WHERE THERE'S MUCK, THERE'S BRASS

THE HIDDEN VALUE OF OUR WASTE

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EXECUTIVE SUMMARY

One man's trash is another man's treasure. At least, it could be if waste valorisation sees the levels of investment and support it needs to address two of the world's greatest concerns at the current time: economic stability and environmental sustainability.

This report investigates the UK's waste valorisation supply chain. We will look into the huge range of industries and processes where you transform waste materials into valuable commodities.

For example, the agriculture, food and drink, manufacturing, electronics, clothing and textiles, transport, construction and mining sectors are all involved in this space. Each one is working to develop and optimise processes including pyrolysis, flow technology, chemical conversion and solid state fermentation to extract the highest value from waste byproducts by manufacturing high-value chemicals, fuels and other products.

Progress in the waste valorisation sector is ongoing, yet slow. For the valorisation of waste to reach market maturity and acceptance, we need to see a substantial overhaul of governmental policy to address the sector's current political and socioeconomic constraints.

The sheer scale of the waste valorisation sector's diversity is the crux of the issue. Extracting value from waste relies on the collaboration of disparate industries and the development of novel technologies in a time where austerity means government bodies, academia and industry cannot be seen to waste money on frivolous pursuits.

However, organisations have to invest high amounts in embryonic waste valorisation technologies where a ROI is not guaranteed, yields fluctuate wildly and a lack of a centralised funding agency and clear, long term political strategies do not incentivise those interested in pursuing waste valorisation. The public's preconceived ideas on quality, the reputational risk for organisations and NIMBYism does little to help.

It's a catch-22 situation and it does feel like the waste valorisation sector is going around in circles, instead of facilitating the circular economy.

Luckily, change is forthcoming from the UK's laboratories and small businesses. Small pockets of resistance are forming and local knowledge and collaboration is helping waste valorisation to break into the mainstream thanks to the dedication of this demographic.

To accelerate this work, financial security and a collaborative forum must be provided to those organisations willing to invest in and develop the waste valorisation industry to secure our financial security on a global scale in the years ahead.

EXPLAINING THE VALORISATION OF WASTE

What is waste valorisation?

Waste valorisation is an umbrella term to cover any industrial processing activity that aims to reuse, recycle or compost waste materials so that they are transformed into useful products or sources of energy.

There are many ways to give waste value.

You may process a discarded product, byproduct or residue into a raw material, use waste materials to enhance a manufacturing process or add waste materials to finished products to alter or enhance their properties.

You can also extract energy from waste, which is normally done by combusting waste material to generate heat. This is perhaps the simplest way to acquire value from waste, but also the least efficient. Properly processing waste to extract valuable compounds will generally provide more profits and less environmental damage than burning waste in a furnace.

Even if energy is the desired product from valorising waste, the production of biofuels as a renewable energy source provides many advantages over raw combustion, and is one of the prime avenues for waste valorisation that multiple industries can take advantage of.

Incineration is best seen as a last resort for waste valorisation. Although it is preferable to landfill, it doesn't generate significant value from waste and is far from being environmentally friendly. Therefore, the focus for this paper is on the valuable materials and compounds that can be economically extracted and repurposed from waste.

How can we define "value"?

Valorisation processes can be broadly split into two categories: low-value valorisation and high-value valorisation. Low-value processes generate less valuable end-products, but generally require less work to produce, while the opposite is true for high-value processes.

An example of low-value valorisation is that of a farmer using the waste stalks from his wheat harvest as straw for his livestock. This straw helps remove manure from an animal's environment, which can then be used as fertiliser to grow more wheat. In this example, the waste from the farmer's crop is valorised for his livestock, and the waste from his livestock is valorised for his crop.

High-value valorisation typically requires waste material to be processed before its true worth can be acquired. The farmer in the above example receives minimal value from using his wheat stalks as animal bedding. If those wheat stalks could be converted into a more valuable substance, such as fuel for his tractor, the efficiency and profitability of his business could significantly increase.

High value valorisation is, of course, preferable to low value alternatives, although this avenue is often not practically or financially viable. Unfortunately, much technology still needs meaningful advancement until valuable materials can be valorised from the majority of waste that is produced.

The changing attitude to waste valorisation

Over the past 10 years, the amount of household waste we recycle in the UK has increased three-fold and, in 2009, more than

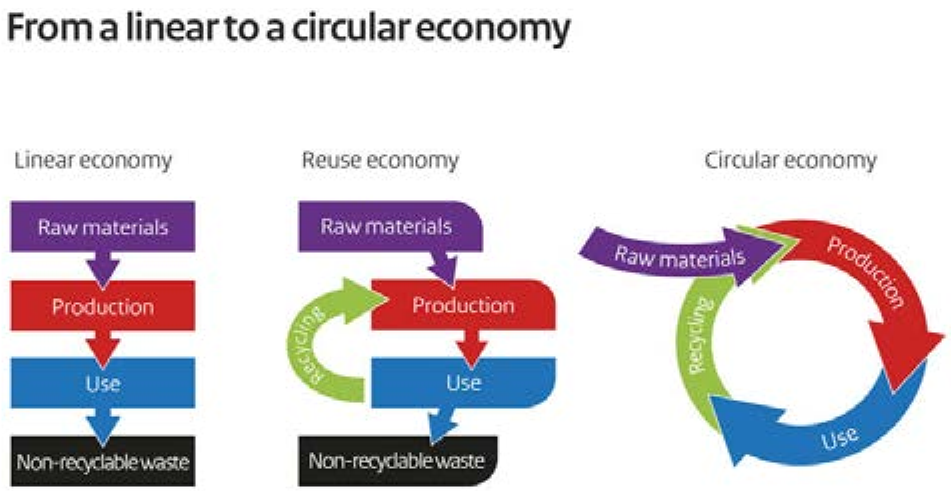


Image credit: https://www.government.nl/binaries/medium/content/gallery/government/content-afbeeldingen/infographics/from-linear-to-a-circulair-economy.jpg half of our business waste was recycled or re-used. It's good progress, but we are still generating substantial quantities of residual waste in this country with more than 17 million tonnes coming from households alone every year.[1]

A concept that has gained popularity in recent years is that of a 'circular economy', an economic model where waste products are used as resources for production across all industries, minimising both waste output and the consumption of raw materials.

Currently, the vast majority of industry and commerce operates within a linear model, where raw materials are harvested, processed into resources, manufactured as goods, used, and then eventually disposed of as waste. By converting waste into raw materials, this linear supply chain can be closed into a loop, significantly improving the sustainability of the economy as we know it.

Why is the valorisation of waste important?

The are two main benefits to waste valorisation. The first is that it provides an additional revenue stream to several industries that so far remains largely untapped. The second benefit is that efficient valorisation can significantly reduce the environmental damage caused by carbon emissions and waste disposal.

Waste, by its very definition, is often destined for landfill, and is where more than half of all waste generated in the UK ends up every year.[2] Sending waste to landfill is ideally avoided wherever possible because, aside from wasting potentially valuable materials, landfills leak toxic substances into the ground, air and water table, creating significant environmental damage to the surrounding area and contributing to greenhouse gas emissions.

Maximising the efficiency of waste recovery and valorisation is key to creating a sustainable economy and maximising overall productivity.

Legislation of waste

Waste management in the UK is primarily governed through the Environmental Protection Act 1990, an act of parliament that contains legislation covering air, ground, and water pollution levels, as well as the responsibilities of local authorities, businesses and UK citizens to properly dispose of waste. Failing to follow the laws set out in the Environmental Protection Act is a civil offense and companies can face large fines for failing to comply with regulations. For example, in June 2017, the supermarket, Tesco, was ordered to pay £8 million in fines after a leak at a petrol tank spilled more than 23,000 litres of fuel in Haslingden.[3]

The Environmental Protection Act also contains tight legislation regarding the disposal of hazardous waste. Due to these regulations, it is often highly impractical, or impossible, to recycle or valorise hazardous waste materials.

EU legislation regarding waste management is largely defined by the EU Landfill Directive, which defines proper landfill management policies and details what types of waste are suitable for different landfill sites. As well as ensuring that landfills are managed safely and cause as little damage to the surrounding environment as possible, the Landfill Directive also aims to significantly cut down on landfill use overall and promote recycling and other waste valorisation processes. The current target in place for the Directive is a maximum landfilling rate of 25% by 2025.[4]

1. http://www.wrap.org.uk/content/energy-recovery-maximising-value-waste-materials
2.https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/593040/UK_statsonwaste_statsnotice_Dec2016_FINALv2_2.pdf
3.http://www.bbc.co.uk/news/uk-england-lancashire-40295238
4. http://ec.europa.eu/environment/waste/landfill_index.htm

WHERE YOU CAN GET VALUE FROM WASTE

Which industries are using waste valorisation?

Agriculture

Agriculture is one of the most suitable industries for waste valorisation, due to the application of waste plant material as a feedstock in the production of biofuels. The use of biofuels worldwide is steadily increasing, with global production exceeding 80 million tonnes of oil equivalent in 2016. [5]

Because of their relatively low carbon emissions, and potential as a renewable source of fuel, biofuels could one day entirely replace the use of fossil fuel and, as the world's oil supply creeps towards depletion, the value of biofuels, and the materials needed to make them, is only going to increase.

Agricultural waste can also to be used to

5.http://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy/renewable-energy/biofuels-production.html produce organic plastics and polymers for use in manufacturing. Such plastics can be biodegradable, making them an ideal material for disposable items such as packaging or cutlery. Bioplastics produced from starch can even be made edible, and are used to produce pharmaceutical capsules. [6]

For example, bioplastics manufacturer, Biotec, produce a patented edible plastic called BIOPLAST TPS that is used both to package food and as the plastic coating for various liquid capsules.

