# The High-Speed Identification and Sorting of Nonferrous Scrap

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*There are various approaches to sorting alloys. Perhaps the most simple method and one which is in greatest use today is hand sortation, which is normally a rather inaccurate process. An opportunity exists to recover low-grade nonferrous scrap by sorting it into various alloys with high accuracy by applying spectrographic analysis techniques. This article presents an alternative method for scrap identification and sortation in which optoelectronics are utilized to make a rapid and accurate identification of the scrap item. The scrap is then sorted automatically without operator intervention.*

## INTRODUCTION

Each year, U.S. industry discards millions of tonnes of nonferrous metals as waste because it is either impractical or uneconomical to recover this material using current technology. Many alloys are downgraded in value due to contamination that cannot be cost-effectively removed. In addition, millions of tonnes of nonferrous metals are shipped overseas to China and elsewhere, for separation into higher-value scrap grades using low-cost labor for visual identification and sorting.

Traditionally, the metals business and/or the recycling business have been moribund businesses, slow to adopt new technologies. An opportunity exists to transform this industry by moving it from older methods of handpicking and visual identification to fully automated, high-efficiency sortation methods—using computers, robotics, and other automated materials-handling systems.

This will have not only positive benefits to the scrap industry, but will provide spillover benefits both to industries generating scrap, which will be able to sell their scrap material at higher prices, and to other industries utilizing scrap materials, which will be able to purchase scrap at lower prices. It is for that reason that agencies of the U.S. government such as the National Institute of Standards and Technology (NIST) and the National Science Foundation (NSF) are funding new technology aimed at advancing U.S. scrap processing technology.

This paper will describe the progress of Spectramet® Technology activities, funded by the NSF under its Small Business Innovation Research Program (SBIR) and the NIST Advanced Technology Program (ATP). These programs have been aimed at developing a platform of high-speed identification and sorting technologies for unambiguously separating mixed nonferrous metal scrap by alloy type.

See the sidebar for details on past and current sortation methods.

Figure 1. A full-scale Chinese metal sortation factory. Laborers generally work for wages of about 10 cents per day. This photo as well as the cover photo are the work of Adam Minter, an independent journalist and photographer based in Shanghai, China. More details about this facility can be found in the About the Cover text on page 1.

## AN ANALOGY TO THE RAG-PICKING BUSINESS

The way scrap is separated today is reminiscent of the rag-picking business that was prevalent years ago. No less than 400 different types of woolens, silk, cotton, canvas, and rags were bought by industry for various purposes. Bottles, broken glass, straps, old paper, boxes, metal extracted from buttons or picture frames, shoes, crusts of bread, bones, or even small locks of hair—all were reworked, remodeled, and resold in various forms.

The ragpickers of Paris were organized in a hierarchical, disciplined system. At the bottom there was the night collector, who did not have his own collection patch or tools. He was promoted to a runner when he had equipped himself with a basket carried on his back, a lantern, and a hook with which he combed through worn out brushes, old clothing, fish heads, or vegetable peelings. He worked all night long sorting these materials. At a still higher level, the "placer" had his own patch and had first pick of the refuse from eight to ten buildings. Patches were much-sought-after commodities and were handed down from generation to generation or sold like lawyers' practices at varying prices depending upon the wealth of the district. However, around 1870, the traditional rag and bone trade declined in the face of competition from industrial development and the invention of new manufacturing processes. Many aspects of the business have not changed much, and the scrap-sorting methods in China are reminiscent of the rag-picking methods of 19th century Europe.

A photograph of Chinese workers sorting mixed nonferrous metal concentrates from automobile shredders is shown on the cover of this issue. These metals are similar to the metals processed in the United States using heavy media separators. In China, it is clear that automation and automated equipment are not part of the process. Instead workers wearing face masks, hats, and gloves sort each piece of metal one by one putting it into the appropriate container based on visual appearance, apparent density, and surface texture. Often, the scrap-sorters in China work at a wage rate of 10 cents per day. Figure 1 shows a full-scale sortation factory in China.

