WHITE PAPER:
WASTE NO MORE

RECYCLING WITH SPECTRAL CAMERA

specim

SPECTRAL IMAGING
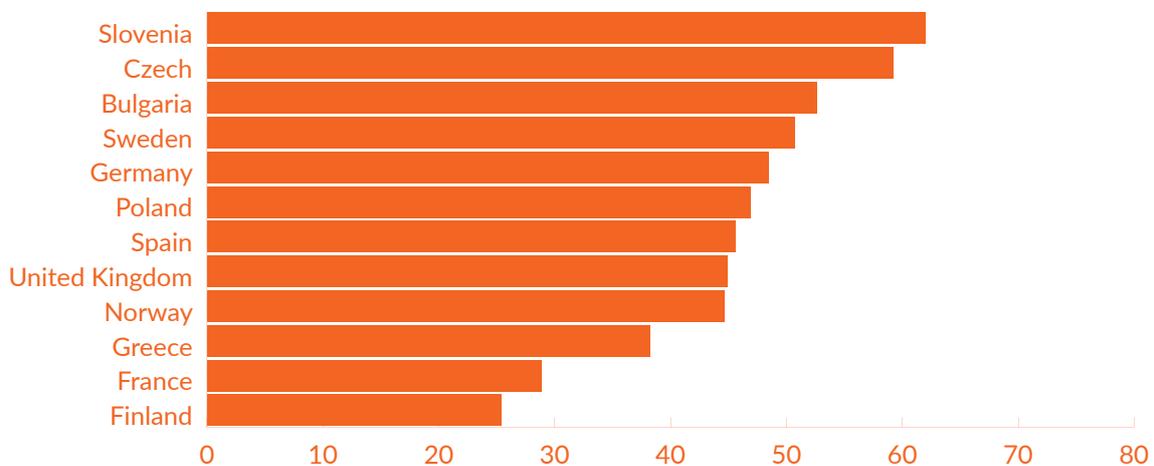
Table of Contents

01. There is more to recycle

Efficient recycling of waste into reusable raw materials is one of the significant efforts we must take to stop global warming and over-exploitation of natural resources. That is why governments are setting strict requirements for recycling efficiency.
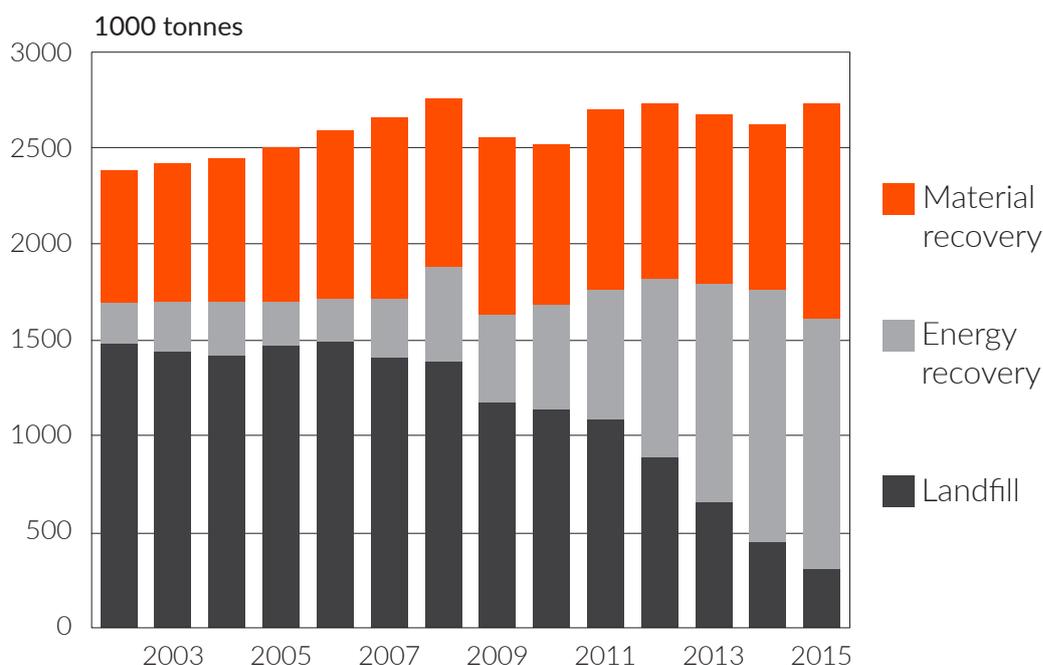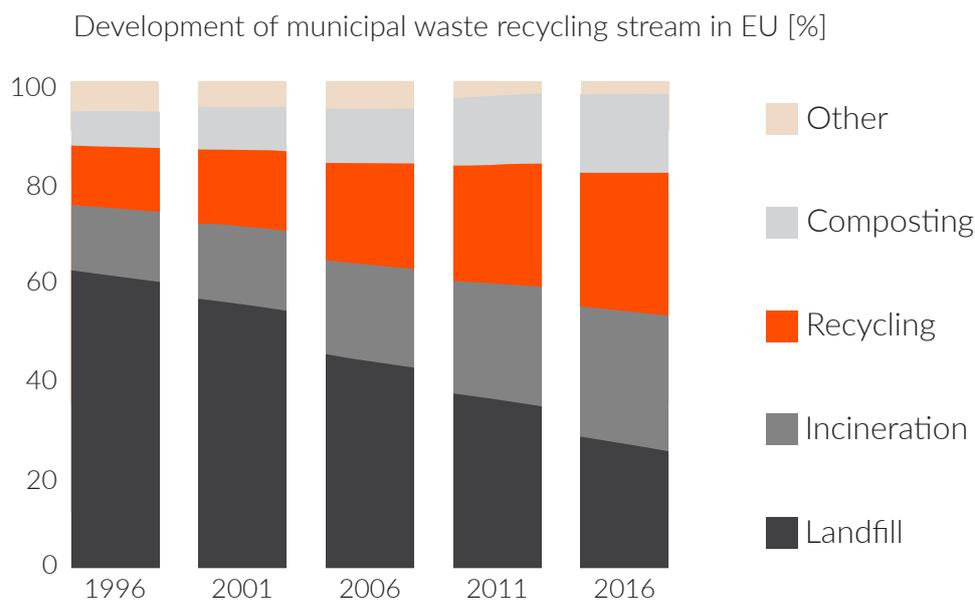
- In the EU, the target is that 65% of municipal and 75% of packing waste is reused or recycled and a maximum of 10% is placed to landfill by 2030 (see the graph below)
- European Commission's Circular Plastics Alliance contributes to achieving at least 10 million tons of recycled plastics into new products on the EU market by 2025.