The manure of livestock also contains meaningful value in the production of methane from biogas. Many agricultural enterprises perform low-value valorisation on livestock manure through its use as a fertiliser, as it takes little more than a shovel and a muck spreader to convert this waste into a resource. Converting this manure into biogas represents a far more valuable avenue for valorisation and so, as more biogas facilities are constructed and availability improves, the potential value of livestock manure will likely increase.

Food and drink

The food industry is one of the biggest contributors to waste. In the UK alone, food accounts for 10 million tonnes of waste valuing £17 billion a year, 60% of which could have been avoided. [7]

Although the overall efficiency of the industry is often called into question, extracting meaningful value from food waste can significantly reduce the environmental and financial costs of production.

The Courtauld Commitment 2025 is attempting to address these issues with its ambitious goal to cut the resources needed to provide our food and drink by one-fifth over ten years. One of the four overarching targets is to use the unavoidable waste from the industry for higher value applications. According to the 2025 Commitment, it aims to: "get more value from waste and surplus food and drink: identify wastes and surpluses that are currently ignored, match them to end-uses which deliver higher value, and help broker links to innovative technologies and new market opportunities." [8]

Like the agricultural industry, waste animal and plant material can be used as feedstocks to produce various biofuels and bioplastics, representing some of the largest potential for high-value valorisation.

The processing of pharmaceutical products is another high-value application area for the food and drinks industry. For example, pharmaceuticals giant GSK uses food-grade glucose as one of the key ingredients at its Irvine site to produce antibiotic medicines, but this ingredient has been known to have highly volatile pricing.

GSK recently worked with the Biorenewables Development Centre (BDC) at the University of York to find a more sustainable supply from starch/cellulose feedstocks and it successfully identified new potential sources of glucose from the food manufacturing supply chain to manufacture pharmaceuticals. The BDC completed two successful pilot-scale fermentation trials to assess the potential of using these by-products and, in collaboration with GSK, it is exploring methods to convert these feedstocks into antibiotics at a commercial scale.

At the other end of the valorisation spectrum, surplus food can also be easily valorised into animal feed, although this process is unsuitable for most spoiled or cooked food and is considered a low-value process. An interesting scheme to reduce surplus food waste is the increasing availability of misshapen produce for commercial use. Due to EU legislation governing the aesthetics standards of fruit and vegetables, approximately 40% of edible crops are discarded for simply not having sufficient visual appeal. [9]

6.http://en.biotec.de/bioplast/bioplast-tps
7. http://www.wrap.org.uk/sites/files/wrap/Estimates_%20in_the_UK_Jan17.pdf
8. http://www.wrap.org.uk/content/inspiring-action
9. http://www.wonkyvegboxes.co.uk/about

In 2014, French supermarket chain, Intermarché, launched a line of 'Inglorious' produce - misshapen fruit and vegetables that were sold at a discounted price. The UK company, Wonky Vegetables Ltd., is attempting a similar approach, and supplies misshapen produce to supermarkets such as Asda and Tescos.

The food and drink industry is also one of the largest consumers of bioplastics, which is one of the potential products from food waste valorisation. Bioplastics are widely used in food packaging, plastic wraps and drinks bottles for their biodegradable qualities. In addition, many of these bioplastics can also be effectively recycled. Efficient recycling policy combined with the valorisation of organic waste could significantly reduce the costs and environmental impact of packaging on both company revenues and the environment.

Case study: The REFLEX Project

Flexible packaging uses a range of materials with a total of 414,000 tonnes of plastic-based flexible packaging placed on the UK market each year. [10] The majority of this material ends up in landfills or is incinerated to recover its energy content.

A pilot demonstration project called REFLEX involved a consortium of companies across the flexible packaging value chain and aimed to understand and address the technical barriers to mechanically recycling flexible packaging in the post-consumer waste stream. The two-year project was co-funded by the UK's innovation agency, Innovate UK.

The REFLEX project undertook compositional analysis of a representative sample of flexible packaging in the post-consumer waste stream. This showed that approximately 40% is polyethylene (PE), 35% is polypropylene (PP) and 20% are non-polyolefin laminates. With nearly 80% of flexible packaging classified as polyolefin material, the project suggested this was a "positive finding, as a larger proportion of the current post consumer waste stream is potentially recyclable than previously believed".[11]

Several practical trials were conducted to demonstrate and evaluate the sorting and recycling of flexible packaging using existing and established technologies. The REFLEX project also explored opportunities to adapt or redesign current flexible packaging to improve recyclability at end of life where appropriate from a Life Cycle Assessment (LCA) perspective.

A key output of the REFLEX project is the development of a set of preliminary 'Design for Recycling' Guidelines. The aim of the guidelines is to provide information to packaging designers and technologists, filling machine manufacturers, brand owners, retailers and convertors to support them in designing and specifying plastic-based flexible packaging suitable for mechanical recycling at end of life.

The guidelines provide information on key components of flexible packaging structures, such as polymer type and coatings, and how these influence the suitability of packaging structures for mechanical recycling or energy recovery at end of life.

Richard McKinlay, head of the circular economy at consulting services company Axion, said: "While this was a pilot demonstration project, it demonstrated that the design and the recycling of flexible packaging and other post consumer products are so linked that the organisations involved across the entire supply chain need to talk to one another."

The report also highlights the high level of investment required for waste valorisation to work across the supply chain. A case study, based on an outline business model, was developed to estimate what is needed to establish a collection, sorting and reprocessing

10. http://www.wrap.org.uk/sites/files/wrap/Plastics_Market_Situation_Report.pdf
11. http://www.reflexproject.co.uk/wp-content/uploads/2016/12/REFLEX-Summary-report.-Final-report.pdf

infrastructure for post-consumer flexible packaging in the UK. The analysis found there is a viable business case for establishing this infrastructure in the UK, with an estimated investment of £100 million required to achieve full deployment, including costs to modify existing sorting facilities and to construct two purpose-built reprocessing plants.

The pilot is now complete and is being followed up with further projects, including the pan-European CEFLEX project. CEFLEX is a collaborative project across the supply chain that wants to make flexible packaging even more relevant to the circular economy.

Case study: NewTriton

Food and beverage giant PepsiCo is currently running an Innovate UK project known as "NewTrition" on waste valorisation. The joint UK/India project has just started and is due to finish in early 2019.

John Bows, R&D director at Pepsico, said: "PepsiCo R&D has been interested in waste valorisation for years (through internal funding and various collaborative attempts for external funding) but this project is the first to get any form of funding. the challenge being that cost reduction alone is not strategic enough without a product innovation angle, which is what the NewTrition proposal overcame."

The NewTrition (ReNEWable, sustainable nuTRITION) project aims to provide an approach in the re-use of commercial waste streams to create a market first, late stage customisation ingredient, which reduces oil and salt in the diet. The project also aims to develop an innovative process that is compatible with existing production and control systems to enable increased dietary fibre in the final product .

This will not only deliver major waste reductions but will also dramatically reduce CO2 emissions from transport and enhance the shelf life of a product 'made to consume', thereby reducing waste in both the distribution system and in domestic use. The system will be engineered by combining innovative process engineering know how, informed by food science research and development, with a ready market and supply chain to exploit the innovation. Outputs from this research will benefit India's economy through increased efficiencies and reduced need for raw material importation, and socio-economic development through environmental and human sustainability benefits. [12]

Manufacturing

Due to the wide range of materials and resources used in the manufacturing industry, there are many methods of valorisation available at multiple stages of the supply chain.

The majority of metals, paper, cardboard, fabrics and woods can be valorised, although the value of materials obtained can vary significantly depending on the exact wastes and processes that are used.

Maintaining a high quality end-product is essential to proper manufacturing waste valorisation, as the recycling processes for paper, metal and fabric respectively yield paper, metal and fabric as the end results. As technology improves and recycled materials continue to grow in quality, the manufacturing industry could significantly reduce its dependence on raw resources.

One of the most commonly used materials in manufacturing, plastics, represent significant challenges when it comes to effective valorisation. Although there are many recycling processes in wide use, these can only be used with specific types of plastics and almost invariably yield low-quality materials. In addition, plastic recycling produces harmful emissions and consumes a large amount of energy, and is therefore one of least

12. http://gtr.rcuk.ac.uk/projects?ref=102759

environmentally-friendly methods of recycling in current use.

Synthetic plastics are not biodegradable and so minimising plastic waste is vital to sustaining a healthy environment. Finding a green and efficient way to valorise plastic waste is a difficult hurdle to overcome, but the need for a viable solution is quickly becoming a necessity.

Electronics and electricals

The processing of large electronic appliances, such as ovens, is a well established process that reclaims steel and other valuable metals from waste appliances. Many appliance retailers will offer to dispose of a customer's previous appliance for free in order to harvest valuable materials from consumer waste.

The reclamation of materials from fridges is strictly regulated by government standards on the disposal of ozone-damaging gases, such as CFCs, and so require separate processing facilities from other large electrical goods like ovens and washing machines.

Another important area of waste valorisation in the electronics industry is the recovery of valuable materials from computer devices and circuit boards, which includes precious metals such as gold. The electronics industry is a huge sector, expected to reach a worldwide value of $2.9 trillion by 2020. [13]

With millions of new devices and components being manufactured on a daily basis, and the short functional lifespan of many computer products, it's little surprise that more than 40 million tonnes of electronic waste is produced each year.[14] Efficiently valorising this waste drastically cuts down on manufacturing costs, so many companies will offer to purchase outdated mobile phones and computers from consumers in order to valorise the waste for a direct profit.