It is difficult to visually identify different types of aluminum metal once they are mixed together. Thus, while the Chinese workers are capable of sorting aluminum alloys from other alloys, such as copper and zinc, they cannot sort one type of aluminum alloy from another. An exception to this rule might be their ability to identify cast versus wrought alloys based on their differing visual appearance. Figure 2 shows a photograph of aerospace metal turnings that have been shredded into smaller chips. Figure 3 shows samples of aerospace metals such as turbine blades and fasteners. These aerospace metals command a high value in the marketplace, but in many instances conventional sorting technologies are incapable of cost-effectively identifying and sorting them. A new high-speed identification and automated sorting technology would be particularly applicable in these high-value superalloy applications.

## wTe'S PLASTIC RECYCLING AND RECLAIMING BUSINESS

Optoelectronic sortation is not new to wTe Corporation. The recycling company, based in Bedford, Massachu-

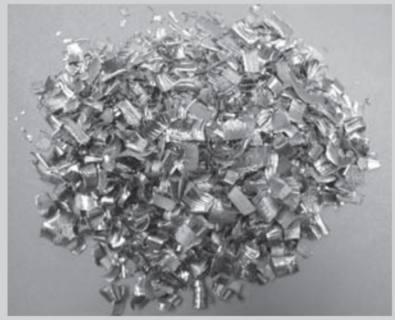

Figure 2. Aerospace metal turnings after shredding.

Figure 3. Aerospace metals, including turbine blades and fasteners.

Figure 4. Bails of PET bottle feedstock will be recycled by wTe's UltrePET plastic recycling subsidiary using optoelectronic sensing technology.

Figure 5. Materials on the left are transported, using cranes, into the automobile shredder on the right.

Figure 6. Various nonferrous metals after processing in the nonferrous metal separation system.

setts, has an UltrePET® plastic recycling subsidiary that is highly experienced in sorting plastic bottles using optoelectronics. A photograph of incoming baled polyethylene terephthalate (PET) bottle feedstocks is provided in Figure 4. After the bails are broken and the bottles are freed from one another, optoelectronic devices identify each bottle by color and also by chemical composition. Green bottles are automatically sorted from clear bottles. Bottles containing polyvinyl chloride (PVC) are identified chemically and automatically sorted from PET bottles. The bottles are then granulated, washed, sorted by gravity, and cleaned to remove glue and other contaminants. Eddy current separators and electrostatic separators are utilized to remove metals from plastics. Heavy-media separation techniques are employed in metal recovery. The overall operation is fully integrated, automated, and complex. Each day, nearly 2 million bottles are transformed into finished-product pellets for resale into high-grade markets, including using the resin to make new soda bottles. The quality of sorting must be sufficiently reliable that the finished products contain only one part of PVC for every 100,000 parts of PET (10 ppm). Contamination in excess of this level affects the color and the intrinsic viscosity of the finished product, lowering its value or making it unusable.

The challenge in the metals business is to apply a similar technology to sorting mixed metals at high speeds and at high volumes. The technologies employed are different for metals than for plastics, but the concepts are the same.

A photograph of wTe's auto shredder operation is provided in Figure 5. The facility takes in three types of feedstocks as its raw material: flattened automobiles, ferrous metals from the refuse-derived-fuel types of waste-to-energy plants, and ferrous metals that have been combusted in mass-burn types of waste-to-energy plants. These materials are introduced by cranes into an automobile shredder which then deploys air classifiers to segregate seat covers, foam cushions, dirt, and dust from the rest of the automobile. In subsequent steps, magnetic separators segregate magnetic metals such as iron and steel from the nonmagnetic metals such as aluminum, copper, and zinc. Eddy current separators sort conductive materials from nonconductive materials and thus are used to sort wood, heavy plastics, rubber, and paper from the mixed nonferrous metals. The ferrous metals are then shipped to market.

Nonferrous metals are further processed in the proprietary metal-separation systems (i.e., the Spectramet Technology) which are the subject of this paper. Figure 6 shows what some of these nonferrous metals look like after they have been processed in the nonferrous metal separation system. As can be seen, these nonferrous metals are a combination of different types of metals. It is the goal of the Spectramet technology to take this mixture of nonferrous metals and sort them by type.

