



Working Paper - Markets and Sorting Assessment

Oregon Plastics Recovery Assessment

April 2014

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Section 1: Introduction

This report was produced by a project team composed led by Reclay StewardEdge, with support from Cascadia Consulting Group. This report:

- Provides a summary of recycling markets for recovered plastics to understand better what markets are currently available and what plastics types are currently recyclable by today's market standards;
- Provides a comprehensive summary of recovery markets that non-recycled plastics can be directed to for conversion into energy or chemicals;
- Identifies available commercial and pre-commercial technologies for sorting plastics into materials market categories either at a materials recovery facility (MRF), a plastics recycling facility (PRF) or at a reprocessing/reclamation operation.

Section 2: Overview of Recycling Markets

Overview of Existing Recycling Markets

This section discusses recycling markets with a focus on Oregon, but including a general discussion of markets throughout the Pacific Northwest and the U.S.. Table 1 shows estimates of the amount of Oregon plastics that are collected for recycling in Oregon in three large categories that are reported by DEQ.

Table 1 Plastics Recycling in Oregon (2012)

Plastics Type	Recycling (tons)
Rigid plastic containers	29,541
Plastic film	14,869
Plastic other	10,992
Total plastic recycled	55,332

These materials are sorted by MRFs, collectors of recyclable materials, and generators (especially in the case of film plastics), and sent to reclaimers in the Northwest (including British Columbia and Alberta), California, Nevada, and as far away as Florida, as well as exporting plastics to Asia.

Oregon Markets

Oregon plastics reclaimers recycle approximately 30 million pounds per year (15,000 tons), or approximately 25 percent of Oregon plastics that currently are collected for recycling. These reclaimers have the ability to recycle far more plastics than they currently process. Following is a summary of these Oregon reclaimers and the materials they process:

- **Agri-Plas**, Brooks, OR – contractor for the Ag Container Recycling Council for ID, OR, WA. Recycles many forms of agricultural plastics, including triple-rinsed agricultural pesticide containers, agricultural/industrial film, woven PP seed bags, PET strapping, bale twine, drip tape, and plant pots. Resins handled are primarily polyethylene and polypropylene. Does not accept plastics that is heavily contaminated with soil or organic materials
- **Denton Plastics**, Portland OR – primarily recycles clean post-commercial materials with a focus on polypropylene and polyethylene. Processes and densifies film. Also recycles polystyrene and engineering resins such as ABS.
- **Northwest Polymers**, Molalla, OR. Only process plastics from commercial and industrial businesses that have manufacturing scrap, or post-use crates, bins, pipes, etc. Also recycle PVC window manufacturing scrap.
- **ORPET**, Warren, OR – Primarily grinds and washes deposit PET bottles from Oregon. Supplements with small amounts of PET bottles from Oregon residential curbside programs.

Northwest Region Markets

- **Epic Plastics**, Lodi, CA – reclaims polyethylene and polypropylene plastic bottles.
- **Merlin Plastics**, Calgary, Alberta – grinds and washes PET bottles.
- **Merlin Plastics**, Delta, British Columbia – reclaimer for segregated bales of HDPE bottles, L(L)DPE, PP, PVC bottles, non-bottle containers (injection grade), and clean polyethylene film.
- **Peninsula Plastics**, Turlock, CA – Grinds and washes PET bottles.
- **Trex**, Fernley, NV – Recycles polyethylene film plastics into decking materials.

Export Markets

Oregon has one container terminal in Portland for exporting plastics. The freight lines that service this terminal are limited in the destinations they ship to, with limited services to two ports in mainland China, Korea, Japan, Central America, and through the Panama Canal to Europe. Much more flexibility for containerized cargo is available through container ports in Seattle and Tacoma.

Most of the mixed and contaminated plastics from Oregon is sent to export markets for further sorting and recycling. This includes mixed residential rigid containers, such as pre-picked bales where PET and HDPE bottles have been removed and the remainder baled together. MRF film and lower grades of mixed film is also sent to export markets for recycling.

While markets for plastic bottles have been steady, mixed rigids and MRF film have been more difficult to move, largely as a result of China's Green Fence initiative to improve the quality of materials being imported into that country and develop its own internal recycling collection infrastructure. The in-practice change in specifications for what is allowed into China has resulted in a back-up of material at handling facilities in Oregon. This material is moving slowly to alternative markets in India, Malaysia, and Vietnam. However, material from Europe and other countries and U.S. states is flowing to these same alternative markets and there is not sufficient capacity to handle all of the material. Furthermore, many of the alternative Asian markets are sorting and upgrading what is being to them and then sending the material on to China as single-resin commodities that will pass customs import requirements.

Market Specifications and Quality

Ultimate consumers of recycled plastics need plastics to be sorted by resin and grade –fractional melt polyethylene suitable for profile extrusion is one example. The ultimate manufacturers of recycled content products normally only make their products from one or two resin grades. They either need upstream suppliers to sort and reclaim the plastics for them, or if they are integrated into both reclamation and product manufacturing, they only purchase very specific bales of sorted plastics from MRFs and/or commercial generators who have large volumes of plastic discards.

Markets dictate quality standards and specifications based on their technological and economic ability to produce a recycled resin that performs as a cost-effective alternative to other sources of resin supply. Any decision regarding collection systems or investments in markets, therefore, needs to be based on whether the system can supply recycled resin that is a cost-effective alternative to other material sources including pre-consumer manufacturing scrap and virgin plastics.

China's Green Fence has had a large impact on prices and acceptable contamination, especially for film grades and mixed plastics bales. China is taking fewer grades directly now (e.g., mixed resin bales and bales with non-plastic contaminants are not being imported), but prices for acceptable grades that can be imported into China are fairly strong now. Prices for mixed and lower-quality bales dropped as a result of the Green Fence and have rebounded somewhat, but are not expected to climb to previous levels. Given the fundamental reasons for why China implemented Green Fence, it is expected that the initiative will have a permanent stimulus to improve the quality of mixed plastics sent for export from the U.S., and an ongoing diminished price for contaminated materials that require intermediate sorting in third countries before ultimately making their way into the Chinese marketplace.