There is no shortage of demand for the metal components that can be extracted from electronic waste, but finding value in the non-metal waste, especially the plastics used in circuitry, has proved challenging.

Case study: A new approach to "end of life" batteries

Aceleron is an emerging cleantech startup with a vision to accelerate access to energy storage by transforming end of life lithium batteries, such as those found in electric vehicles, into safe cost effective energy storage for developing regions.

The company is developing a process on an industrial scale where lithium ion batteries can be taken from multiple sources and, effectively, upcycled. Carlton Cummins, technical director and cofounder at Aceleron, explained: "We are developing a process that is robust enough to take batteries from a range of sources and reuse them for other applications."

"A lot of our processes are about testing and identifying where the battery is in its lifecycle and what it could be used for. That's a key thing. Anybody could take a waste battery and reuse it but if you don't know what you have then you can't verify that it's fit for purpose," Cummins added.

Aceleron has to liaise with existing channels to collect the batteries and then test them to identify the potential value using an in house method that's three times faster than standard lithium ion battery testing to improve turnaround.

The collection and testing stages are relatively easy as the manufacturers are usually happy to share the necessary information to such renovation work, and the testing process is adaptable to work across different battery chemistries, capacities and user profiles.

Aceleron is also developing a viable product range. Cummins explained: "At the moment, we have a very vanilla product which is a drop-in replacement to the lead-acid battery that's used in caravans, canal boats and other residential properties that need a battery to

13. http://www.prnewswire.com/news-releases/global-consumer-electronics-market-to-reach-us-29-trillion-by-2020---persistence-market-research-609486755.html

14. https://www.thebalance.com/e-waste-recycling-facts-and-figures-2878189

provide electricity to that property. Lead acid batteries are the cheapest power source for such applications but they are in no way the highest performing. We are developing a lithium ion battery that balances the price and the performance."

The company has a "global ambition" and an interest in taking its processes and products particularly to developing regions. Cummins explained that there is a "greater need" in such geographical areas because of the lack of local infrastructure means that high-tech items, such as batteries, must be shipped into the region and when those batteries reach the end of life, then the region is stuck with the waste and no means to valorise that waste.

But, if you change this mindset so a problematic or rundown battery can be renovated locally and reused then this empowers people, as Cummins explained: "People don't want the battery, they want what the battery does. So, why would you burden them with dealing with the battery waste when you could change the relationship where they could get what they want by collecting testing and building a product on home soil?"

Clothing and textiles

The clothing and textiles industry is worth $439.1 billion globally[15] and the waste it produces is significant. In the UK alone, 350,000 tonnes of waste clothing are sent to landfill each year.[16]

Some of the waste clothing produced in first world countries is exported to developing nations and donated to communities, but the majority of valorised material is recycled through several methods.

For clothes made purely from organic materials, usually cotton, the recycling process is relatively simple. After dyes and other contaminants are removed, the material is shredded into fibres and then respun into new yarn for manufacturing.

Clothes made of synthetic material, typically polyester, are shredded into small parts and then melted down and processed into granules. These granules must then be further processed to be made suitable for textile production.

Instead of making yarn, lower-grade materials can instead be compressed to make foam fillings used in furniture padding and car insulation, or turned into cloth rags for industrial use.

Through effective valorisation, the clothing and textiles industries could significantly reduce their waste output and cut significant costs in the purchasing of raw materials required for production, as the recycling potential for the materials involved in production is very high when compared to other sectors.

Transport

Waste valorisation is already a widespread practise in the transport and automobile industries, thanks to the high value of the materials in use and the relatively short lifespan of vehicles and component parts.

The processes for extracting and refining materials like steel, plastic and glass from defunct vehicles is well established, with the scrap metal industry being worth $17.5 billion globally in 2015.[17]

However, valorising one of the transport industry's biggest forms of waste, spent tyres, is still something of a challenge. Because of the size and durability of tyres, they are difficult to dispose of and take up an excessive amount of space in landfills. For many years, the vast

15. http://www.eulerhermes.com/economic-research/sector-risks/Global-Textile-Report/Pages/default.aspx

16. http://www.wrap.org.uk/sites/files/wrap/VoC%20FINAL%20online%202012%2007%2011.pdf

17. http://www.isri.org/docs/default-source/recycling-industry/facts-and-figures-fact-sheet---recycling.pdf?sfvrsn=4

Image credit: http://www.amusingplanet.com/2015/01/worlds-biggest-tire-graveyard-in.html

majority of waste tyres were simply piled up into large mounds and left to gather dust.

Since 2010, more than 90% of waste tyres in Europe have been successfully recovered and valorised.[18] Unfortunately, the prevailing method for valorising tyres is incineration for energy production. Although this is preferable to landfill (and tyre mounds), burning tyres is both inefficient and damaging to the environment.

As well as incineration, there are some recycling avenues available, as waste tyres can be used in the production of rubber asphalt and other low-grade construction materials.

Using advanced valorising methods on tyres is still largely in the experimental stages, but tyres could be efficiently converted into valuable fuels, like syngas, through pyrolysis technology. However, due to the size of tyres and the risk of toxic emissions, innovation is still required before an effective process can be developed.

Construction

The waste from the UK construction industry amounts to more than 50 millions tonnes a year and, as the demand for new buildings constantly increases, the production of waste materials is only going to grow.

There are numerous methods of valorisation available for many construction materials, although they often yield low-quality products and have difficulty generating value. For example, clay bricks can be reclaimed and used to create new bricks, but these recycled bricks are typically weaker than new bricks and are not significantly cheaper to produce. Waste bricks can also be broken down into fragments to be used in landscaping, surfacing and road construction, but these applications still don't generate meaningful profit.

Concrete is another large component of waste, generally generated through demolition projects, but it also fails to generate much value through valorisation. Like bricks, waste concrete can be broken into fragments to be used as gravel for road construction and landscaping. Because of the difficulties involved in transporting large pieces of concrete, much of the waste concrete from demolition projects is crushed on-site, and

18. http://www.etrma.org/uploads/Modules/Documentsmanager/brochure-elt-2011-final.pdf

so much of the valorisation process is completed incidentally.

Regardless of the low value of recycled materials, the UK construction industry successfully recovered 89.9% of non-hazardous waste in 2014.[18]

There are also many waste materials generated in construction that can't be valorised through existing processes. Carpet, which is generally comprised of a mixture of organic fabrics and plastic compounds, cannot be efficiently processed into valuable materials and is therefore responsible for a significant amount of waste, for example.

The waste materials generated from construction projects can typically be repurposed for use on other projects, but the waste from demolition projects (of which there is a lot) is often too heavily contaminated by substances like mortar and plaster to be suitable for many valorisation processes.

Due to this practically unavoidable source of waste, there is an emphasis on reusing or repurposing buildings as opposed to demolishing them outright. However, in many cases, this would be impractical or otherwise stall efficient development.

Mining

Although there are valorisation processes in place for mining, they generally only provide low-value materials. However, due to the vast quantity of waste produced by mining operations, using efficient valorisation methods is practically a necessity.

Large pieces of rock extracted during mining hold meaningful value in themselves, and can be sold on to be used as building materials, or set aside to be eventually used to fill in the mine when operations are complete. Large quantities of soil can be used in the same way.

When ore is processed, large quantities of ground rock, called tailings, are produced as waste. This waste rock can be used to manufacture concrete, although this is often of little value. It is, however, often more practical and economical to use the concrete made from tailings on-site instead of using manufactured concrete purchased from a supplier.

Slag is the melted rock waste created as a byproduct in the smelting of ores. Slag can be used in the manufacturing of materials used in road construction and so holds some value. Another byproduct of smelting is sulphur dioxide, an acidic gas that is damaging to the environment. Harvesting this gas during the smelting process significantly reduces the environmental impact of mining operations, as well as providing a valuable resource for the manufacture of sulphuric acid, which is widely used in the chemicals industry to make fertilisers and in the production of copper and zinc.

Key stakeholders and re-manufacturers

International and national bodies

The European Union has made nearly €80 billion available to fund research projects as part of the Horizon 2020 programme. Although Horizon 2020 funds many projects in various fields through it's rather vague objective to "drive economic growth and create jobs… with emphasis on excellent science, industrial leadership and tackling societal challenges", developing waste valorisation technology through research projects has the added benefit of indirect contribution to the EU's Landfill Directive.[20]

One such project to have already recieved Horizon 2020 funding is the rather awkwardly named REFRESH (Resource Efficient Food and dRink for the Entire Supply cHain), a valorisation

19. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/593040/UK_statsonwaste_statsnotice_Dec2016_FINALv2_2.pdf
20. https://ec.europa.eu/programmes/horizon2020/en/what-horizon-2020

project focused on reducing waste in the food and drink industry.

The UK-based charity, WRAP, works with governments and businesses to reduce carbon emissions, minimise waste and develop better strategies for resource management. Between 2010 and 2015, WRAP take credit for reducing greenhouse emissions by 50 million tonnes, diverting 29 million tonnes of waste from landfill and delivering £1 billion in savings through recycling and valorisation.[21]

The Institute for European Environmental Policy (IEEP) is a non-profit think-tank organisation that provides research and policy insights to national bodies, academia and industrial enterprises with the goal of reducing the environmental impact of industry and increase supply chain sustainability.

Waste service providers

The ESA (Environmental Services Association) is the UK trade association for the resource and waste management industry. As well as being a forum for various waste service providers to communicate, the ESA provides training, seminars and research to its members to help improve waste and resource management across the UK.

