were properly separated by the sorter from a mixed container stream.

Conclusion

The testing of the optical sorting system has demonstrated that it is capable of improving the quality of materials coming out of MRFs. The results of sorting a mix of PLA products from mixed containers showed that the optical sorter can identify PLA when it is present in any of the product forms tested, and separate it from other products. The results from Sample 7 showed that when the machinery is set to separate only the PLA from "other" materials it can achieve a 99.6 percent recovery rate. Once again, however, some stakeholders doubted whether this high recovery rate could be achieved consistently over time. This study did not attempt to measure the economic feasibility of consistently achieving a high separation rate.

4. *Can the optical sorting system effectively separate various other types of plastics from each other, from a pre-sorted mixed plastics stream?*

Discussion

The optical sorter was used to rerun sorted mixed plastics that were left after the higher value PET and HDPE were removed in the container sort lines in standard MRF operations. More than 40 percent of the materials in these sorted mixed plastics loads were PET and HDPE that had not been recovered by the MRF operation, and could be recovered using the optical system.

Conclusion

Recovery of this additional PET and HDPE from the mixed plastics stream may not increase the overall recycling rate in California since these materials are already being counted as recovered as mixed plastics, and may well be being high-graded in China where most of our mixed plastics are currently being shipped. However, an important benefit to recovering them in California is that more materials may be used in manufacturing new products in the state if the materials are locally processed to a higher level of quality.

Reprocessing the sorted mixed plastics stream through optical scanners can direct more materials to high-value markets, and provide additional revenue to MRF operators. It is possible that the additional revenue from the sale of the PET and HDPE will pay for the cost of this additional processing.

# Summary of Findings

- The Pellenc/Titus optical system is capable of removing many types of contaminants from PET loads previously sorted at the MRF, increasing the quality of marketed PET. More than 8 percent of the materials in loads sorted by the MRFs as “clean” PET bottles were found to be other plastics.
- The optical system is capable of separating PLA bottles only, or mixed PLA bottles, cups, and clamshells from all other mixed containers at a MRF. Separating PLA will allow it to be recovered for further processing into new PLA products, when appropriate facilities are in place. The results from Sample 7 showed that when the machinery is set to separate only PLA from “other” materials, it can achieve a 99.6 percent recovery rate. However, no attempt was made to repeat this high separation rate, and some stakeholders doubted whether this high recovery rate could be achieved consistently over time. This study did not attempt to measure the economic feasibility of consistently achieving a high separation rate. Less favorable results were achieved when the incoming materials were sorted into three fractions.
- The optical system is capable of separating multiple plastic resins from each other to produce higher-value marketable materials from mixed plastic containers inadequately sorted at the MRF.
- The optical system is capable of recovering high-value plastics (notably PET and HDPE) from the sorted mixed plastics stream as currently sold by the MRFs, potentially offering an additional revenue stream for recovery facilities.

# Conclusions and Recommendations

The bioplastics sorting project demonstrated the Pellenc/Titus mobile optical sorting system can add value to recovered plastics by removing contaminants and redirecting traditional and non-traditional materials to their appropriate markets. Overall recovery rates for PET and HDPE could be increased by efficient use of this technology. A system of this type also could be used to positively sort PLA for recycling, addressing a major challenge as bioplastic packaging grows in market share.

Additionally, reprocessing the sorted mixed plastics stream (resin codes 3-7) through optical scanners can make more materials available to high-value markets, and may provide additional revenue to MRF operators. Although a complete cost-benefit analysis was beyond the scope of this project, it is possible the revenue from the sale of additional PET and HDPE recovered would pay for the cost of this secondary processing.

Recovery rates can be increased by running materials through the sorting system more than once, or by running loads through a second sorting machine. Realistically, sorting more than once is not likely to happen at most MRFs due to throughput and economic constraints. But it may be advantageous for reclaimers to install such an optical sorting system because they already have to re-sort the PET they purchase to ensure it meets their quality requirements. In the resorting process, reclaimers lose desirable material, and revenue, that is inadvertently sorted into their residuals.