Another photograph of mixed nonferrous metals is provided in Figure 7. These metals include aluminum, zinc, copper, brass, bronze, and other metals and alloys such as stainless steels. It is interesting to note that most of the metals are present as a single alloy, not combinations or mixtures of metals. Fasteners, brazes, welds, and joints have largely been broken by the shredder. The alloys have already been liberated. The challenge is to identify at high speeds each of the small pieces by alloy type and automatically sort them. Not only is it possible to sort materials from automobile shredders, but it is also possible to sort materials from conven-

## PAST AND CURRENT METHODS FOR SORTATION

### Spark Testing and Chemical Methods

Methods of identifying scrap metal include the application of spark testing and chemical analysis. In the case of spark testing, a sample is picked up by the operator and touched to a grinding wheel. The operator examines the length of the spark generated when the sample is ground on the wheel. For example titanium generates a very long brilliant white spark while aluminum generates a shorter, duller spark. By examining the spark and essentially feeling the metal and looking at its surface texture, the operator identifies the particular alloy group. In this case, titanium can be sorted from aluminum. However it would not be possible for the operator to determine the particular alloy of titanium. Furthermore, the operator could not determine the alloy of aluminum, or even the aluminum grouping in terms of 2000 series, 3000 series, and the like. Another similar, but far more time-consuming method of analysis is chemical analysis. This is not a quantitative chemical analysis, but an analysis that resembles a litmus test. Chemical analysis kits are available for which an operator can guess the type of alloy under consideration and then apply drops of chemicals onto its surface. Based on the change in coloration of the chemicals, essentially like a litmus test, the operator can confirm the identity of the alloy that is under examination by comparing the reaction and color to a table of results. This method of analysis is time-consuming and requires significant experience in evaluating the various chemical reactions. The Institute of Scrap Recycling Industries provides courses to teach scrap dealers and operators how to apply spark testing and chemical analysis to the sortation of nonferrous metal scrap. These methods are still in use today.

### Heavy Media Methods

Another method of analysis includes heavy media separation. In heavy media separation, various metals having a range of densities are placed into a liquid bath containing a fine suspension of water and magnetite. The quantity of magnetite in suspension is adjusted so that the apparent density of the fluid is in between the specific density of the alloys that are to be sorted. For example, in trying to sort aluminum from other heavy nonferrous metals (e.g., copper, zinc, etc.) the apparent specific density of the fluid medium is set in the range 3.0 to 3.5. Since aluminum has a specific density of 2.7 and most of the other heavy nonferrous metals have specific densities on the order of 6.0–7.0 or above, the aluminum floats to the top of this fluid suspension while the heavier nonferrous metals will sink. In this manner, aluminum can be sorted from other nonferrous metals using heavy media. Heavy media separation is not effective for sorting the higher-density alloys, such as sorting copper from zinc, because it is not practical to achieve fluid-specific densities in the range of 7.0 g/cc or above. However, heavy media separation is the most effective method for sorting mixed aluminum from other heavier nonferrous metals recovered from automobile shredder nonferrous concentrates. Heavy media sortation is not effective at sorting various aluminum alloys. For example, it is not possible to sort 2000 series aluminum from 3000 series or 5000 series.

### Handheld XRF and OES Spectrographic Analyzers

Recently, handheld spectrographic analyzers have come onto the market. Examples of suppliers of these types of analyzers include Niton and Innovex. These types of analyzers utilize x-rays to generate x-ray florescence (XRF) from the unknown sample in order to obtain an identification of the particular alloy under consideration. Another handheld spectrographic analysis device utilizes an optical emission spectrograph (OES).