SWR (Specialist Waste Recycling) is the largest outsourced waste service provider in the UK.[22] The company aims for a 'zero-to-landfill' policy, where all collected waste is converted into useful resources or, as a last result, incinerated to produce energy. The company's successes include their work with restaurant chain, Pizza Express, where 100% of food waste was successfully diverted away from landfill and into anaerobic digestion processes.[23]

Organisations

The opportunities to deliver value from waste are increasing as the technologies and processes to reach market maturity develop. As a result, there are a range of companies working in waste valorisation across different horizontal and vertical markets. Here are the companies we spoke to for the purposes of this report:

Aqua Enviro

Aqua Enviro are wastewater treatment experts, with a particular focus on operating and optimising Anaerobic Digestion (AD) systems for digestion of sewage sludges. The company also applies this expertise in the waste sector. David Tompkins, head of Knowledge Exchange and Innovation at Aqua Enviro, said: "Valorisation for us means maximising biogas and ensuring that digestate / biosolids meets the requirements of the various certification schemes and customers."

Aqua Enviro collaborates with the Biorenewables Development Centre (BDC) at the University of York on a joint upstream / downstream service, in which the BDC consider valorisation options while Aqua Enviro consider the impact of the valorisation on downstream effluent and waste treatment, "since one of our major concerns is that the true costs of valorisation are rarely considered," Tompkins added. Aqua Enviro also runs conferences and other events, and have hosted events on biorefining in the past.

Axion

Axion is an engineering-led company operating in the resource recovery sector. It's approach to waste valorisation is twofold: IT provides consultancy services across the wider waste valorisation market and runs a processing operation in partnership with the second largest metal recycler in the UK (S. Norton).

When metal-based components are recycled (be that a car, radiator or washing machine) they are first shredded and a residue is created that is a mixture of plastic, stone, glass and all the other

21. http://www.wrap.org.uk/sites/files/wrap/WRAP-Plan-Resource-Revolution-Creating-the-Future.pdf
22. https://swrwastemanagement.co.uk/
23. https://swrwastemanagement.co.uk/case-studies/pizzaexpress/

constituent materials in that original product. Axion offers a process that separates out the different materials into useable products to make an aggregate product.

Richard McKinlay, head of the circular economy at consulting group Axion, explained: "We make a fine product that can go into building materials. We also recover the plastics and separate them further to make injection-grade remouldable plastic, which can go back into automotive applications or pipework and other such applications."

The requirement for such processing is, in part, due to the End of Life Vehicles (ELVs) Directive, which means you have to process and recover around 95% of an ELV.

The Biorenewables Development Centre

The Biorenewables Development Centre (BDC) is a not-for-profit subsidiary of the University of York and aims to bring research and industry together to better optimise processes for waste valorisation. As well as leading new research projects, the BDC supplies funding and support to small businesses to help increase efficiency and waste recovery on a case-by-case basis.

For example, using novel processing equipment available at the BDC, Quorn is exploring new uses for by-products from their vegetarian food production process. Unlike other brands using soy or grains, Quorn's product range is made with mycoprotein, produced by fermentation – a process commonly used in foodstuffs including bread and beer. As part of the business' continued innovations, the team at Quorn are working with a variety of partners to explore the best uses for by-products from their production process.

Developing effective systems to turn the biological portion of municipal and commercial solid waste (BioSW) into useful products, such as high-value chemicals and biofuels, is a challenge that Wilson Bio-Chemical is now tackling with the help of researchers at the Centre for Novel Agricultural Products (CNAP) in the Biology Department, University of York; and scale-up specialists at the BDC. This work has the potential to be a game-changing approach to mixed waste that will not only divert waste from landfill, but also displace fossil fuels and their associated carbon emissions.

With the help of the BDC, Wilson Bio-Chemical opened its Micro Autoclave Fibre Production Plant for turning municipal solid waste (MSW) into biomass fibre that can be converted into a range of useful products last year. This new technology aims to divert substantial amounts of mixed waste from landfill and produce a range of chemicals and fuels to replace the use of fossil-resource-based products.

BioVale

BioVale promotes and develops the bioeconomy across Yorkshire and the Humber region. Margaret Smallwood, CEO of BioVale, said: "We realised that Yorkshire is a really good place to focus on the bioeconomy because we have a very diverse and innovative agriculture, substantial bio-based industries and a quite an outstanding knowledge base."

NNFCC

Established by the UK Government in 2003 as the National Non-Food Crops Centre, NNFCC has grown into a commercial bioeconomy consultancy serving an international client base across bioenergy and bio-based products. The company initially focused on the development of the rural economy, through the development of industrial crop applications. This approach has widened over the years to embrace climate change mitigation through biofuel and bioenergy deployment. The NNFCC also covers land and marine based bio-based feedstock from agriculture and forestry through to municipal and industrial wastes.

HOW TO GET VALUE FROM YOUR WASTE

How to valorise waste

Sorting materials for valorisation

Sorting waste is the first, and often most labour-intensive, part of any valorisation process. Many processes are sensitive to contaminants or impurities, and so waste needs to be separated into usable and unusable materials.

This sorting process varies between materials and processes, but often the initial sorting of waste must be performed by hand. Various automation technologies have been tested and, in some cases, implemented, although these often prove to be somewhat ineffective.

Once unusable waste has been removed, the remaining materials are often shredded or otherwise broken down before being processed into valuable products.

Some materials can be further sorted after being granulated. For example, the steel components of a car can be easily separated from other materials with magnets once the vehicle has been broken down into manageable pieces.

For the valorisation of plastic waste, you can also separate the polymer type with methods such as near infrared or density sorting, but it is difficult to separate the different grades of polymer.

Polypropylene is a prime example of a materials comprised of many different grades. While you can process waste polypropylene for different applications by melting the polypropylene, introducing additives into the mix, modifying the melt flow, the viscosity, and the impact strength and introducing different materials to give the plastic different properties – you still cannot separate the different grades of plastic.

McKinlay said: "It's just a fact of life that you can separate them to a point but you will not be able to separate them fully."

"It's similar with post-consumer metal waste, such as non-ferrous metals like aluminium, S. Norton can recover a fraction of missed non-ferrous metals and then recover the aluminium out of that mix, but we still have 200 different types of aluminium within that remaining mixture," McKinlay added.

This remaining mixture can be melted down, analysed in terms of its composition and then materials must be added to give the resulting mixture the required properties. "There's definitely a lot of science that goes into valorising waste. You can't ever just take what you've got and put it into a high grade application. You have to have a level of qualification and processing to bring in the properties that you need," McKinlay added.

Let's look at those processing techniques now.

Current processing techniques

Flow technology

One of the biggest obstacles to efficient valorisation is the sorting process, and so effective automation is in strong demand. Recycling reverse-vending machine manufacturer, TOMARA, has made significant advances in this field with the recent release of their latest innovation, Flow technology.

Reverse-vending machines are used to collect plastic bottles for recycling, and are typically deployed on the commercial level in recycling centres. Flow technology is able to rapidly scan and identify the plastic materials inserted into these machines and automatically sort them. The rapid speed of this process in a significant upgrade as, with previous technologies, plastic waste needed to be mechanically rotated for the sensors to properly identify.

Although the speed improvements of flow technology are a relatively minor convenience

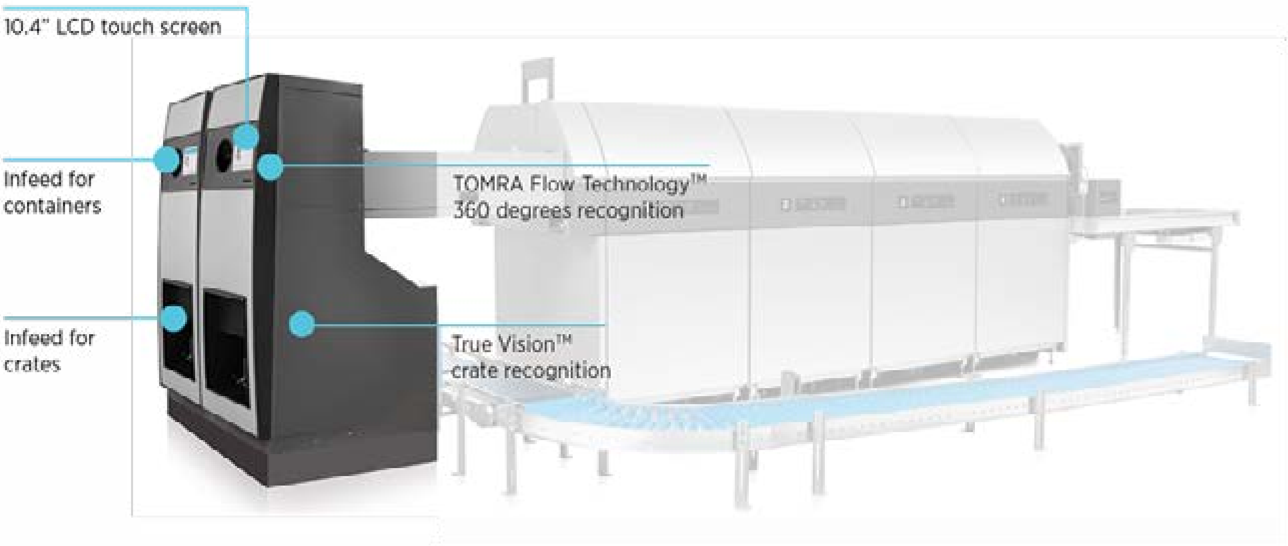


Image credit: https://www.tomra.com/en/collection/reverse-vending/products/front-end on the commercial level, its applications on the industrial scale could dramatically improve the efficiency and reduce the labour costs of plastic recycling processes.

Microwaves

The Green Chemistry Centre of Excellence, based at the University of York, have been conducting research into the effects of microwave radiation on organic waste.