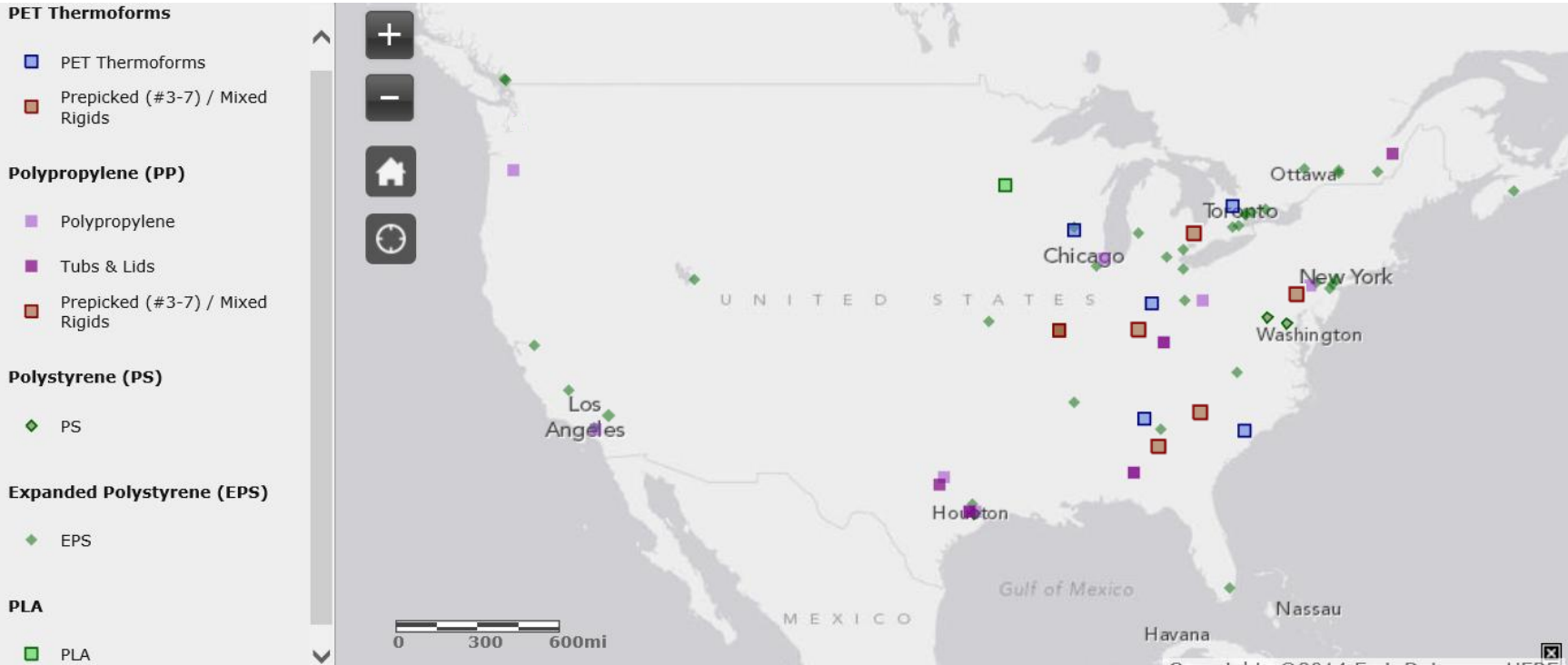
Some post-consumer plastics have very limited reclamation markets, with little or no U.S. market demand. Materials that are challenged in terms of reclamation markets include PVC packaging, metallized film (film chip bags), multi-layer film, compostable/degradable plastics, and electronics plastics with brominated flame retardants, and plastics from durable goods that are shredded to separate metals from plastics and other materials.

In summary, the primary challenges to plastics recycling markets are receiving contaminated materials, lack of infrastructure for sorting mixed plastics in the Northwest, cost-effectiveness of sorting of resins, high trucking and shipping costs, ensuring that suppliers are representing what they are selling accurately, and questions over whether lower-grade plastics have sufficient intrinsic value, especially compared to alternative sources of supply, to be cost-effectively recycled.

Market Options for Mixed Plastics and Minor Resins

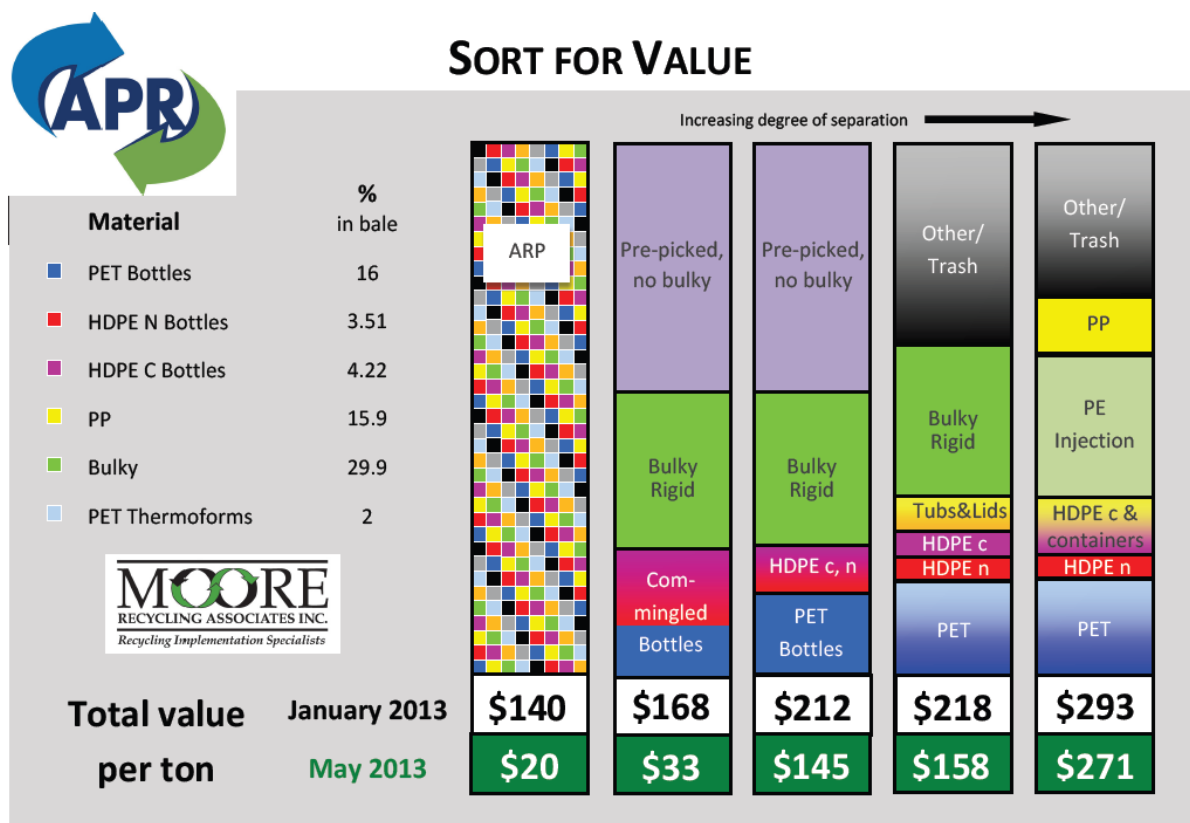
Figure 1 shows emerging domestic plastics markets for plastics materials like PET thermoforms and mixed grades of plastics. As the figure shows, there are virtually no markets for these grades in the Northwest.