- By 1 January 2025, EU member states will set up separate collections of textiles and hazardous waste from households.
- By 31 December 2023, EU member states will ensure that bio-waste is either collected separately or recycled at source (home composting).

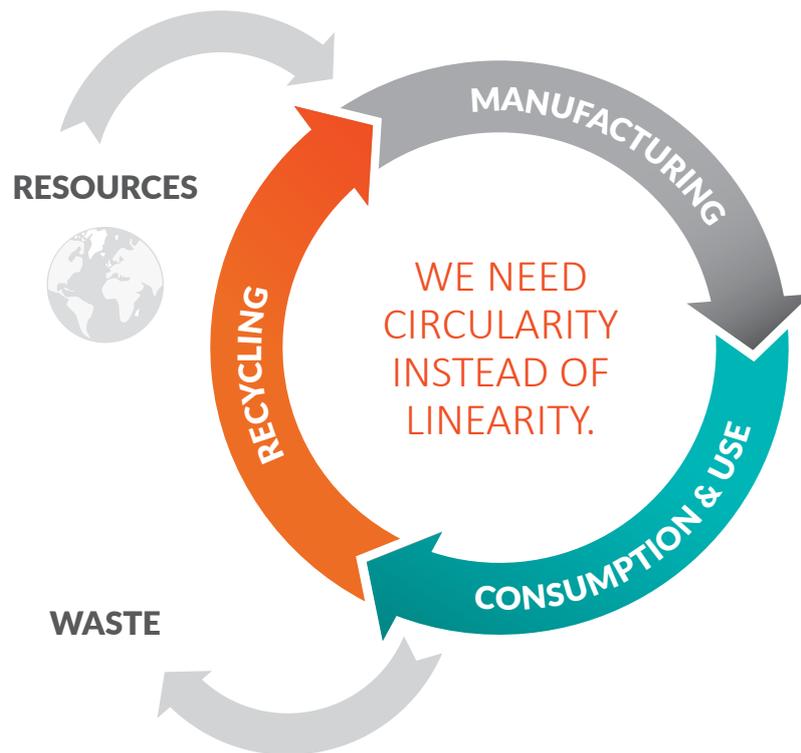Recycling rates for plastic packaging waste - Eurostat 2016

According to statistics, collected waste percentages in many European countries appear to be far above 80%. Germany, for example, gives recycling rates of 67% for household waste, around 70% for production and commercial waste, and almost 90% for construction and demolition waste. At the same time, there are countries where the recovery rate is less than 40%.