Microwaves are already used in the disposal of medical waste as a method of sterilization, where waste material is heated until all biological organisms contained within are destroyed. Microwave technology is generally favoured over incineration, due to a higher energy efficiency and greater portability.[24]

However, new research has shown that microwave radiation could have even more applications in waste disposal. By accurately regulating the heat and precision of microwaves, they can be used to specifically control the decomposition of organic waste so that desired compounds are released. In one such experiment, sugars, furans, cellulose, and other valuable chemicals were successfully extracted from waste orange peel through controlled microwave radiation exposure. [25]

Some of the possible products that can be produced from microwaving waste include, biofuel, syngas, sugars, furans and carbon compounds.

The Biorefinery Microwave Demonstrator facility, housed at the University of York's Biorenewables Development Center, is a prototype technology only capable of processing 30kg of waste an hour in a continuous flow. If this technology can be refined and made commercially viable, it could significantly benefit the waste valorisation of all types of biomatter.

This technology may be especially useful to the agricultural industry. Due to the low energy consumption of microwaves, they can be made portable with relative ease, and are already used within medical waste treatment vehicles. If microwave-powered biorefineries can be made similarly portable, they could be invaluable in the valorisation of waste in remote locations, such as farms.

Pyrolysis/gasification

Pyrolysis is a process that involves heating organic waste in an oxygen-free environment to extract valuable gases from the feedstock. An oxygen-free environment can be created in numerous ways, including the use of vacuum chambers or submerging the reactants in water.

Pyrolysis produces carbon char or tar and a gaseous mixture known as syngas, often comprised of hydrogen and carbon oxides. Both the char/tar and the syngas produced can have value in biofuel production or manufacturing.

Historically, pyrolysis has been used to produce charcoal throughout Europe. Charcoal is still a valuable material to this day, with a diverse range of uses including fuel, filtration and soil enrichment.

Gasification is a very similar process to pyrolysis, but uses a low-oxygen environment as opposed to an oxygen-free one.

Pyrolysis and gasification can also be used to process synthetic waste, most notably tyres and various plastics. Through pyrolysis/gasification, the hydrocarbons packed into these waste materials can be reclaimed for use as fuel or in the production of certain chemicals.

For the most part, pyrolysis and gasification produce low-value materials and moisture contamination issues exist, which require the preprocessing of materials and products to remove such contaminants. This adds to

24. http://www.wastemed.com/treat2.htm
25. https://www.york.ac.uk/media/chemistry/research/greenchemistry/brochures/MW-2014_RGB.pdf

the expense of such processes and, if a low value material results, then it may not make good economic sense to use such a technique. For example, if moisture contaminants have been removed then the materials could be mechanically recycled to produce a higher-value end product.

Mechanical Recycling

This technique recovers plastic waste using mechanical processes such as grinding, washing, separating, drying, re-granulating and compounding. This produces recyclates, which can be converted into new plastics products.

Only thermoplastic materials, such as polymers, are of interest for this process. These can be re-melted and reprocessed into viable products using techniques such as injection moulding or extrusion.

Thermoplastics are comprised of multiple polymers with different physical and mechanical properties. This presents a major hurdle for mechanical recycling as this mix of polymers can have inferior mechanical properties and the resulting recyclates can be unsuitable for many applications. As such, mechanical recycling is generally only feasible for homogeneous, single polymer streams or for defined mixtures of polymers that can be effectively separated into the individual polymers.

Solid State Fermentation

Fermentation is a process that uses microorganisms to convert organic compounds into useful or desired molecules. Liquid fermentation has been used throughout history, and is still used today, in the manufacturing of alcoholic beverages, vinegars and bread.

Where liquid fermentation requires a large amount of water for the microorganisms to thrive, solid state fermentation occurs in an environment that only requires minimal or ambient water levels. Not only is this process more cost-effective and efficient than the liquid alternative, it also allows for the use of a more diverse range of microorganisms, such as filamentous fungi, which could significantly broaden the range of suitable feedstocks required for fermentation.

Depending on the feedstock and microorganisms used, solid state fermentation can produce a variety of valuable enzymes, which can be used in the food, manufacturing, agriculture and chemical industries. Some enzymes can even be used to further convert organic waste into valuable bioalcohols.

Microbial Digestion

Microbial digestion is a somewhat similar process to fermentation, where microorganisms are used to break down waste product into valuable substances. Unlike fermentation, microbial digestion uses anaerobic organisms that do not require oxygen. This means feedstocks do not require aeration during the digestion process, reducing the labor costs involved in valorising waste through this method.

Digestion of organic waste produces various gases, the most valuable of which is methane. Methane is a widely used fuel and is the main component of natural gas, which is supplied domestically through pipelines to power gas ovens and central heating, and is the preferred hydrocarbon for electricity generation in power plants across the world.

The solid remains of the feedstock that are left after digestion are known as digestate. Solid digestate can be used in manufacturing to create low-grade building materials and liquid digestate can be used as fertiliser in agriculture.

Because anaerobic organisms do not require oxygen, they are ideal for use with wastewater and other liquid waste products. Sewage is often treated with microorganisms to remove organic waste prior to further purification or disposal into waterways and landfill.

Chemical recycling

Although plastic recycling is widely publicised, effectively generating meaningful value from waste plastic still presents many difficulties. Typical recycling plants cannot process the majority of plastic waste and a significant amount of energy and resources are dedicated to separating out the usable waste material.

Once sorted, the plastics fit for processing are then heated to high temperatures to create a uniform substance that is often shaped into pellets that can be melted down and used in manufacturing. Recycled plastic is often brittle and generally inferior to petroplastics created from fossil fuels.

Due to this drop in quality, recyclable plastics are inevitably downgraded into low-quality materials that are no longer suitable for valorisation. This means that all plastic, even that which is recycled, will eventually end up as landfill. Combine this fact with the permanency of plastic waste and it is clear that the world's dependency on plastic materials is unsustainable.

Thermal conversion

Thermal conversion, also known as combustion or incineration, is the process of simply burning waste materials. Although thermal conversion is neither efficient nor environmentally friendly, it is the easiest way to extract some value from waste.

Burning waste can be used to generate electricity, although a typical waste-to-energy power plant only operates at approximately 35% electrical efficiency. [26]

Virtually any solid waste can be used in thermal conversion, and so the process is useful for acquiring value from otherwise worthless materials or as a means of valorisation in locations where other processes are unavailable.

What materials can you produce using green processing technologies?

High-value chemicals

Bioplastics

Bioplastics are a category of plastic materials that have a wide range of applications, the most popular of which is their suitability as a biodegradable material for disposable items, such as packaging, cutlery and drinking straws.

Bioplastics can be produced from waste biomass, typically sourced from vegetable fats or corn starch. However, some variants are derived from cellulose or ethanol, which can be easily acquired from agricultural feedstock.

Starch-based bioplastics are the most widely used for their relative ease of manufacture and versatility. Although naturally biodegradable, other materials can be blended with the polymer to create non-biodegradable variations.

Bioplastics are still widely manufactured from raw agricultural materials and developments in obtaining sufficient materials from waste matter are needed before bioplastics sourced from waste become economically viable.

Organic acids

Organic acids are acidic compounds derived from a huge variety of sources. They can be created through anaerobic digestion processes, and can be recovered as a byproduct from

26. https://waste-management-world.com/a/maximising-electrical-efficiency-at-waste-to-energy-plants

other biomatter valorisation processes. Household waste has the possibility to be a strong source of organic acids, as it has been shown that lactic, acetic, propionic and butyric acids can all be efficiently extracted. [27]

The vast majority of organic acids are of a weak acidity, and so are valued for sensitive cleaning applications and suitable for human and animal consumption.

The most typical organic acids used for cleaning products are citric acid, acetic acid and acetone. These compounds can remove rust and scaling from delicate metals without damaging the material beneath, unlike stronger acidic solutions such as hydrochloric and sulphuric acid.

In food production, organic acids have been widely used throughout human history as a preservative. Weak acids can kill pH-sensitive bacteria such as E. coli and salmonella without affecting the taste or texture of the food, and so are widely used in the meat production industry.

Organic acids are also used as nutritional supplements in the animal feed of pigs and poultry, as they can inhibit the growth of harmful bacteria in these animals guts' and so limit the spread of infectious intestinal diseases.

Furans

Furans are a type of aromatic compound that is widely used in the chemicals industry. Due to the unique chemical structure of aromatic compounds, they are used as one of the basic building blocks in the manufacturing of many valuable chemicals.

Currently, furans are primarily acquired from crude oil and so are both an unsustainable and environmentally unfriendly resource. Acquiring furans and other aromatic compounds from biomatter, and waste in particular, could prove to be a highly profitable area of valorisation for sugar-rich waste biomass.

Converting waste into furans is still under research, but some of the proposed and tested methods include heating waste with superheated steam to 'boil off' furans, and mixing waste biomatter into a slurry that is then heated with solvents to extract furans and useful acids.

A research project working on valorising waste for furans is the Waste2Aromatics project from Dutch research centre, Biorizon. The project has reported high success rates in their experiments with various types of organic waste and expect profitable commercial operations to be possible with continued research. [28]

Fuels

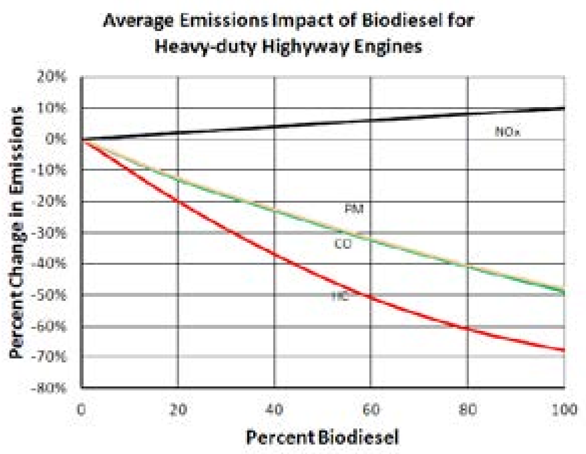
Biodiesel

Biodiesels are organically-derived diesel fuels produced from vegetable oils or animal fats instead of crude oil. They are widely used as fuel for automobiles, trains and aircraft as either a pure biofuel or in combination with traditional petro-diesels.