Figure 1 Emerging US Plastics Markets



No one can predict if China's Green fence will be loosened and if higher bale prices and market flexibility to ship mixed materials directly to China will return. Therefore, if increasing quantities of plastics are to be diverted from disposal in Oregon to recycling markets, consideration should be given to investments in the state to sort a broader array of plastics for domestic market specifications and market value. Figure 2 below shows the market value matrix of sorted market grades for domestic recycling markets.

Figure 2 Sort for Value Matrix



As the figure shows, as more plastics sorts are performed, the market value of the collected plastics increases significantly. Market price stability and the ability to consistently ship material regardless of market conditions are also benefits. The May 2013 pricing values in the figure depict the time period when the impact of Green Fence on markets was the most intense.

Section 3: Overview of Recovery Options

Recovery Options

Introduction

Recovery options include processes that convert material resources into energy or chemicals, rather than return them to use as a polymer. Recovery options are less desired than recycling because they do not utilize the highest and best use of the material properties of the polymers. However, recovery

options are preferred to loss of the resources through landfill disposal if those materials otherwise would not be recycled for technical or economic reasons.

The following recovery options are discussed in this section:

- Pyrolysis;
- Gasification;
- Engineered Fuel;
- Industrial Use; and
- Waste-to-Energy.

The discussion of each recovery option includes a description of the technology, a summary of the market status including general U.S. description and specific opportunities in Oregon and Washington, and a summary of specifications and order of magnitude financial costs. The end of this section also includes a table that provides a comprehensive list of potential recovery markets for plastics from Oregon.

Pyrolysis

Technology Description: Pyrolysis is a high temperature (350 - 800°C) low-oxygen processes that breaks plastics down to short-chain hydrocarbons without burning them, unlike regular combustion that requires an oxygen-rich environment for combustion. Most pyrolysis systems have been developed primarily to treat otherwise non-recycled plastic waste streams, although pyrolysis can treat rubber (e.g., car tires), organic materials, and mixed municipal solid waste. Products of pyrolysis include a gaseous fraction (that may be collected and combusted with oxygen to provide heat to fuel the pyrolysis process), liquid crude-like oils, waxes, metals (if material processed contains metals), and a sludge and/or carbon char. There are a number of technology vendors who are developing competing technologies that may yield varying amounts of the product streams listed, based on differences in process conditions, use of catalysts, and feedstock accepted. The primary product marketed by plastics pyrolysis companies in North America is crude-like oils, which average 80-90 percent of system output.¹ This oil is normally sent to a refinery where it is refined and blended with other refinery products.

Market Status: Reclay StewardEdge is aware of four plants in the United States that are currently operating on a commercial-scale ongoing basis to process plastics as follows:

- WM Agilyx Wastech, Portland, OR - 40 tons per day capacity, 14,225 tons per year by permit, with plant operations contracted to Agilyx Corporation.
- Rational Energies, Plymouth, MN, 40 tons per day facility using Agilyx's technology.
- GenAgain Technologies, Lithia Springs, GA , 40 tons per day facility using Agilyx's technology.
- Plastic2Oil LLC (JBI Inc.), Niagara Falls, NY, 30 tons per day facility (estimated), with their own technology.

The above plants began operating in the last three years. There are a number of smaller research and development/demonstration facilities that operate for small periods of time. Several other commercial-scale plastics pyrolysis facilities that have been announced and are in various states of development or seeking financing. This technology can be considered to be on the cusp of being commercialized if the merchant commercial plants listed above prove economically viable over the long run.

¹ "Conversion Technology: A complement To Plastic Recycling," 4R Sustainability Inc., April 2011.

Specifications and Financial: Pyrolysis technologies are able to accept mixed unsorted plastic resins, including multi-layer films, metalized/coated film, and plastics with contamination from food, dirt, and paper residues. Pyrolysis facilities, however, seek polyolefin resins and engineering grade resins as they provide the highest yield. PET and PVC can be processed but are not desired because of the low yield of product oil. Furthermore, pyrolysis of PVC and PVDC results in organic chlorides in the product oil or production of hydrochloric acid, which requires further treatment of the product. Pyrolysis facilities generally request that a good faith effort be made to exclude chlorinated resins, but that such materials can be handled by pyrolysis systems at normal levels found in packaging waste streams. Business models for pyrolysis facilities are based on obtaining non-recycled plastic at little or no cost.² This generally means that they will not source material from long distances because of the freight cost involved, nor will they normally pay a market value for plastic.

Gasification

Technology Description: Gasification is similar to pyrolysis in that it treats waste in an elevated temperature low oxygen environment so that plastics break down without burning. Like pyrolysis, gasification can process either mixed municipal solid waste (MSW) or separated plastics. Gasification operates at a higher range than pyrolysis, typically 800 - 1200°C, and often includes the introduction of controlled amounts of oxygen and steam so that the material fully decomposes into synthesis gas (syngas) made up of hydrogen and carbon monoxide and ash or slag byproducts. Hydrogen syngas that is produced is utilized may be used as a renewable replacement for natural gas for heat production and electrical power generation. Syngases can also be collected and converted into methanol, ethanol, and other chemicals.

Market Status: Different technologies have been developed to handle various waste inputs for gasification, but they can be generally divided into thermal technologies and plasma arc technologies. Plasma arc uses an electric arc to heat the waste to extremely high temperatures, whereas thermal gasification technologies combust fuels to produce the heat needed in the gasification module. Like the development of pyrolysis, gasification technologies are just entering the commercialized stage of development. At the time of this report there were five plants operating in North America to gasify solid waste materials, four in the United States and one in Canada. All of the U.S. plants were demonstration scale facilities, or were designed at a smaller scale for industrial process waste streams – three of the plants use plasma arc gasification technology. One of the five U.S. plants, the largest at 40,000 tons per year is located in Dalton, Georgia, where it gasifies post-consumer carpet (composed of a mixture of plastic resins). In Oregon, InEnTec Columbia Ridge LLC operates a plasma gasifier at the Columbia Ridge landfill, where it can gasify up to 9,125 tons per year of solid waste. The first large scale plant began operations in the spring of 2014 in Edmonton, Alberta, Canada, processing up to 110,000 tons per year of residual waste (including non-recycled plastics) that remains after mixed MSW has been processed to remove recyclable and compostable materials.