A company named Spectro is a supplier of this type of handheld analyzer. In the case of OES analyzers, an arc or spark is applied to the sample and sensitive light detectors read the light spectrum emitted from the spark. The spectrum is characteristic of the alloy and can be used to identify the composition of the alloy. In the case of both XRF and OES analyzers, it is necessary to place the analyzer on top of the sample (or the sample on top of the analyzer) by picking up the sample and pushing the analyzer against its surface. The time required to develop a valid spectrum can vary from a few seconds to one-half minute or more. The operator then reads the output. In many cases the output can be a quantitative analysis showing the percentage of each element present. In other cases, the output includes an estimate of the particular alloy that was examined. An example would be copper 360. In the event the analyzer cannot determine the exact composition, alternative alloys approximating the composition of the sample are also suggested. Optical emission spectrograph analyzers work well on aluminum samples. However, XRF analyzers do not work well on aluminum samples because the XRF emissions from aluminum have such low characteristic energy levels that the XRF is quickly absorbed in small amounts of air. Thus, the signal output is typically so low that the detectors cannot read it. On the other hand, XRF analyzers can be effective in determining the composition of heavier elements or high Z metal elements. High Z refers to elements that are high on the periodic table.

### Laboratory and Bench-Top Analyzers

Another method of analysis involves bench-top and laboratory analyzers. These units provide much more accurate results than handheld units but are slow and time consuming. Obtaining a highly accurate chemical analysis using these methods can take minutes and, in some cases, hours. However, these types of analyzers can be extremely accurate and reliable.

### Laser-Induced Breakdown Spectroscopy

Laser-induced breakdown spectroscopy (LIBS) is a sorting technology that utilizes a laser beam to produce the same type of light emission plasma as is produced using the OES methods described previously. This technology has been effective for sorting aluminum alloys and magnesium alloys at high speeds, but a full-scale system is not yet commercially available in the general marketplace. The application of LIBS technology has not been previously described in the literature for determining the composition of high Z alloys or sorting among various alloys high on the periodic table such as copper-base alloys, nickel-base alloys, cobalt alloys, and the like. While it seems the technology would be applicable to this type of sortation, no demonstration of such technology has been reported in the literature using LIBS.

### The Spectramet Technology

An opportunity exists to recover mixed nonferrous metal scrap by sorting the scrap into various alloys with high accuracy using optoelectronics. This would be accomplished by applying a new high-speed analysis technique, the details of which cannot be disclosed at this time due to patent disclosure restrictions. A new company dedicated to commercializing this technology, named Spectramet® LLC, is in the midst of developing a platform of high-speed identification and sorting technologies using various optoelectronic sensors and methods. The Spectramet technology can sort a wide range of metals into various alloy types very quickly—in a few milliseconds—and very accurately, meaning that the sortation is essentially unambiguous.

tional nonferrous metal scrap yards such as those shown in Figure 8.

Also amenable to optoelectronic sortation are the post-combustion nonferrous concentrates from a waste-energy plant such as those shown in Figure 9. As can be seen by looking at this photograph, it is extremely difficult to identify individual metal types. To further sort them by alloy type would seem virtually impossible. However, after cleaning and processing using special optoelectronic technologies, these post-combustion materials can be identified by their alloy content and sorted accordingly.

The Spectramet technology is also capable of processing selected nonferrous feedstocks from high-value aerospace industry sources, recovering such items as turbine blades made from nickel, cobalt, and titanium alloys.

## wTe AND NRT AGREEMENT

In seeking to address the sortation of metals using optoelectronics, wTe sought an experienced company well versed in optoelectronic sortation. In some of its previous projects, wTe had utilized National Recovery Technologies (NRT) for high-speed optoelectronic sortation of plastics. National Recovery Technologies had experience not only in sorting whole plastic bottles, but also bottles that had already been granulated into flake form. The company had demonstrated a commercial capability to sort in excess of 10 bottles per second when the bottles were whole. With respect to sorting small flakes, NRT had demonstrated the ability to sort at the rate of 10,000 particles per second or faster. wTe envisioned that with NRT's optoelectronic technology, it would be possible to sort metals in the same way that plastics were sorted in the past. wTe and NRT's experience with the plastic sortation system would facilitate the plunge into scrap metals. The type of process for sorting metals would be very similar to that used to sort plastics, except for the need to sort metals into many more products. Clearly the technologies that would be required to accomplish these sorts for metals would be different than for plastics. However, the fundamental application of optoelectronics and materials handling would be very much the same. In order to take advantage of this prior experience and technology, wTe entered into a long-term exclusive arrangement with NRT to devise a new technology for metals.