The production of biodiesel from waste can be especially valuable to the meat and fish industry. Animal fat and waste fish oil are prime sources of the lipids used in biodiesel manufacture. However, it would be inefficient and financially unviable to raise livestock or catch fish for the dedicated purpose of biodiesel production. As such, waste product from these industries represents the only viable source of animal-based materials for biodiesel production.

As well as their potential as a renewable source of energy, biodiesels are valued for their low carbon emissions in comparison to fossil fuels. Research from Argonne National Laboratory has shown that 100% biodiesel fuel produces 74% less greenhouse gases than petrodiesel equivalents. [29]

27. https://www.ncbi.nlm.nih.gov/pubmed/10595448
28. http://www.biorizon.eu/images/uploads/66-68.pdf
29. https://www.afdc.energy.gov/vehicles/diesels_emissions.html



https://www.afdc.energy.gov/vehicles/diesels_emissions.html

Bio-alcohols

The term bio-alcohols refers to alcohol compounds that are produced from biomass for use as fuel. Where biodiesel can be used an alternative to fossil fuels in diesel engines, bio-alcohols can be used as the renewable equivalent for combustion engines.

The most commonly used biofuel is ethanol, although methanol, butanol and propanol can also be used as fuels or in the chemical manufacturing industry.

Ethanol is valuable as an alternative fuel that could be both sustainable and less environmentally damaging than fossil fuels. Ethanol is also widely used as an additive in petrol manufacturing to increase the octane content of fuel.

Higher octane ratings ensure that fuel mixtures do not ignite under compression and therefore aid the stability of ignition timings and increase overall engine efficiency. Currently, generating profit from ethanol production is far more viable through use as a petrol additive than as an alternative fuel.

Although entire crops are dedicated to ethanol production, such as corn and sugarcane, almost any organic matter has the potential to be converted into bio-alcohols. Waste materials that are high in starch or cellulose are ideal sources of ethanol, which can be obtained through various fermentation processes.

Syngas/Biogas

Biogas is a term that refers to the gases produced by processing biological waste, generally through fermentation by microorganisms. Biogas is typically a mixture of methane and carbon dioxide, but it can also contain small amounts of other gases.

Biogas can be processed to concentrate the levels of methane and compress the gas into a state that is suitable for use as a fuel. This biofuel can be made to the same standards as natural gas, and so can be used in many existing engines as a substitute for natural methane gas, which is an especially valuable resource in electrical energy production.

Syngas is a different type of gas that can be produced from waste biomatter, and is valuable for its hydrogen content. Like biogas, syngas can be used as a fuel in engines and generators, although it also has further applications in the production of chemicals, industrial gases and fertilisers.

Syngas is an abbreviated term for synthesis gas, as it used as a reaction intermediate in the manufacturing of synthetic chemicals such as ammonia and methanol. It is also used for the production of synthetic natural gas, a substitute for oil-based domestic gas supply. Without further processing, Syngas has approximately 50% less energy density than natural gas.[30]

Sulphuric acid can also be obtained as a byproduct of syngas production, which is a valuable resource in the chemicals industry.

Acquiring syngas from waste involves a process of gasification, where the waste material is heated to high temperatures in a pressurised, low-oxygen environment. Unlike

30. http://biofuel.org.uk/what-is-syngas.html http://biofuel.org.uk/what-is-syngas.html

the fermentation process for biogas, syngas requires significantly more energy to produce.

Obtaining syngas or biogas from waste is dependant on the type of materials used as feedstock. Biogas production is best suited to waste that is high in starch or sugar content, whereas syngas can be obtained from a wider variety of municipal waste.

Biofuels from pyrolysis oils

Pyrolysis oils are the organic equivalent to crude oil. They are produced by raising biomass to a temperature of 500°C or higher in an oxygen-free environment to prevent combustion and other unwanted reactions. The resulting product is a dense, viscous substance known as bio-oil.

Historically, bio-oils in the form of wood-tar have been used as a water-repellant to treat wooden structures such as roofs and boats. Other bio-oils, or derivatives from bio-oils, are still used today as wood preservatives, cleaning fluids and as flavourings in food production.

The use of pyrolysis oils as a fuel is still in the experimental stages, as an effective process to refine these oils into compounds with a higher energy density is yet to be developed.

If an effective method is successfully deployed, waste wood from agricultural sources can be processed into biofuels with similar efficiency to other biofuel manufacturing methods.

CHALLENGES FOR WASTE VALORISATION

While there are many hurdles to overcome in the waste valorisation sector, the root cause of all such issues are economic in nature. If the value of waste valorisation can be communicated across political, social, technological, legal and (to a lesser degree) environmental quarters then it will truly start to see widespread adoption.

"There isn't so much a technology barrier as an economic barrier for waste valorisation"
- Richard McKinlay, head of the circular economy at Axion.

PESTLE Analysis

Political drivers

There are many political drivers and initiatives within the waste valorisation market, which include carbon and landfill targets, governmental incentives (such as recycling credits), trading schemes and public sector procurement policies.

But a stronger and more cohesive approach is needed where the barriers to waste valorisation across every political and geographical boundary must be brought down for the sector to truly thrive in the years ahead. And, although this may sound counterintuitive, a global approach is needed to see local success for waste valorisation.

A lack of long term strategy is stifling the waste valorisation sector

Consistent policies are needed to promote waste valorisation is hampering development in the UK's waste valorisation sector.

"Policy uncertainty is the biggest challenge the

UK waste valorisation sector is facing," according to Dr Jeremy Tomkinson, CEO and lead consultant for biofuels at the NNFCC. *"Every three months the regulations change, leaving everyone wondering what's going on. Brexit is the elephant in the room, we are involved in various projects which are currently being left in limbo as we wait for 2019 and further information on the government's plans."*

This leaves the market to decide the approach to take for waste valorisation. Tomkinson added: "If you just let the market decide, it will do what is the most cost effective, easiest and what makes makes the most money. Not necessarily what is most strategically important to the country - that's where policy needs to come in."

For example, gate fees for alternative waste treatment options (such as incineration) go against the waste valorisation ethos to maximise efficiency. Tomkinson explained: "Incinerators do not want efficiency as they are paid by mass so the last thing they want is an efficient process. In sectors [like this] where the market simply won't come to the optimal, most efficient solution, this is where policy needs to intervene."

"There is a lot of phenomenally exciting work going on but this is all outside of the government 'assisted areas'. Many developers feel like they are completing projects in spite of the government not because of it, as currently it is more of a hindrance. The promise of a government using a regulatory light touch hasn't appeared as we find renewable regulations like the FITS being changed every quarter."*

**** FITS: Feed-In Tariffs. These apply to small-scale generation of electricity using eligible renewable technologies. To encourage development of these technologies, feed-in tariffs pay the generator a certain amount even for energy which the generator themselves consumes.*** [31]

"Certainly in the field of EfW (Energy from Waste) it feels like we're going round in circles. Whilst one department is happy to export RDF (Refuse Derived Fuel) to the continent for incineration we have another actively promoting the use of the same resource for energy recovery in the UK. Surely now is the time to sort out what we need for the UK post 2019, if we get this wrong now we could rue the day for years to come," Tomkinson added.

Connected thinking through government interaction

Connectivity is key across all the horizontal and vertical markets, as Margaret Smallwood, CEO of BioVale, said: *"Although the government invests in connecting academia to industry, it's just as important to make the new connections between these industries which have not interacted in the past. Trade associations don't do it because they are focused on their own sector, and there isn't really anyone to do that unless the government steps in."*

Localisation matters

While a global approach to valorisation is needed at every point in the supply chain, such collaboration must be facilitated at a local level. For example, EU policy lays down that, within Europe, waste should be disposed of as close as possible to where it is produced (known as the Proximity Principle). The need for localisation of waste management makes sense to reduce transport costs and develop an optimised supply chain. As Smallwood explained: *"If you have food waste, for example, you do not want to be moving it miles and miles, you need someone to deal with it close to home."*

This is where local authorities must aid local businesses to realise the most amount of

31."Feed-in Tariffs: get money for generating your own electricity". Department of Energy and Climate Change. Retrieved 8 August 2013.

value from waste. This, in turn can create a cluster of innovation for valorisation, *"So, there are good reasons to make those local connections between organisations,"* Smallwood added.

Economic drivers

While competition remains low in this industry due to its infancy, cost is a major barrier preventing the waste valorisation market from reaching full maturity.

Yet, economic drivers are the beating heart of the waste valorisation movement. If we can remanufacture, reuse and recycle so that one industry's waste becomes another's raw material, we can move to a more circular economy where waste is eliminated and resources are used in an efficient and sustainable way to maximise productivity and profits on an epic scale.