Specifications and Financial: Gasification facilities can process a wide variety of plastics (including PVC) and are often designed to process refuse derived fuel after mixed municipal solid waste has been processed to remove recyclables. One of the existing industrial gasification facilities was specifically designed to process chlorinated compounds, such as PVC. Cost data is difficult to obtain because plants

² Ibid.

are either operated by developers as demonstration facilities or for in-house industrial waste treatment. Estimates provided by technology vendors indicate the cost to process the waste is approximately \$50 per short ton,³ which depends on the cost of electricity or fuel required to run the process and amount of pre-processing of waste that is needed. Edmonton and Ottawa plants in Canada are being developed under long-term municipal contracts to process municipal solid waste, and cost data is publicly available – the Edmonton plant will charge tip fees of CAN \$75 per tonne and the Ottawa plant will charge CAN \$83.25 per tonne. According to the City of Edmonton, its contract terms require that any other suppliers of material to the facility must be charged a fee higher than what the city pays, even if it were baled non-recycled plastics.

Engineered Fuel

Technology Description: Mixed plastics and organic material, such as paper, are processed to remove unsuitable materials (or selectively sourced), size-reduced to a consistent particle size, and then most commonly agglomerated or pressed into uniform pellets or cubes. The pellets are then sold as fuel for industrial boilers, power generation plants, and cement kilns where they supplement and partially replace primary solid fuels including coal, wood/biomass, and petroleum coke. In some cases the fuel is not pelletized and is sold in loose form. The use of loose unpelletized fuel is discussed in the following section on Industrial Uses.

Market Status: Reclay StewardEdge has identified seven commercial-scale facilities in operation in the United States that utilize scrap plastics and paper to manufacture solid fuel pellets (there are many more that make fuel pellets from clean wood waste). Three of these facilities process municipal solid waste to remove and recycle materials for recycling, remove and dispose of PVC, and use the nonrecycled paper and plastics in the waste to make their pellets. The others primarily use material that has been diverted from the commercial and industrial waste stream such as paper and plastics converting waste for their pellets. Increasingly, however, pellet producers also are investigating using MRF residuals to produce a fuel pellet. Waste Management Inc. has a small pilot fuel pellet plant in San Antonio Texas and a large commercial scale facility to process MSW in Philadelphia, Pennsylvania. There are no fuel pellet facilities in the Pacific Northwest.

Specifications and Financial: For product consistency, certificate of approval/permit limitations (for both themselves and their customers), and pollution control reasons manufacturers need to produce consistent product in terms of pellet size, moisture content, Btu value, non-combustible contaminants, and exclusion of materials that can release combustion pollutants. Fuel pellet producers do not typically accept PVC items above *de minimus* levels and some facilities prefer not to receive metallized film (e.g., potato chip bags). Pellet manufacturers that utilize only post-industrial or MRF scrap typically charge a small tip fee for collecting/receiving materials, whereas facilities that process MSW and produce pellets charge equivalent tip fees to disposal facilities.

Industrial Uses

Overview: There are several industries that have the potential to use film plastics in their processes. The industries discussed in this section combust solid fuels and most currently use some type of

³ “Environmental and Economic Analysis of Emerging Plastics Conversion Technologies,” RTI International, January 2012.

recovered materials as supplemental fuel sources, such as tire-derived fuel.⁴ Other industries such as the steel-making industry could use recovered film plastics as a chemical reducing agent in the steel-making process. Although the largest market segment for coal is electrical power generation, it is not discussed in this section as a potential recovery market for residential film plastics (as a supplement to coal) because of the additional expense associated with fuel preparation/handling, modifications of governmental approvals, and cost of pollution control system upgrades. Because the market potential differs across each of the industries that are discussed in this section, each is discussed separately below.

Cement/Lime Kilns

Technology Description: Portland cement and lime are industrial and construction materials that are produced from minerals using high temperature kilns. These kilns require a lot of energy and are substantial contributors to greenhouse gases. Cement kilns throughout the world make significant use of renewable and waste fuel sources.

Market Status: There are between ten and thirteen of 107 cement kilns located in the United States that will specifically accept non-recycled plastics. Large cement companies have developed materials sourcing divisions for supplying their cement kilns with waste-derived fuel. The Geocycle division of Holcoim Cement has eleven locations, although the one nearest to Oregon is located in Trident, Montana. Similarly, Systech Environmental Corporation prepares alternative fuels for its parent, Lafarge North America Cement; however, it does not have any location on the US West Coast. Ash Grove Cement, Durkee, Oregon is the only cement plant in the state. Approximately 8 percent of its fuel comes from the combustion of scrap tires with the remainder from coal.

Specifications and Financial:

Cement kilns that combust alternative fuels, including plastics, typically charge a small tip fee, although in some cases they may pay a small positive value depending on the energy value of the material and whether the material has been pre-processed into a form that can be readily fed into the kiln, such as being shredded. Alternative fuel material normally must be shredded down to a 2-4 inch particle size so that it can be handled by fuel handling systems that are designed to feed coal. Unlike most other recovery markets, cement kilns willingly accept metallized film.

Pulp and Paper Mills

Reclay StewardEdge is aware of with 32 pulp and paper mills in the United States that combust alternative fuels such as tire derived fuel; however, none in the Pacific Northwest do so. There does not appear to be good opportunities for sending non-recycled plastics to paper mills in the region at this time given their lack of use of other .

Steel Mills

The process of making iron from iron ore is a chemical one that is conducted in a basic oxygen process furnace at high temperatures. Iron ore is mostly Fe_2O_3 , with other oxides of iron. In order to make

⁴ Materials used to make tires are closely related to those used to make plastics packaging and industries that use tire derived fuel can be considered potential markets for plastics derived fuel. Tire-derived fuel is used extensively throughout the United States and Europe in cement kilns, waste boilers at pulp and paper mills, coal-fired electricity generation plants, waste-to-energy (WtE) processes, and various industrial boiler plants. Relatively few tires in Canada go to such energy applications

elemental iron, a carbon source (reducing agent) must be chemically reacted with the oxygen in iron ore, reducing it to elemental Fe and giving off CO₂ as a byproduct. Iron mills typically use pulverized coal or natural gas as the carbon source. This process leaves excess carbon dissolved in the metal – if this excess carbon is burned out to reduce the carbon to lower levels, it produces the material known as steel. This process of making iron or steel from iron ore is called the basic oxygen process. There are 35 such basic oxygen furnaces, all located in the Eastern US. A second type of steel mill that does not make iron and steel from ore, but instead uses recycled scrap metal is called an electric arc furnace. There is one electric arc furnace steel mill in Oregon, Cascade Steel, located in McMinnville.