However, a closer look shows that most of the collected waste is currently used for energy production and burnt in power plants. In other words, waste is changing the format, not reused - we are still far away from our recycling targets. We are not exploiting maximum recycling potential, and much of the recyclable materials do not get recycled.

Development of municipal waste recycling stream in EU [%]

Municipal waste by treatment method in Finland 2002-2015. Source: Statistics Finland.
https://www.stat.fi/til/jate/2015/jate_2015_2016-12-20_tie_001_en.html

The benefits of efficient recycling are clear: recycling conserves natural resources and reduces greenhouse gases and pollution, as well as the use of fossil fuels in energy production: it reduces energy consumption for about 70% for plastics, 60% for steel, 40% for paper and 30 % for glass.

RESOURCES

MANUFACTURING

RECYCLING

WE NEED CIRCULARITY INSTEAD OF LINEARITY.

CONSUMPTION & USE
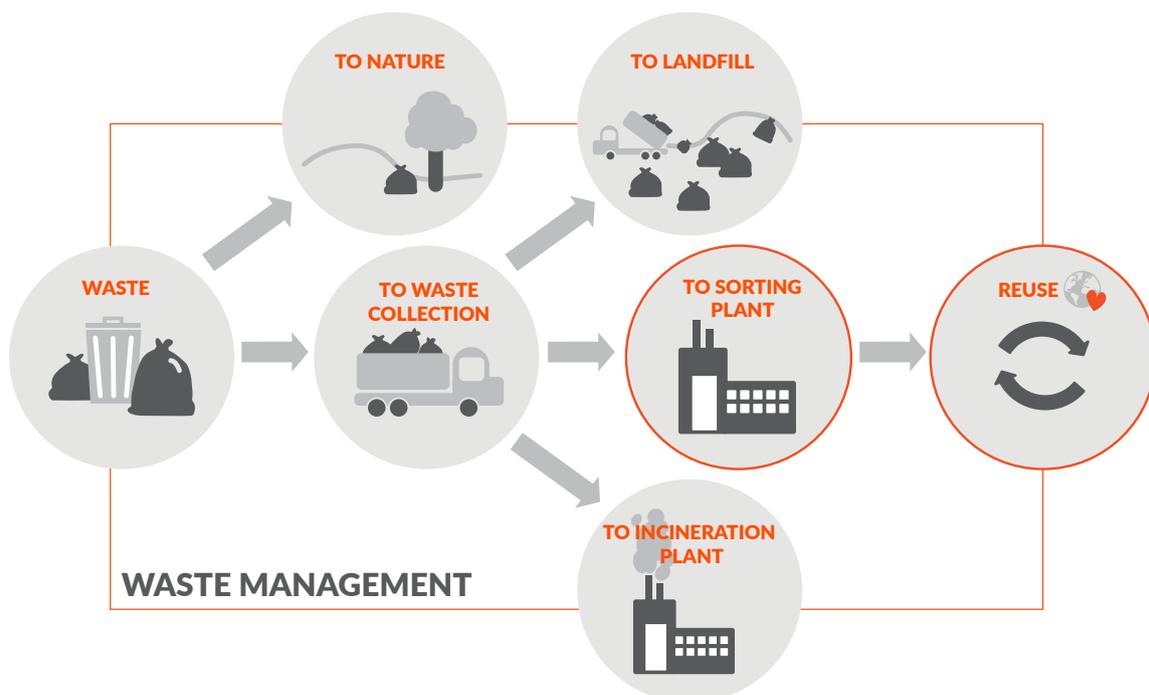
WASTE

What is more, it is not only about the ecological benefits: significant value lies in the material we waste. Efficient sorting and recycling of different materials can turn into profit with proper material handling methods. Also, recycling and reusing of materials need to be cheaper and easier than using virgin materials. This potential is yet to be uncovered, as in many cases using natural resources in production is less expensive than using recycled material.