An unguaranteed return on investment

Concerns over a ROI remain prevalent as the processing of materials for waste valorisation requires a substantial infrastructure and R&D investment to ascertain the feasibility of such techniques. McKinlay said: "*The technology is there but without better economics it's so hard to justify installing more processing infrastructure. You need to prove the payback on such investments."*

Fluctuating yields

Another concern around cost is the fluctuating yield you will receive from your waste. For example, if you are processing post-consumer milk bottles then the amount of residue milk, moisture or non-recyclable material will differ across batches, causing your yield to vary, making it difficult to predict your profit margins. McKinlay said: *"You need to ensure the quality of the incoming material, which in the responsibility of the consumer and the original producers of the material."*

Aqua Enviro's Tompkins said: "The issue at the moment is that there are a large number of valorisation approaches that work in the lab (and perhaps at pilot), but the availability of waste to feed these approaches is limited or unknown, and the true costs of producing the new material aren't properly understood."

"I fear that we will see a scramble for quantities of consistent feedstock to feed one or two modest-scale biorefining processes, and that challenges associated with adding value to any type of mixed waste (including household food waste) will not be addressed," he added.

One solution could be to buy in waste, but then you may have different qualities from different suppliers, which is difficult for processors to manage on a short and long term basis. For example, there were high profile cases of recycling processes who went into administration in 2014 who bought material from waste management companies, according to McKinlay, who added: *"They were buying on one side and selling on the other and the prices fluctuated. So, sometimes they would be in a good situation where they could buy at a low amount and sell at a high amount – but sometimes it was the other way round."*

"If you can eliminate the buying in of material then you can control your material, bring in a lot more stability and this allows you to look to increase your value from the material," McKinlay added.

Lack of a centralised funding agency

The absence of a consistent form of funding also makes the complexity of applying for waste valorisation incentive schemes unattractive for companies. Simply put, there are too many routes to receive small pockets of funding, whereas a single funding body would help organisations interested in waste valorisation. Smallwood said: *"There are so many different systems and I think there's an onus on the government to make that sort of innovation support much simpler and bring it together in one place."*

Social drivers

The pressure to conform for consumers and manufacturers

Concerns about yield rates mean it's important that consumers to adhere to basic recycling rules such as, for example, not contaminating their waste by putting the wrong item in the wrong bin. But this pressure on the consumer is unfair, according to Aceleron's Cummins, who said: *"If you observe the whole dynamic, you realise the circular economy is pushed at the consumer because it's the easiest person to pitch the problem at. But there are a lot of problems that the consumers really shouldn't be dealing with."*

"For example, food packaging recycling. You often have three different materials on a packet that need to go into three different bins. And the consumer bears the responsibility to identify, separate and dispose of those different materials into different bins. But the packaging was designed that way. Instead, it should be designed to make it as easy as possible. The same logic applies to batteries. When we come to disassemble them, they should be designed to facilitate their recycling or renovation," Cummins added.

In other words, start-of-life manufacturers should try to design products that will have the maximum value at the end of life, instead of just being recycled into a low grade application.

It's the responsibility of consumers and manufacturers. *"Both parties need to make sure the material can be processed and that we can get a high quality material out of that process,"* McKinlay added.

The importance of connectivity

One waste product may not necessarily equate to one form of value-added material after processing and this results in a complicated supply chain across multiple industries.

For example, if you manufacture a product with onions, the onion skins are not edible and cannot be further used in the food supply chain. But, they are filled with useful substances such as antioxidants and dyes that could be useful and valuable in other applications. *"You need to bring together quite a complicated group of people together to make that happen, including a technology provider, someone who can use that technology - and there may be more than one user,"* according to Smallwood.

And, in some cases, it may make more sense to send a residue for AD but, in other cases, there may be a sound economic case to continue to process and add value to the byproduct. *"It's very much horses for courses. We need different via*ble supply chains for dealing with waste," Smallwood added.

"Creating those new value chains and the connections between them is vital. With this new sector, people do not know each other. They talk different languages. Having someone

to help interface and make those connections is really important and being able to do that at a local level is important too."

"Often different sectors are using the same basic science and you can reuse discoveries from one sector in another sector - that means you get more bang for your buck in terms of R&D. There are a lot of opportunities in terms of innovation but also in terms of the supply chain," Smallwood added.

The NIMBY (Not In My Back Yard) retaliation

Proximity initiatives are not a popular approach with the general public as environmental technologies consultant, Derek Pedley, explained: *"If someone comes into your area and wants to build a waste management plant, you're up in arms. That's because we don't treatment of waste on our own doorsteps."*

For example, an action group was recently launched by concerned villagers in the Cambridgeshire village of Hemingford Abbots to *"fight plans to dump a giant recycling plant on their doorsteps"* following the announcement construction industry supplier, Mick George, has earmarked a nearby 42-acre site to develop a waste handling and recycling operations centre.[32]

Reputational Risk

The amount of publicity surrounding recycling and other green initiatives has made the manufacturing sector a little nervous, as Margaret Smallwood, CEO at BioVale, explained: *"As with all industries, people are prepared to talk about their successes but less prepared to talk about their failures. But it's important to share that information so others do not make the same mistakes. So, facilitating those trusted spaces where people can share their experience and make the connections is key."*

This is an important point. Because waste valorisation is not a mature concept, it can be difficult for those interested in adopting such practices to know the best approach to take. A safe, collaborative environment is needed where all interested parties can interact without the fear of condemnation from external forces.

Overcoming preconceived ideas on quality

A key challenge is encouraging the end user to pay the same or a very similar amount for recycling content as they would for virgin materials or goods. McKinlay explained: *"By the time you have processed the material,a lot of money has gone into that process and you need to sell the processed materials at the same price as virgin material. The end user needs to commit to using recycled content but there's a negativity around recycled content because of preconceived ideas of quality."*

The virgin material manufacturers, including Dupont, Total and Dow, are now investing in recycling operations to overcomes such preconceptions by matching the properties of a virgin polymer by, for example, creating a 50/50 mix of virgin and recycled polymer. This helps to build consumer confidence as the product is from a well-known manufacturer with established processing capabilities. McKinlay added: *"It's a change in mindset from the old idea of taking waste and 'where there's muck there's brass' to the very scientific, complicated and expensive processing that's now carried out."*

32. http://www.huntspost.co.uk/news/group-to-fight-mick-george-recycling-plant-in-hemingford-1-5038435

Technological drivers

"A lot of technologies are not proven and there's a need for government to help derisk them" Margaret Smallwood, CEO of BioVale.

Pushing for more value across the value chain

Waste valorisation is still in its infancy and a coherent approach to collection, disassembly, sorting and reprocessing technologies is required. McKinlay said: *"There is a disconnect. The potential value needs to be seen across the whole value chain."*

Aceleron: Providing a cohesive technical approach

While only within the confines of one company, Aceleron's three-stage approach to collect, test and produce a value-added product from waste lithium-ion batteries is an example of how others in the waste valorisation industry could take a more connected approach to the supply chain.

The company has a patent on its battery assembly hardware, which allows remanufacturers to quickly disassemble the battery pack so its components can be refurbished or recycled. Its technical director and cofounder, Carlton Cummins, explained: "Because we spent a lot of time disassembling other people's waste, we learnt how other people build batteries. So, when we built our new battery, we redesigned how it works."

"The industry has a nasty habit of forgetting that everything dies. So, we have a habit of making things that do the job for the first application but we forget that at some point it needs to return to return to the Earth or be managed appropriately," Cummins said.

"We way we built our battery is so that we would be happy to take it back at end of life. We are hoping that such a system will change the relationship people have with a battery where it is not just seen as a product with a linear lifecycle but as something we could keep in a loop."

"Even if these batteries have to go on their final trip to the crusher, when all their value has truly been extracted. It is important to extract the full value but not to create another waste problem while doing so. We need to solve today's problems without creating problems for the future," Cummins added.

Knowing when to add value

There are many different ways to process and add "value" to a waste product. Where we draw this line, with regards to what constitutes value and what does not, is tricky.

For example, if you take a very low grade of plastic mixes, different types of polymer are present in that mix. You can, in theory, make a low-grade board which retains that polymer mix, but you're not getting the full value out of the material. Instead, you could take that plastic mix, separate out the different types of plastic and reintroduce it into high grade applications, hence adding more value to the processing chain. Axion's McKinlay said: *"There's definitely a difference between taking a material as it is and using it as is, versus taking that material, looking at the properties and seeing if you can modify that material to add more value to it."*

"This is especially true for polymers and metals. For polymers, we recover polypropylene and we can either sell it as it is, or we can work with the customer to modify it to match it to the

properties they need for a specific application. By doing that you add more value to the polymer, and what you need is clever polymer scientists, you need a lab and the right resources to achieve that. You can't just take it away and shred it."

There is a time and a place for such high-grade processing, as McKinlay added: "I think there is still a need for these lower grade applications, just from a volume point of view. It may not be the best in the long term, but in the short term you can target different markets and perhaps in the future look to access additional markets but there is an argument for all sorts of recycling activities to find a use."

Legal drivers

Turning waste into a resource is one key to a circular economy. The objectives and targets set in waste protocols, product stewardship legislation, national and European legislation and landfill restrictions have been key drivers to improve waste valorisation, stimulate innovation in recycling, limit the use of landfilling, and create incentives to change consumer behaviour.

However, more could be done in the legislative space to further encourage the advancement and adoption of waste valorisation processes through economic drivers. *"We need better economic drivers. Either through legislation that says people must use recycled content or increasing taxes on people putting low-potential material on the market in the first place. There definitely needs to be more economic incentives, otherwise it's too easy to use landfill,"* McKinlay added.

Environment drivers

Waste valorisation is also one component of the wider circular economy. If realised, the shift to the reuse, material recycling and valorisation of waste would have a huge environmental impact.

The environmental drivers for waste valorisation mirror that of the wider waste management sector. Such processes address concerns around the overconsumption of natural resources and the techniques used to extract such materials, the world's overflowing landfill sites and the wider impact of climate change due to air and water pollution.