While the sorting trials demonstrate the *potential* for improved recovery of materials, more research is needed to narrow the factors that affect actual performance in day-to-day operations. The project team's collective experience in the industry suggests multiple variables can affect both recovery rates and the quality of materials produced when deploying an optical system. The equipment must be properly calibrated and/or conditions modified to achieve optimal results. Variables include:

- The loading of the system feed belts
- The number of sorts being performed each time the machine is run
- The composition of incoming materials
- The amount of the material to be separated as a percent of the total amount of material processed
- Splitting of incoming material into two or three fractions
- How effectively the materials were initially processed
- Space constraints at the processing facility
- Cost of labor

Stakeholder engagement was a fundamental component of this project. From the start, Future 500 communicated with groups and companies with a vested stake in improving recovery of bioplastics and recycling in California in general. The project team held a stakeholders meeting in October 2012 to discuss the sorting results and to solicit technical and policy recommendations. The participants addressed several key questions, including:

- *What are the data gaps? Are additional sorts needed to fill the data gaps? Do we need to evaluate additional infrastructure and equipment pilots?*
- *What should be the role of state policy in moving forward?*
- *What materials could be added to recycling programs to increase recycling?*
- *What is needed to a) capture cleaner PET; and b) divert more PET and HDPE from mixed plastics?*
- *What is the role of optical sorting in helping to achieve a statewide 75% recycling goal?*

Some stakeholders, especially those processing PET, feel that PLA cannot be sorted out effectively despite improved technology. They believe PLA will continue to contaminate PET feedstocks and compromise existing recycling systems. Nevertheless, the workshop generated a number of policy suggestions to explore in legislation or by other means, including various ways to incentivize improved sorting and higher recovery:

- Participants suggested several regional “intermediate” processing facilities located throughout the state may be the most cost-effective way to process mixed materials through an optical sorting system.
- The state should consider re-implementing a plastics "Quality Incentive Payment" for facilities which market materials that meet certain quality standards. The bar would need to be set high enough so California processors could capture the incentive payment to better compete with foreign buyers, but low enough to make it achievable.
- Currently the “glass-cleaning regulation” (Public Resources Code §2425h) allows CRV claims on glass material with greater than 10%contamination, if the processor cleans the glass to ASTM specifications for glass container manufacture. A similar approach could be applied to PET and HDPE, creating an incentive to improve sorting methods.
- MRF performance standards could be established to reduce contamination in recovered plastics shipped to market.
- Higher CRV processing payments would help pull smaller-volume bottles and containers from the waste stream and provide revenue for improved recovery.
- The Plastic Market Development Payment (PMDP) program, which pays California processors and manufacturers a premium for using recycled plastics in-state, could be expanded.
- Stricter enforcement of the Rigid Plastic Packaging Container (RPPC) regulations may help ensure cleaner streams and improved plastic recovery; some participants stated the HDPE reclaiming industry in California became established largely because of such policies.
- Design for Recyclability (DfR) guidelines would help assure end-of-life considerations as part of initial packaging design. DfR could be tied to the CRV program, so manufacturers’ CRV payments would be higher if the containers don’t meet the recyclability guidelines.
- California could increase minimum recycled-content requirements for selected resins.

# Abbreviations and Acronyms

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| | |
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| HDPE | High density polyethylene |
| LDPE | Low density polyethylene |
| MRF | Materials Recovery Facility |
| PET | Polyethylene Terephthalate |
| PHA | Polyhydroxyalkanoate |
| PLA | Polylactic acid |
| PP | Polypropylene |

# Glossary of Terms

Bioplastic — As used in this report, a form of plastic made from plant based materials.

Materials Recovery Facility (or MRF) — A facility where materials that are collected mixed together are sorted for sale as commodities, and contaminants are removed from the commodities.

Negative Sort — Sorting of materials where the desired items are not directly separated from other materials on the sort line, but allowed to continue unimpeded into a separate bin at the end of the line.

Positive Sort — Sorting of materials where the desired items are sorted or separated out from the primary stream.

Reclaimer — A facility that processes plastics to add further value, typically by separating, removing contaminants, reducing in size (creating pellets or flakes), and washing the plastics. Reclaiming occurs after materials recovery facility processing and before manufacturing final products.

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