With political will in place and clear benefits listed, why are the recycling numbers still as low as they are?

02. Recycling can be more efficient

A typical waste management process includes the collection of waste to a recovery facility, segregation to different waste fractions, necessary cleaning and final classification to separate products which are then either incinerated to produce energy, recycled based on product type and purity, or placed to landfill.

The sorting process is a critical step in many types of recycling, from pallets to plastics, and more. Better accuracy means better separation of different grades of material, which results in higher value recovery. A typical sorting process is based on a mix of techniques and cannot rely on just one detection technology. In many cases, the available detection technology limits the types and the amount of the collected material that we can sort.

Today, most of the recovery or recycling plants use different technologies from bar code readers and RGB cameras to x-ray and eddy current systems. While they are capable technologies to a certain extent, they are not perfect solutions as they cannot recognize the material. For example, if a plastic bottle is missing a label with the printed barcode, it is not possible to say if it is PET or HDPE. Eddy current detector can sort out conductive metals but not separate plastics or pulp. RGB camera can sort bottles to transparent, black and colored but is still missing the actual material information. Consequently, we lose recyclable material to landfill or energy production, while the recycled portion is not pure enough for possible reuse. The poor result can also cause a loss of profits, which makes recycling impractical or dependent on public support.

As different waste streams require different detection and processing methods to be recycled efficiently, current recycling methods are not flexible, efficient, and informative enough to tackle the challenge.

Currently, to make up for inadequate detection technologies, human labor must be used to make classification on materials based on their earlier experience and learning capability. Although this creates jobs, they are by far not the safest and most desirable of professions. What is more, picking waste from the stream by hand is slow, inaccurate, and expensive and yet, separating dangerous materials or plastic types in clear plastics bottles is still impossible. There is also the question of ethics: waste is shipped to lower cost countries where people - also child labor – is used to sort materials from conveyor belts manually.

A recycling plant must have sensors capable of separating different materials reliably and with high purity, and this is where spectral imaging can make a difference.

03. How a spectral camera improves recycling?

Spectral camera technology can identify different materials accurately and reliably based on their chemical composition. It measures and analyzes the spectrum of light reflected from or transmitted through the material. In the visible region, the spectrum is different and characteristic for each color. When measuring the spectrum beyond the visible region called near infrared (NIR), we see that chemically different materials have different spectrum.

So-called multispectral technology has improved the situation; however, it has its limitations. Multispectral cameras acquire spectral data typically with one, two or three, or in some cameras, maximum in 8 spectral bands, meaning that in each sorting location it identifies only a few basic materials. The purity of the result is also often limited as there are interfering factors in the material stream.

Until now, spectral cameras that would fit the industrial environments have not been available: industrial use of spectral imaging has been restricted by insufficient performance of spectral cameras in terms of speed, spatial resolution, ruggedness and connectivity, as well as by their high cost.

The situation has now changed. The recent development has improved both speed and resolution of spectral cameras, while their implementation cost now meets the ROI criteria of industrial solutions. What is more, in parallel to the spectral camera development, algorithms and solutions for real-time processing of a large amount of data produced by the spectral cameras are also now available.

For in-line industrial applications, a line scan type spectral camera is the only practical and properly working solution, as it captures the entire spectral data from each pixel in the line precisely at the same time.

Hyperspectral camera and real-time processing unit — Commercial machine vision tools for sorting control — Sorting

A line scan (push-broom) type spectral camera can be installed, together with proper line illumination and the real-time data processing solution, on existing and new sorting lines like any line-scan camera. The material identification result, pixel by pixel, is available through a standard interface (like Gen<I>Cam) to commercial machine vision systems. The results can then be used to control the air nozzles or picking robots.

A spectral camera solution provides superior performance and several benefits in various waste treatment processes over conventional sensor technologies, as summarized in Table 1.