Summary

P

Drivers include carbon and landfill targets, governmental incentives, trading schemes and public sector procurement policies.

Connected thinking through government interaction needed

Localisation incentives required

Clearer long term policies lacking in the UK

E

An unguaranteed return on investment

Fluctuating yields

Lack of a centralised funding agency

S

The pressure to conform for consumers and manufacturers

The importance of connectivity

NIMBYism

Reputational Risk

Overcoming preconceived ideas on quality

T

A coherent approach to collection, disassembly, sorting and reprocessing technologies is required

More development in "high value" valorisation technologies is required

L

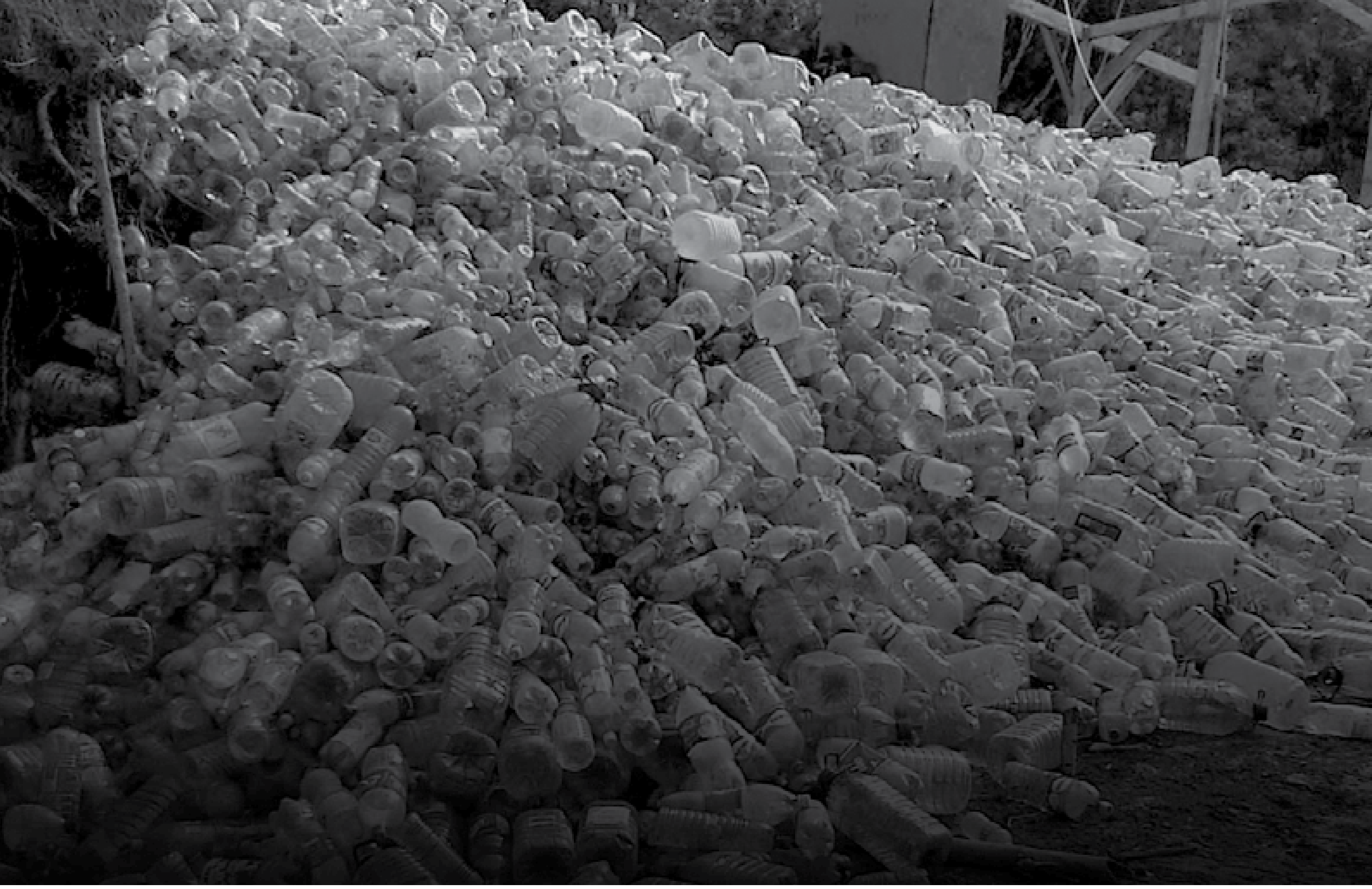
Waste protocols, product stewardship legislation, national and European legislation and landfill restrictions stimulate innovation in recycling, limit the use of landfilling, and create incentives to change consumer behaviour

Better economic drivers through legislative change are needed

E

Reduce the pressure on natural resources and the effects of climate change due to air and water pollution

31."Feed-in Tariffs: get money for generating your own electricity". Department of Energy and Climate Change. Retrieved 8 August 2013.



HOW LABORATORIES CAN HELP WASTE VALORISATION

The waste valorisation sector is still in its infancy but the financial and environmental potential of this industry cannot be overstated.

Many stakeholders need to play a part for this industry to reach maturity. The UK Government, in particular, seems to have overlooked the importance of waste valorisation. Long term strategies and fundings opportunities from a centralised body need to be readily available for the industry to thrive. The general public seems, at best, disengaged with the sector and industries need to see a guaranteed return on investment before developing or implementing valorisation strategies.

Laboratories also have three key roles to play on both in terms of encouraging innovation and collaboration in the waste valorisation sector.

1. Supplying industry with pre-sorted waste

The recycling and disposal of waste from laboratories must be stringently monitored with processes in place for the segregation, collection and disposal of waste. For example, the segregation of hazardous and non-hazardous waste materials is a legal requirement. If done incorrectly, this could both lead to legal and financial penalties, depending upon the severity of the noncompliance.

As such, laboratories are in a unique position to provide the wider supply chain with pre-sorted waste, negating the need for many of the cumbersome preprocessing activities previously mentioned in this report.

If laboratories can reach out to local businesses working in (or interested in) the waste valorisation sector, a supply chain can be established. In other words, laboratories can provide the waste valorisation sector with the raw material (the pre-sorted waste) it needs to develop innovative new processes.

2. Valorising inside the laboratory

Innovation does not, of course, belong purely outside of the laboratory. Laboratories need to implement strategies to reuse unwanted material, redistribute surplus chemicals, and reduce hazards. Practices that implement this strategy include purchasing only what is needed, keeping chemical inventories to prevent the purchase of duplicates, and reusing excess materials.

For example, the opportunities for high value valorisation techniques from waste chemicals are rife - but industry has failed to fully develop waste valorisation in this area. As major chemical waste producers, laboratories could exploit this untapped resource by developing in-house processes.

3. Bringing it all together: Waste valorisation enablers

Laboratories work with a range of parties for waste disposal. This usually includes the waste producers, domestic and special waste management teams, waste managers and third-party contractors and suppliers.

Laboratories are, therefore, at the heart of the waste industry. Their unique combination of local knowledge and a global perspective could provide the knowledge and resources to form the bridge between the waste producers and valorisers.

The Biorenewables Development Centre (BDC) at the University of York is a clear example of how to bring research and industry together to better optimise processes for waste valorisation.

If other laboratories can mirror this approach, the nation's laboratories can negate many of the issues currently hampering the waste valorisation sector.

A coherent approach to collection, disassembly, sorting and reprocessing technologies and the development of high value techniques can both be facilitated. The return on investment of such strategies can be demonstrated. This may persuade the UK Government to invest in waste valorisation - and the preconceived ideas of waste valorisation within the wider population could start to dissolve.

Simply put, if the nation's laboratories can start to supply, innovate and collaborate within waste valorisation then they could unlock the entire industry for the world to realise the full myriad of its environmental and economic benefits.

THE FUTURE OF WASTE VALORISATION

Waste valorisation is an attractive concept that has gained increasing popularity as the combination of the adverse effects of climate change and austerity come into focus on an international stage.

If there was ever a time when the world needed something for nothing, it's now.

Because of this, organisations are not only developing waste valorisation strategies with the highest value but are also focusing on the design and development of greener materials and technologies to facilitate the wider circular economy.

The fly in the ointment is the lack of government support in the UK to incentivise such activities. Help is available, but it is sporadic in nature and constantly changing policies and legislation make it difficult to develop and implement long term projects and strategies.

Pockets of innovation are springing up within the waste valorisation section. One example of this is Aceleron's renovation and redesign of lithium ion batteries. Not only does this address an area where demand for an environmentally sound solution will be under increasing pressure as our demand for battery-fueled electronics increases, such solutions are also economically attractive due to their cyclic ethos to renovate, reuse and repeat. And this solution its eyes on providing a global solution to the circular economy.

Such high-level aspirations are not just admirable, they are necessary and provide the much-needed environmental and economic balance for waste valorisation to see further adoption.

Perhaps the main and most important issue to be addressed for the sake of future generations, currently way overlooked, are the social implications of waste valorisation.

The extended perception of waste as a problem, as something without value that needs to be consigned to landfill or an incinerator must stop. Government policies must be clear and forthcoming to facilitate this change across the supply chain.

Waste needs to be regarded as a highly valuable resource. While this resource is significantly complex in terms of its variability in composition and diversity across industrial sectors, it could also provide a limitless number of innovative solutions and alternative end products through advanced valorisation strategies.

To realise the huge potential value of waste valorisation, we need to see a monumental shift in attitude where the joint efforts from a range of disciplines lead us toward a more sustainable society and economy, not to mention an environmentally sounder planet.

The current generation just needs to accept that our trash will be viewed as a goldmine by future generations.

Where there's muck there will be brass now, and in the years ahead.