One steel producer in Japan and two in Europe use non-recycled plastics as the carbon source instead of coal or natural gas (polyethylene plastic is 86 percent by weight carbon) in the making of iron and steel from ore. Currently, no North American mills use recovered plastics as the reducing agent. There is one company in the Eastern US that hopes to change this. International Recycling Group operates NURRC LLC's sole U.S. facility in Spartanburg, S.C., to convert "previously unmarketable plastic" into a low-cost reducing agent for blast furnaces. Because of the distance to this potential market, and because this potential market is not yet operating, there is not believed to be an opportunity to use waste-derived plastics from Oregon for this application.

Waste-to-Energy

Overview: Waste-to-energy (WTE) is the process of combusting mixed municipal solid waste to produce electricity. Although WTE plants are designed to combust MSW generated from their partner jurisdictions, plants with excess capacity may accept some non-recycled film plastics from elsewhere.

Market Status: Oregon has one WTE plant that is owned and operated by Covanta Marion Inc. The facility began commercial operations in 1986 and processes on average 550 tons of MSW each day (180,000 tons of Marion County's MSW annually), providing the 325,000 citizens of Marion County with a disposal option while generating provides 11 megawatts per hour of electricity that is sold to Portland General Electric Company. The facility processes about 90 percent of the County's non-recycled waste – the other 10 percent consists of construction and demolition wastes, food processing waste, and other miscellaneous non-burnable materials. Ferrous and non-ferrous metals which were not previously separated from the waste are picked out of the ash with large magnets and an eddy current machine – the facility does not pre-process waste that will be combusted, other than manually removing non-processible material from the tip floor.

Specifications and Financial: Most WTE plants are financed as disposal facilities under agreement with a host jurisdiction and so have limited ability to accept waste from outside the host jurisdiction. Any facility that would have excess capacity can be expected to charge at full disposal tip fee prices to accept such waste. Because segregated plastics has a higher energy value than MSW, any facility willing to accept plastics from outside their jurisdiction would need to blend and meter the plastics in with other waste in order to avoid temperature spikes and processing inconsistencies. WTE plants are able to accept all types of plastics for disposal and energy recovery. The tip fee at this facility is \$67.50 per ton

Summary of Recovery Options

Table 6 summarizes the market specifications and value (or tip fee charged) for loads of plastic delivered to each type of recovery market

Table 2 Summary of Recovery Market Specifications and Material Value

Recovery Market	Typical Specification	Delivered Value (per ton)
Pyrolysis	May be mixed with rigid plastics. PVC must be less than 10%. ¹ PET is not desired due to low oil yields. Most exclude metallized film.	\$0
Gasification	None. Separation of film from solid waste is not required.	-\$75 to -\$85
Engineered Fuel (Pellets)	May be mixed with contaminated paper. No PVC or metallized film above incidental levels.	unknown to -\$85
Industrial Uses	No PVC. Specifications vary among industry types (e.g., cement kilns accept metallized film; others may accept plastics/paper mixes).	\$0 to -\$40
Waste-to-Energy	None. Separation of film from solid waste is not required.	-\$67.50

Source: Reclay StewardEdge

¹The threshold level for PVC is generally corresponds to the level that it is found in the residual packaging waste stream after bottles have been removed for recycling. Oregon's air quality permit for the Agilyx facility requires 90% removal of PVC from the feedstock stream.

As Table 6 shows, there is a wide variation in specifications and delivered value. Those recovery markets that accept mixed municipal solid waste, such as energy-from-waste and gasification, have the least demanding specifications, but also have the lowest market value offered since they charge tip fees that are on par with disposal facilities. As materials move up the value chain the specifications typically get more stringent and the material value increases. It is possible for some recovery markets, specifically industrial uses and pyrolysis, to pay a small positive value for recovered plastics, under certain circumstances. This can occur when energy costs for traditional fuels are high. For engineered fuel and industrial uses, it also depends on the availability of other alternative combustible waste materials in a local area. As long as there is a surplus of these other combustible waste materials, it is not likely that positive value will be paid and that tip fees will be charged.

Reclay StewardEdge offers the following recovery market conclusions:

- There are few pyrolysis, gasification, and engineered fuel pellet facilities operating commercially in North America. There is market risk associated with such a small number of facilities, especially since the next best market may be a far distance and transportation to that market may be costly. Pyrolysis and gasification are not yet in widespread commercial use.
- For all the technologies discussed, commercial economic viability is highly dependent on local conditions (e.g. transportation costs, landfill tip fees, availability of other diverted materials with energy value, and electricity cost for those conversion technologies that use large amounts of electricity).
- A diversified approach with several recovery markets for non-recycled plastics should be considered if recovery is to be a key element of plastics diversion from waste in Oregon in the future.

Section 4: Sorting Technologies

This report section discusses plastics sorting and processing technologies that can be employed by materials recovery facilities, plastics recovery facilities, and reprocessors for the recycling of plastics, including stage of technology development. A list of equipment vendors is included at the end of this report in the appendix.

In order to be recycled to their highest and best use, plastics need to be separated from other non-plastic materials, and then they need to be sorted into plastics grades based on resin type (e.g., polypropylene), processing characteristics (e.g., melt flow), and sometimes other factors such as color. Ideally, generators at the point of generation of post-consumer plastics would segregate one grade of plastics from other grades of plastics/other discards in order to avoid incurring sorting costs. However, this is only feasible for certain industrial and commercial generators, such as segregating polyethylene film by furniture stores and warehouse/distribution centers. For most generators of plastics discards, including most business and residences, the recyclables they generate are so diverse that recyclables are commingled for collection convenience or economies-of-scale, necessitating that recyclers separate plastics from other material types and then sort the plastics into market grades.

Non-durable plastic products and packaging are often individual plastic items, which allow sorting to be performed on the whole piece level. However, most durable plastic products are joined with other materials into composite products, and the plastics in these durable products may not be easily separable as whole pieces from other materials. Examples include plastic parts in automobiles, plastics housings for electronics, and plastic flat panel computer and television display screens. For these materials, either expensive manual dismantling is required, or the composite products can be shredded with sorting occurring on the small particle level. The discussion of sorting in this section is focused on sorting of individual whole pieces of plastics that are not part of composite products, which can be employed at the local and state level (MRFs and local recyclers).

Materials Recovery Facility Technologies

The ability of MRFs to cost-effectively employ sorting technologies to separate plastics from other recyclables and sort plastics by type depends on the size and throughput of the MRFs. Following is a description of the various sort technologies and discussion of how they may be applied.