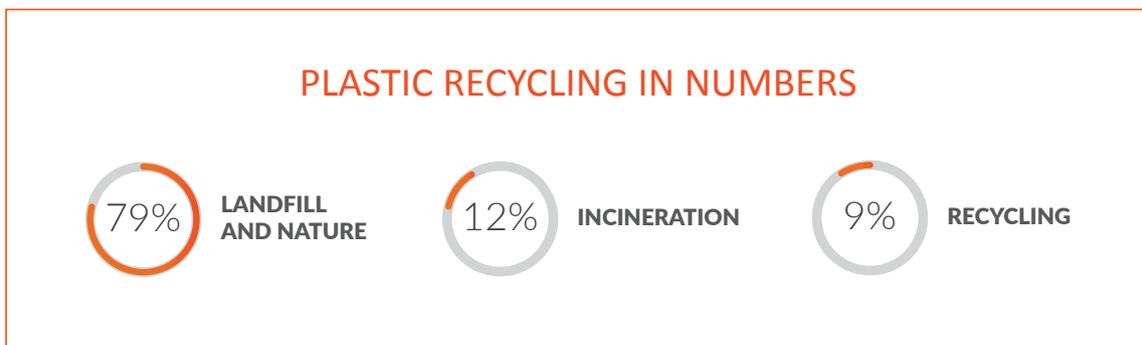| Added value by spectral imaging in sorting waste streams		
Waste	**Capability**	**Benefits**
Municipality waste	Simultaneous identification of materials in the mixed waste stream	Separation and valorization for plastics, textiles, metals, glass, paper, cardboard
Construction waste	Simultaneous identification of materials in the mixed waste stream	Separation of combustible materials, valorization of wood, glass, metal
Industrial waste	Simultaneous identification of materials in the mixed waste stream	Separation of combustible materials, valorization
Plastics	Simultaneous reliable identification of multiple plastics (polymers)	Improved (near 100%) purity and higher value of recycled fragments
Textiles	Identifications and classification to natural and synthetic fibers.	Both qualitative and quantitative analysis (mixed textiles)
Waste for incineration	Moisture and chemical composition of the material stream. Quantification for caloric value.	Optimization of the incineration process

Table 1

When used together with other technologies, spectral cameras make sorting more accurate by providing precise information on material type. The latest generation of hyperspectral cameras can increase the purity of recycled materials to close to 100%; for example, increasing the purity of recycled plastic by even a few percents can double its value. What is more, extracting more recyclable material also means that we are disposing less waste to landfill.

Unlike a multi-spectral camera with fixed spectral bands, the spectral camera is flexible and can adapt to sorting various waste streams. It can also adopt new sorting algorithms when they become available.

04. Example applications and benefits

Plastic recycling

Out of all the plastic manufactured, only 9% gets recycled. 12% is incinerated for energy, and 79% goes to landfills or nature. It is estimated that by 2050 there will be more plastic in the oceans than fish.

PLASTIC RECYCLING IN NUMBERS

79% **LANDFILL AND NATURE**   12% **INCINERATION**   9% **RECYCLING**

Majority of non-recyclable plastic waste comes from not being able to separate different plastic types from each other reliably.

When we sort and separate the collected plastic, we can re-use the high-quality and valuable polymers. The main objective in sorting is to reduce the quantity of non-targeted plastic polymers and to reduce the number of non-plastics like paper, metal, glass, oil, soil, or other contaminants. There may also be unwanted additives like flame retardants within the plastic, that can be detected, identified, and sorted with spectral cameras.

Most polymers have identifiable signatures in the NIR spectral region and can thus be sorted. However, many of the spectral signatures are close to each other. Here, the spectral camera's high spectral resolution is a key to high sorting accuracy. With PP, PE, and PET plastics, for example, close to 99% purity can be achieved.