The result was Spectramet, a limited liability company that would be owned equally by NRT and wTe. National Recovery Technology would be primarily responsible for basic research, equipment manufacture, and development of optoelectronics and materials handling technology. wTe would provide access to its scrap operations, materials handling expertise, and product sales, and would be a beta site for the first facility.

The focus of the business concept was to be on ownership and operation, not on the business of equipment sales, which had been the focus of NRT in the past. The expectation was that the business would develop proprietary technology that would be patented and protected as a trade secret. The Spectramet business was to be modeled after wTe's UltrePET plastics business, but equipment that would be developed would be proprietary and would only be used by the new Spectramet operation. National Recovery Technology, which had been a supplier of plastics equipment and machinery for UltrePET, would not sell to others. In addition, NRT would only deploy its equipment for use by the joint venture. The goal was to sort metals as wTe had sorted plastics, automatically and on a large scale.

Figure 7. Nonferrous scrap from the separation system, before sortation.

Figure 8. Materials from conventional nonferrous scrap yards. Spectramet is capable of sorting these materials in addition to those shredded and separated at its own facility.

Figure 9. Post-combustion nonferrous concentrates from waste-energy plants can also be sorted using Spectramet technology.

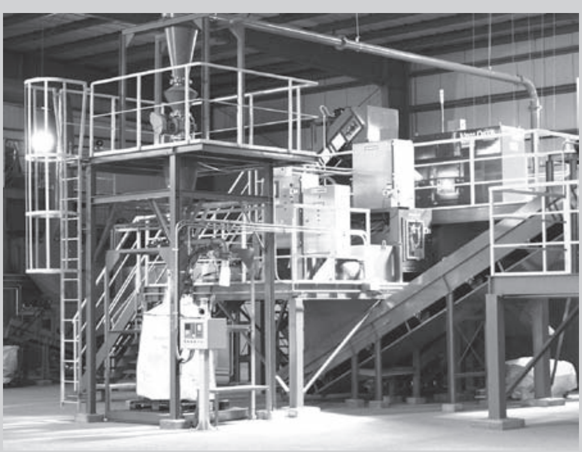

Figure 10. An NRT machine vision and x-ray-based inspection and sorting system installed in a plastics recycling facility located in Nagoya, Japan.

Building this type of automated machinery was not new to NRT. A photograph of an NRT machine vision and x-ray vision system for sorting plastics located in Japan is shown in Figure 10. This is typical of the equipment that NRT manufactures, sells, installs, and services worldwide, including installations in North America, South America, Europe, Asia, and Australia. Photographs of NRT plastics processing systems included at UltrePET are provided in Figure 11. MultiSort® and VinylCycle® systems are utilized to sort plastics by color and material composition. The VinylCycle in particular is aimed at sorting PVC plastics from PET plastics. National Recovery Technology has technologies that accomplish this function both on whole bottles and on bottles that have been granulated into flakes. As can be seen in Figure 12, the whole-bottle sort system feeds plastic bottles that have been flattened or bailed on a high-speed wide conveyor belt across sensors. Figure 12 shows the movement of the materials as they pass across the sensors. Materials are identified, and based on their color and composition, air jets are used to separate one type of bottle from another at high speeds. A flake sorting system installed in a plastics recycling plant located in Venice, Italy is shown in Figure 13.