Separation Technologies

Residential recyclables, and increasingly industrial, commercial, and institutional (ICI) recyclables, are collected commingled as mixtures of paper, plastics, glass, and metals. The first step to sorting plastics into market grades is to separate other materials out of mixed recyclables so that only plastics remain, after which the plastics are sorted into market grades. Combinations of mechanical equipment and manual sorters perform this separation.

Figure 3 Screen



In the United States, equipment called screens is used to assist in performing this separation, separating two dimensional paper from three dimensional containers where at least 10 tons per hour of recyclables are being processed. Screens are made up of a series of rotating shafts with discs or fingers mounted on them. Larger-sized flat materials are pushed up and over the top of the screen, whereas smaller sized or three dimensional materials either fall between the gaps between the shafts or roll down and off the bottom of the screens. However, plastics with a large two dimensional surface area such as lids or thermoforms often wind up sorted by screens with paper. These plastics must be removed from the paper sorting area of MRFs and conveyed to the containers sorting part of the plants if they are to be recycled instead of disposed.

Screens are not effective in separating flat two-dimensional plastics, film plastics, large plastics (over gallon size), small plastics less than 2 inches in size, or foam polystyrene. These materials either must be removed by hand before being feed into screens, must be collected separate from other mixed recyclables, or must be separated using equipment such as ballistic separators.

Ballistic separators are inclined reciprocating floor machines that walk larger-sized flat two-dimensional materials up and over the top of the unit, whereas small materials fall through holes in the floor and round three-dimensional materials roll down to the bottom of the unit. They perform the same function as screens, except that they are gentler on the recyclables fed into them and so are able to handle large plastics, film plastics, and polystyrene foam. Ballistic separators are used in Europe for sorting plastics and metals (in Europe, paper is normally collected in a separate stream). Ballistic separators are used in North America to sort MSW and construction and demolition debris. Some residential MRFs in the United States that desire to handle a more diverse-stream of recyclables are considering ballistic separators in place of the more traditional screens.

Figure 4 Ballistic Separator



The following subsections describe sorting technologies for plastics after other paper and other containers have been separated from the plastics using mechanical equipment and manual sorters.

Optical Sorting

Most new single-stream MRFs designed to process 20 tons per hour or more of residential recyclables have an optical sorter installed; it is common for new residential MRFs that process more than 20 tons per hour to have more than one machine. Optical sorters work by measuring the spectrum of near infrared (NIR) and/or visible light that is reflected off the surface of items they are sorting, and based on the spectrum reflected back, optical sorters can identify the surface resin and color of the plastic product. Essentially, optical sorters are composed of three components – a feed-regulating conveyor system, a lamp/camera/computer to identify the plastic material and/or color, and a separation system to separate one type of desired plastic material from mixtures of other materials. There are approximately twelve companies that offer optical sorters for sale, and optical sorters are considered to be a widely commercialized technology.

The standard practice up to this point in time is that one machine is used to sort out one plastic material grade from a mixed stream. If additional sorts are to be performed, either more machines in series are needed, or manual sorters downstream of the optical sorters are required. Optical sorters can be equipped with dual-eject capability so that they can positively sort two plastics materials streams out from mixed materials from one machine; however, doing so usually results in more sorting errors than is found in single eject machines (single eject machines are 92-98 percent effective).

Figure 5 Optical Sorters



Optical sorters are programmable and mixes of plastics can be recirculated in separate batches through one machine for further subsorts, as long as the mechanical feeding, takeaway, and sorted material storage systems have been flexibly designed with this in mind. Historically, MRF and PRF mechanical systems have not been designed with this flexibility, and only in the last year or two have sort lines begun to be retrofitted, designed, or used in this manner to allow for one optical sorter to sort more than one type of plastic, or to sort uncolored plastics from colored plastics.

Optical sorters have limitations. Unfortunately, the spectrum (chemical composition read by NIR machines) for materials and grades within one resin category is the same – therefore, blow molded HDPE bottles, injection molded LDPE lids, and LDPE film all appear to be the same material to an optical sorter (i.e., “polyethylene”), even though the materials in this example are three distinct market grades. This means that NIR optical sorters used in MRFs cannot distinguish between these materials and a NIR optical sorter would sort them all into the same category, requiring manual labor after the optical sorter to perform further grade sorts based on processing characteristics or LDPE/HDPE differences. Most NIR machines cannot identify the resin in plastics that have been pigmented black.

None of Oregon’s single stream MRFs have optical sorters installed. Several factors have likely contributed to this situation, including:

- Single-stream MRFs that were constructed a number of years ago and are due for replacement or equipment retrofits;
- Several smaller sized MRFs, rather than fewer but larger MRFs that would have the economies of scale to make use of optical sorters;
- The state’s bottle bill, which recovers a large percentage of PET through the deposit-return infrastructure rather than through residential curbside systems; and
- Reliance on export markets for collected plastics, rather than North American reclaimers who specialize in reclaiming only certain resin types and require sorted materials.

Robotic Sorters

A future technology that may eventually assist in sorting plastic is the robotic sorter, shown in Figure 6. Bollegraaf has experimented with this technology in Germany. The design application of this technology is for quality control sorting and for production sorting in low to medium throughput applications. Units developed so far consist of an optical scanner over a conveyor belt followed by a robotic arm that picks low percentage contaminants from a conveyor and deposits them into a bin, chute or onto another conveyor. This system cannot support the same throughput as other technologies discussed above.

A significant attraction of robot sorters is the potential to sort different grade of plastics at once, instead of requiring a series of binary sequential sorting steps.

Figure 6 Robot Sorter



Source:
solidwastemag.com/news/robomrf/1000213709/

Manual Sorting

Manual sorting is the most universal option in that it can be used to sort any material from any mix in any size facility. Manual sorting is slow, at approximately 400 pounds per hour per sorter for rigid plastic containers, compared to optical sorters, which can sort at over ten times that rate of plastics.

Film Plastics Sorting

Film plastic is 3 percent of disposed MSW in Oregon, and 29 percent of disposed plastics. In order to significantly reduce the disposal of plastics in the state, solutions must be investigated for diversion of film from disposal. While an estimated 19 percent of film is collected for recycling in Oregon, nearly all this film is ICI film collected through commercial recycling programs, including agricultural film, or residential film that is collected through return-to-retail (often grocery) collection programs. Film is generally not collected and sorted in commingled systems because it becomes contaminated and its value becomes minimal, because of technical sorting difficulties in MRFs, and because the cost of separating and sorting in MRFs is very high. This section describes some of the sorting technologies that can be considered for sorting of plastics films.

Film Manual Sorting

Many residential recyclers place film plastics in recycling carts even though it is not accepted in most programs. All of the residential MRFs in Oregon use screens made up of rotating axles to separate paper from containers. Thin film materials such as retail sacks wrap around the axles of these screens, fouling the screens and reducing their efficiency. In most MRFs, this film must be cut off the screens at least once per shift. This film is disposed.