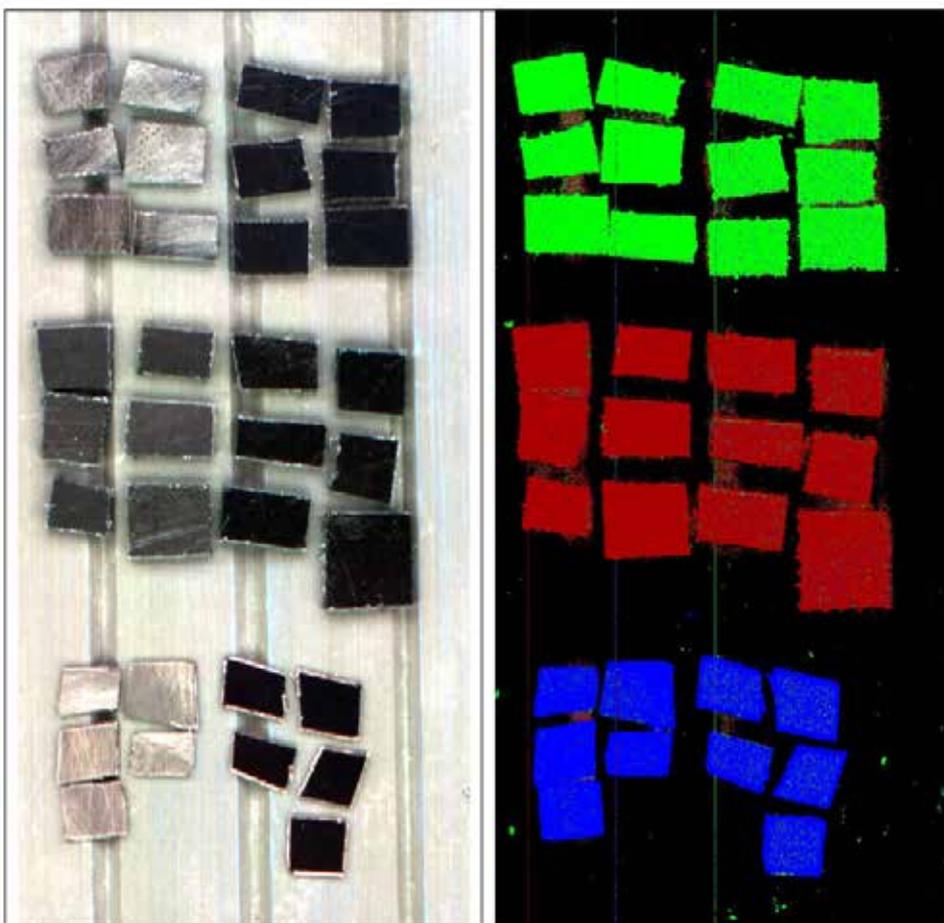| PLASTIC MATERIALS THAT CAN BE SORTED WITH HSI						
1 PET	2 HDPE	3 PVC	4 LDPE	5 PP	6 PS	7 OTHER
POLYETHYLENE TEREPHTHALATE	HIGH DENSITY POLYETHYLENE	POLYVINYL CHLORIDE	LOW DENSITY POLYETHYLENE	POLYPROPYLENE	POLYSTYRENE	OTHER PC POLYCARBONATE

Sorting of black plastics

A large fraction of recyclable plastic constitutes of black plastics, used in particular in the automotive and electronics industries, which have added carbon-based pigment to produce the dark grey or black color. Black plastic types have been notoriously difficult to identify, and so far, there has been no reliable sensor technique to sort these materials for reuse. Even NIR cameras struggle, as the black carbon-based pigment absorbs practically all the NIR light.

Development in spectral camera technology is changing this situation as well. In addition to NIR region, different plastics have characteristics spectral features in the longer infrared region (called mid-wave infrared, MWIR) where most black

pigments are 'less black' (less absorbing) than in the NIR region. Thus, MWIR light can penetrate in and reflect from black materials, making their spectral identification possible. Spectral cameras operating in the MWIR region with required speed, resolution, and sensitivity for industrial in-line use are now available.

With a spectral camera that operates on MWIR region, we can sort black ABS plastics with close to 99 % purity.
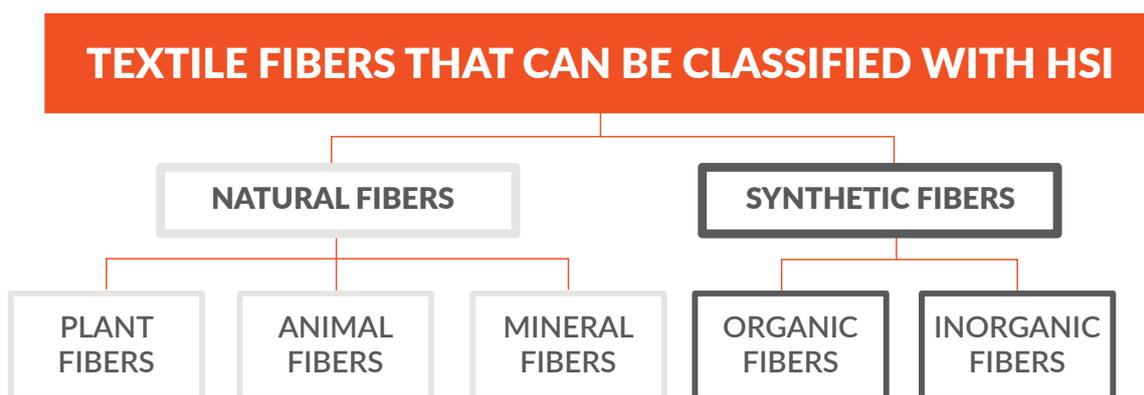
Below is an example of black plastics sorting measured in a laboratory with an MWIR range hyperspectral camera Specim FX50. Twelve pieces of ABS and PE were measured together with ten pieces of PS (34 altogether). For each sample group, half of the samples were shiny, and the second half with diffuse surface. The figure below shows that samples made of ABS, PS, and PE could be accurately sorted.