## NIST-ATP FUNDING

In order to fund development of their technology, wTe and NRT first sought funding under the NSF-SBIR program. Later, after the basic concept of Spectramet technology had been demonstrated, wTe sought additional R&D funding from NIST-ATP. National Science Foundation funding for the proposed technology exceeded $1 million and NIST funding exceeded $2 million. In addition, wTe and NRT provided matching funds to further the development effort. Parts of these funds were utilized to assemble a world-class strategic advisory board including leaders from academia and from industry. The advisers have helped develop the physics and the metallurgy of the technology as well as provide relationships with major industry users. Academic advisers in the area of physics and optoelectronics came from Vanderbilt University in Nashville, Tennessee. Academic advisors in metallurgy came from the Massachusetts Institute of Technology in Cambridge, Massachusetts. Support from executives came from various major industry groups including the aluminum, superalloy, copper, brass, and precious metals industries. Other advisers came from the venture capital industry. Important support was also contributed from technical and business mentors from both the NSF and the NIST-ATP programs.

## BUSINESS AND COMMERCIAL CHALLENGES

The Spectramet business is still in its infancy. There are many remaining challenges both technical and commercial. All must be solved in order to address the overall business opportunity. For example, there is a need to develop and gain acceptance for the new types of products that will be generated from this equipment. Even though these output products are of a composition similar to that of prompt scrap, the shape and size of these feedstocks resembles that of mixed auto-shredder nonferrous metal concentrates. Scrap buyers and smelters are unaccustomed to the shape and size of the scrap and need to build confidence that, notwithstanding its appearance, the quality can be equal to that of finished-specification-grade alloys. The company has been working to develop high-level contacts and commitment for long-term purchase arrangements with major companies. These relationships will be slow to develop and will require learning together through trial melt tests at producer facilities. The strategic advisory board members have been instrumental in building credibility in the marketplace, but it is also essential to build that credibility through repeated plant trials demonstrating quality finished products. It is also necessary to assess user needs and melt shop requirements. The company needs to look at various alternative feedstock supply sources and at the impact of feedstock sources on product in order to assess potential variation in composition of finished products. In addition, the economic and environmental benefits to users must be quantified. Consistency among production lots and variations in compositional analysis must be tracked and statistically analyzed. There are also logistical problems that must be addressed in terms of handling as many as 100 to 200 different alloys in a single processing system. From a profit perspective, the company must be sensitive to balancing its own business interests with the benefits required by its partners. Finally, the company needs to evaluate the benefits of partnering versus the benefits of competitively pricing various products on the open market.


Figure 11. The NRT plastics processing systems included at UltrePET, which utilizes MultiSort and VinylCycle systems to sort plastics by color and material composition.

Figure 12. Flattened bottles being fed by the sort system on a high-speed conveyor belt across the sensors.

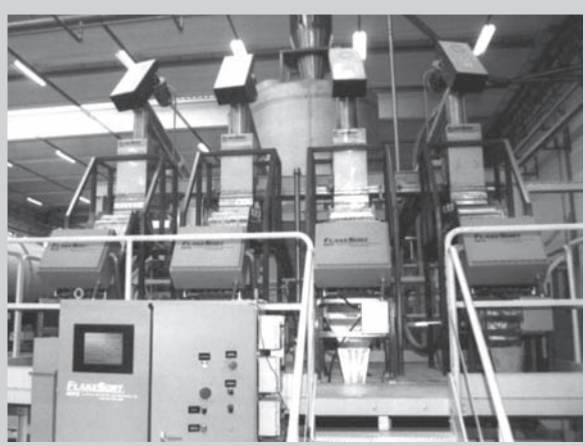

Figure 13. A four-module FlakeSort system installed in a plastics recycling plant in Venice, Italy by NRT.

## CONCLUSION

It has been nine years from the start of this project until products could be sold in the marketplace. Trials with many materials are just beginning. A great deal of work remains to be done in order to establish the economic viability and the business potential of this technology. However, it is the company's position that there is a need for fully automated systems, particularly in the United States, if scrap recovery is to be a successful long-term business. Details of the technology cannot be released because the company's intellectual property protection is still in a preliminary stage. At some point in the future, more open discussion about the technology may be possible. In the meantime, discussions of the kinds of feedstocks processed is possible, as well as the types of products that can be generated from the company's processing system. Spectramet hopes to establish the quality of the products the company can produce, in terms of estimating their value and usability to the marketplace.

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