To avoid fouling screens, MRFs try to manually remove all film in the pre-sort portion of MRFs. Recently constructed/retrofitted large-scale MRFs commonly utilize overhead suction tubes at manual sort stations to collect and convey polyethylene film from the pre-sort area as well as at other points in the MRF to one central point. Manual sorters snatch and lift plastic film to the suction tubes. The plastic film is pulled in by the suction and conveyed to a storage bin where bale quantities are accumulated. This approach to manual film sorting is shown in Figure 7. Older or smaller facilities may manually pick out film at only one point in the MRF and drop it down a chute into a bunker.

Figure 7 Manual Sorting of Film



Manual sorting provides the potential to collect all types of film and sort it into more than one film product grade, such as a higher polyethylene film grade for recycling, and a lower mixed films grade for energy use. To do such sorting would require a separate film sorting conveyor and the following processing steps:

- Separate film from non-film materials (the best practice is for manually sorting film is for all film to be “bags-in-bags,” i.e. all film stuffed inside a tied-off bag);
- Open bags-in-bags so each piece of film is individualized;
- Positively sort out bags and film that is obviously only polyethylene into a one grade;
- Leave all remaining film as a mixed resin/laminate grade.

The primary challenge of manually sorting plastic film is the amount of labor required and the resulting cost. Assuming a worker can make 50 picks per minute, one worker can sort a maximum of 3,000

individualized bags per hour. Using a conversion factor of 275,000 film pieces per ton, it would take one worker approximately 90 hours to pick one ton. Manual sorting costs can be greatly reduced if residents can be trained to package all plastic film into a tied bag. This bag can then be removed at the pre-sort and dropped down a chute to a dedicated film sorting line, on which it would be opened and clean polyethylene picked off and sent to a dedicated film baler. To show the impact on sorting cost and efficiency, if 25 same-film items are in one bag, the productivity of the same worker can be increased from sorting 3,000 individualized film items per hour to sorting 75,000 film items per hour, and can pick a ton in 3.6 hours. The degree to which film is bagged-in-bags is the single-most impactful factor on film sorting costs in a MRF.

Film Grabber

MRF equipment suppliers offer some commercially-available mechanical equipment to assist in sorting films in MRFs. Bollegraaf offers the Film Grabber, shown in Figure 8. The Film Grabber is mounted across a conveyor of mixed recyclables and uses a rotating drum with protruding fingers to comb through the mix of recyclables and hook the film. As the drum rotates the hooked film is lifted out of the other recyclables. When the film reaches the top of the drum the fingers retract and the film is blown off to the collection bin. This technology works well for individualized plastic bags and other very thin and highly flexible materials, but it is not effective in separating bags-in-bags or thicker polyethylene films such as cereal box liners, chip bags, and laminated film plastic packaging. When this technology is used on a fiber or single-stream line this system also captures some paper that would need to be manually separated later.

Figure 8 Bollegraaf Film Grabber



Bollegraaf does not market its Film Grabber as being highly effective in separating film in a single-stream recycling operation. A consideration in placing a Film Grabber in a recycling facility is that the fingers on the grabber drum must be able to reach nearly to the conveyor belt surface to snag a majority of the film. This means that large materials such as OCC, buckets and large bottles need to be removed before the Film Grabber location, which means it would have to follow the pre-sort station and OCC screen in a single-stream facility (many facilities also add a glass screen at this point). Additionally, the Film Grabber must be placed ahead of the ONP screen (which normally immediately follows the OCC/glass screens) to avoid large volumes of plastic film wrapping around the screen shafts.

The Film Grabber is not yet in common use and has only been installed in a few facilities in North America. A dual stream MRF in Canada with a Film Grabber installed on its container sort line is effective in capturing between 30 and 60 percent of the plastic film in the stream. A single-stream MRF in Edmonton, England also uses Film Grabber technology. That MRF sorts recyclables that are collected in many programs using a film blue-bag approach rather than bins or carts (including some programs that accept packaging film). The MRF uses two Film Grabbers located at the front of the sort line just after debugging equipment. These film grabbers were installed primarily to capture the large bags that recyclables had been set out in and thus opened by the bag breakers. In that MRF film Grabbers are effective in capturing up to half of the plastic film out of the single-stream material – it is believed that much of this film is the large blue bags themselves, which would be easier for the Film Grabber to snag, than smaller sized packaging film that may have been the mixed recyclables. Labor is still required after a Film Grabber to sort the film that the Film Grabber fails to capture. Generally speaking, Film Grabbers

are not effective enough to replace manual labor in U.S. MRFs, and so is not a piece of equipment used in this country.

Air Separators

MRF equipment manufacturers make equipment to separate two dimensional flexible materials from three dimensional rigid containers. This equipment is normally employed in single-stream MRFs on the container sorting line immediately after the paper screens have separated paper from containers. The equipment has been designed to capture single sheets of residual paper that has carried over into the container stream, but it also separates individual plastic film products. Bollegraaf's technology, shown in Figure 9, is named the Paper Magnet, CP Manufacturing makes a piece of equipment called an Air Drum Separator, shown in Figure 10, and Machinex calls its equipment an Air Separator (illustration not available). All three vendors' equipment use suction to cause flexible materials like paper and film plastics to be sucked onto and adhere to a moving surface, which directs them down a separate chute, whereas curved rigid materials do not adhere to the surface and continue on their way for further sorting. The current configurations of the various vendors' equipment have not been designed to accommodate the weight or dimensions of bagged film and so their effectiveness for separating bagged film is not known, nor has the effectiveness of different vendors' equipment relative to each other for separating bagged film been evaluated.

BHS offers a front-end piece of equipment called a Nihot Windshifter that is designed to separate dense materials from less dense materials. It can be used at construction and demolition debris recycling operations to separate plastics from heavier non-plastic items.

The primary limitation of air separation equipment is that it cannot distinguish plastic film from paper nor can it separate polyethylene film from other resins or laminates. Manual sorting is also needed to separate polyethylene film from non-polyethylene/laminates.