Textile recycling

Textile reuse and recycling reduces environmental impact compared to incineration and landfilling.

Nearly 100 percent of all textiles and clothing are somehow recyclable if they can be correctly classified and separated based on used fiber type. One obstacle for increasing textile recycling has been the fact that various fibers that comprise clothing make reprocessing and recycling a challenge. Although it is possible to use human labor for classification, this is hardly economically feasible and pose a lot of error sources.

TEXTILE FIBERS THAT CAN BE CLASSIFIED WITH HSI

- **NATURAL FIBERS**
  - PLANT FIBERS
  - ANIMAL FIBERS
  - MINERAL FIBERS
- **SYNTHETIC FIBERS**
  - ORGANIC FIBERS
  - INORGANIC FIBERS

Spectral camera in the NIR spectral region can easily separate the most common types of textile fractions making automatic processing possible, for example using robotics.

The advantages of NIR spectral camera based sorting in the textile industry are:

- Non-contact and suitable to be applied in a conveyer belt
- Gives information about both pure and mixed materials (qualitative and quantitative sorting)
- Classification is not sensitive to used colors or dyes
- Easily configurable for different sorting lines and new materials
- For precise color information, HSI can replace RGB camera

Cotton is an extremely resource-intense crop in terms of water, pesticides, and insecticides. Using recycled cotton can lead to significant savings of natural resources and reduce pollution from agriculture. Some materials such as cotton and linen can be recycled for car insulation or composted, but petroleum-based fibers such as polyester have little chance for reuse.

Material characterization for incineration

Although material recycling percentage is increasing, it will still be necessary to incinerate some part of non-recyclable material. These "waste-to-energy" power plants receive material from various sources like commerce, construction, household and industry and use this for generating power in Refuse Derived Fuel (RDF) power plants.

The value of RDFs is derived from the calorific content (Image KK) – which is determined by material type. Certain materials like glass, rock, or dirt, have zero calorific value. Water content and ice will also affect the process.

Precise combustion process control and calorific values can only be calculated based on proper material recognition. Hyperspectral imaging in the NIR spectral region is capable of providing an in-line solution for this.

05. Conclusion

We need to increase the percentage of waste that is recycled and not just collected and burned for energy production. To achieve this target, we need better detection systems. For instance, robots can work 24/7 accurately and efficiently without fatigue, handle hazardous waste, and operate flexibly for different waste streams - yet they need a visual aid to help them reliably identify the materials. Using hyperspectral imaging together with other technologies and sensors is a crucial step that will help us towards our goal.

Hyperspectral camera technology as well as analysis software are already available and in use in industrial surroundings, and their use is expected to grow at the significant market share. In the future, they will be extensively used and implemented due to the growing need to solve previously unfeasible sorting tasks.

Improved sorting accuracy increases the purity of the recycled material and as a result, the value. The percentage of waste that can be reused will also increase as a result. All this, with the support of political decisions, may yet bring a solution to the overuse of our natural resources.

As the hyperspectral camera hardware has improved and will continue to do so, it will also need algorithms, analysis software, spectral libraries, and other machine vision sensors to produce a complete solution that will be the future of recycling industry.

specim

SPECTRAL IMAGING

Specim – Light is our passion

Specim, Spectral Imaging Ltd. is the world leading manufacturer of hyperspectral imaging instruments and systems. Specim's success is driven by our passion for light. Today that passion has resulted in a range of products from the most advanced remote sensing applications to industrial OEM segment and easy-to-use handheld devices.

For more information visit www.specim.fi