Film Optical Sorting

Optical sorters use conveyor belts moving at high speed and jets of air to sort rigid plastic containers. Film plastics, have a tendency to not remain in place on a fast-moving conveyor belt and swirling jets of air at the sorting end do not lend themselves to optical sorting of thin film products, unless the equipment is adapted for film sorting. TITECH states that its optical sorters can sort a maximum throughput of 0.7 tons per hour of film per meter of optical sorter width. Pellenc in France has also worked to adapt its rigid packaging optical sorter technology to sort PE plastic film from other film resin types. This application is new and currently used on plastic film with a thickness of 2.5 mils or more. Pellenc has had to adapt its machines to use airflow to keep the film from moving as it is scanned and sorted. Since a large percentage of North American residential plastic film is only 0.5 mils thick, Pellenc

Figure 9 Bollegraaf Paper Magnet



Figure 10 CP Manufacturing Air Drum Separator



believes that its technology in its current stage of development would not be very effective for sorting residential North American film.

The German film reprocessor Relux uses NIR optical sorters at its reclamation facility in Germany to sort film that MRFs have separated from other recyclables using manual sorting or other technologies. The incoming bale specification calls for the bales to have at least 92% film plastics and the film is to exclude aluminized plastics (chip bags). Relux begins by shredding the film into large pieces, optically sorts the pieces into PE and non-PE film, and then washes and pelletizes the PE film for sale into film and sheet markets. Multi-layer or non-PE film is sent for energy recovery. If optical sorting of film is to be employed in North America, the most logical place for it to be utilized may be at the reclamation stage rather than at the MRF stage. The project team is not aware of any film reclaimer in North America using optical sorters for film sorting.

Reprocessor Sorting Technologies

Depending on how plastic materials are collected and the products produced at the MRF or return center, some secondary sorting by either a PRF or a plastics reprocessor (reclaimer) may be required.

The MRF sorting technologies discussed above can all be used. Specifically, optical sorting is used to perform quality control checks and remove contaminants, sort by color, and remove color contaminants at the flake level after the plastics has been ground and washed, using the same general technology as whole-container optical sorting, only at a small scale level.

Additional technologies that can be employed by a reprocessor include density separation in a wash system. Washing plastic usually starts with shredding to reduce piece size, followed by washing in heated water containing detergents and wetting agents, where it is mechanically agitated through a series of chambers. The washing performs several functions including:

- Removal of residual foods, oils, and salts;
- Removal of dirt, dust, and glass grit the film picks up through collection and MRF processing;
- Dissolution/pulping and removal of paper and potentially plastic labels if water soluble label adhesives were used;
- Dissolution of water soluble printing inks; and
- Density separation of those plastic materials that are denser than water (e.g., PET, PS, PVC, PLA) from those that are less dense than water (polyethylene and polypropylene).

Washing is not effective in removing some adhesives and the materials attached by these adhesives. Foamed resins that otherwise would sink may float with the desired resins (e.g., polystyrene foam). Also, multi-laminate films may either sink or float depending on the relative proportions and densities of the resins used in them.

Plastics Recovery Facilities

Plastics recovery facilities (PRFs) is a concept that dates back twenty years when Oregon's Garten Foundation received a major grant in 1994 from the plastics industry to install newly developed optical sorting equipment to sort mixed plastic bottles that would be delivered to the facility. Due to technological advances, the equipment at the Garten Foundation became obsolete fairly rapidly. Since that time, the concept of a PRF has not become commonplace in the infrastructure for recycling plastics in the U.S.. In the fall of 2013 a high-technology PRF operated by Waste Management in North Carolina

was shut down as the equipment became old and Waste Management chose to focus on sorting in its MRFs rather than at a centralized PRF.

Only in the past three years has interest in PRFs increased and today and four companies operate six facilities that can be considered to be high-tech PRFs, as opposed to low tech manual sorting like is done in Asia. The capital investment in a high-tech PRF is very large, which forces the scale of a PRF to also be very large – new and existing PRFs range in size from 13,000-55,000 tons per year, placing their scale at the level where they serve as regional sorting assets, not state-level assets. These facilities carry market risk. If MRFs choose to ship baled mixed plastics to export markets where manual sorting is performed, PRFs may lose material to process and may not be able to operate profitably or at scale. Long-term commitments with major MRFs within a region may be needed for developers of a PRF to consider such a facility in the Northwest.

Appendix A – List of Sorting Technology Vendors

MRF Equipment Vendors

CP Manufacturing
1300 Wilson Ave, National City CA 91950
6194773175
hanso@cpmfg.com
<http://www.cpmfg.com/>

Bulk Handling Systems (BHS)
3592 West 5th Avenue, Eugene, OR 97402 USA
8666882066
robbe@bhsequip.com
<http://www.bulkhandlingsystems.com/>

Van Dyk/Bollegraaf
78 Halloween Blvd, Stamford, CT 06902
2039671100
peenkemavandijk@vandykbaler.com
KBrogan@VanDykBaler.com
<http://www.vandykbaler.com/contact.htm>

Machinex
2121, rue Olivier, Plessisville, Qc, Canada
7738678801
nbelanger@mti.machinex.ca
chawn@mti.machinex.ca
<http://www.machinexrecycling.com/>

RRT (Resource Recycling Technologies)
125 Baylis Road, Melville, NY 11747-3895
6317561060
negosi@RRTenviro.com
mjones@rrtenviro.com
<http://www.rrtenviro.com/>

Green Machines
5 Gigante Dr., Hampstead, NH 03841 USA
6033297337
jgreen@greenmachinesales.com
<http://www.greenmachinesales.com/>

SC Enviromental
11520 N. Port Washington Rd. Suite 205
Mequon, WI 53092
Phone: 262-240-1992
<http://www.scenviro.net/contact.html>

JWR, Inc
322 N Watertown St Johnson Creek, WI 53038
(920) 699-2848
jwrinc.net

Recycling Equipment Manufacturing, Inc.
373 Shannon Ln Priest River, ID 83856
(208) 448-4736

Optical Sorter Vendors

MSS
3738 Keystone Av., Nashville, TN 37211
6154810828
hotrock@magsep.com
<http://www.magsep.com/>

NRT
1508 Elm Hill Pike, Suite 102
Nashville, TN 37210 United States
1.615.734.6400
Sales@nrtsorters.com
<http://www.nrtsorters.com/>

Titech
78 Halloween Blvd, Stamford, CT 06902
2035243555
wolf@titech.com
<http://www.titech.com/>

Eagle Vizion
262 PEPIN STREET, OFFICE 201, SHERBROOKE,
QUEBEC, CANADA J1L 2V8
8195637374
NLortie@EagleVizion.com
<http://www.eaglevizion.com/>

Pellanc
921 Arrowhead Terrace, Clayton CA 94517
9258908350
a.descoins@pellencst.com
<http://www.pellencst.com/>

Steinert
285 Shorland Drive
Walton, KY 41094
(800) 595-4014
sales@steinertus.com
www.steinertus.com/

Recovery Systems Company, Inc
1617 5th Street South
Hopkins, MN 55343
888-935-4330
952-935-4330
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