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Waste as an opportunity

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Title	**Waste as an opportunity**
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Keywords	*waste* *waste valorisation* *green chemistry* *waste at a molecular level molecule recycling*
Direct Submission or Supporting Article?	*This is a direct submission*

Abstract:
Waste can be valorised at a molecular level thus broadening the scope for waste utilisation. This requires a multi partner and multidisciplinary approach including engaging different industry sectors and introducing new concepts in education, as well as good public engagement.

SPECIFICATIONS TABLE

Sustainable Development Goals (SDGS) the research contributes to	*GOAL 9: Industry, Innovation and Infrastructure* *GOAL 12: Responsible Consumption and Production* *GOAL 13: Climate Action*
Resource availability	
Related research article – please ensure to include the web address of your article so we can link to it	Kümmerer, K., Clark, J.H. & Zuin, V.G. (2020). Rethinking chemistry for a circular economy. Science, 367(6476), 369-370. ***DOI: 10.1126/science.aba4979***
Ongoing research projects – please ensure to include the web address of your project so we can link to it	*www.york.ac.uk/chemistry/research/green/industry/crci/* *www.circa-com.com*
Stage of research	*This paper demonstrates the societal impacts of a project.*

Waste as an Opportunity

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Social Impact

An increasing world population with its burgeoning middle classes is leading to an unprecedented demand for consumer goods and other articles with a resulting accelerating demand for resources. Our current (linear) economic model for satisfying this demand is based on the use of virgin resources that have been mined (at increasing cost), processed (often in several stages), consumed and then eventually disposed of (often in an uncontrolled way leading to pollution). Each of these stages consumes additional but limited process resources including energy and auxiliaries and in some cases such as pharmaceutical manufacturing the overall resource efficiency can be as low as 1% meaning that the waste exceeds the products by a factor of a hundred. The current global economic model is only sustainable with infinite accessible resources and an infinite capacity for waste. But we know that resources are finite and becoming increasingly expensive to extract, and our landfill sites are filling up with spill-over of wastes leading to serious environmental threats such as plastic wastes in the oceans and toxic metals in the run-off water from landfills (e.g. ca. 10 mg copper per litre). The model is also reliant on the concept of waste as something that the owner no longer values and wishes to be rid of. The green chemistry movement seeks to improve many manufacturing processes and both reduce resource consumption and waste production though with limited success and it cannot stop waste at the end of life of an article. Molecular sciences teach us to view all articles on the basis of the molecules they are made from and in many cases these are essentially unchanged from “new to old” and from “product to waste”. Molecules are the building blocks of most articles in today’s society from pharmaceuticals to plastics and while the molecules in the former and some other articles may be changed for example, through consumption, most are not. We worry quite rightly about persistent chemicals like the perfluorinated compounds (“PFAS”) used as surface treatments in consumer products including cookware, carpets and clothing but these are only a problem because they don’t break down when we want them to (when they are released into the environment). Many chemicals can last a long time unless they react for example, by attack by organisms in the environment (biodegradation). Many of the synthetic molecules we use in almost all of our articles, are manufactured often in complex processes. Where they are unchanged in use, we need to maximise their molecular value (based on all the resources consumed in their manufacture) and useful lifetime through reuse and recycling. Here we explore strategies to help society recognise the value in what has previously been seen as waste: adopting such strategies requires a multi-level partnership involving industrialists including producer associations, waste management authorities and organisationseducators, consumers, municipalities and legislators. In the Circa Renewable Chemistry Institute (CRCI) we are working closely with key industrial actors including the providers of green chemical technologies (including Circa Group AS and Addible ltd), to develop waste valorisation routes that themselves are economically viable and have a low environmental impact.

Methodology

The managed consumption of resources to fit with a sustainable circular economy requires the engagement of many sectors both in terms of discipline and in terms of branches of society (Kummerer, 2020). Chemists, biologists, engineers and environmental scientists need to work with social economists to find the best practical solutions including improved resource consumption and more fundamentally, the highest levels of waste valorisations effectively turning what we now see as waste into a resource. Industry needs to work with waste management companies and learn how to usewaste feedstocks for its manufacturing processes. Educators need to incorporate waste valorisation technologies and strategies into syllabuses both to engender a community-wide appreciation of the value of articles at their normal end-of-life and to help encourage a new generation of people entering the workforce with a desire to implement waste valorisation at all stages in the value chains for all articles. Waste has not been seen as a "sexy" topic in teaching or research, and few graduates have sought careers in the waste industries or in waste management. We can change that with a fundamental shift in attitude from seeing waste as a problem and loss of resource, into seeing it as an opportunity and an exciting new resource that will require the attention of the brightest minds in science, engineering and economics.

A widespread appreciation of the value of what we now see as waste and the willingness to "do something about it" can only work if there is general recognition of examples where the strategy clearly works. While the public can see some value in the modest degree of recycling evident in current articles (e.g. through the use of packaging with some recycled content), waste valorisation is seen as niche and often associated with inferior and low grade products. We are penetrating the wastes at a molecular level so as to help get high value from almost all wastes (Clark, 2016). A good example is food waste which is rich in valuable chemicals such as limonene (Pfaltzgraff, 2013). Another is waste textiles and especially waste clothing. We currently manufacture an astonishing ca. 130 billion items of clothing each year leading to over 90 million tons of waste. Even with a willing public and a well organised infrastructure including second hand markets and charity shops, the wear and tear suffered by most textile fabrics in use reduces their practical value at least as clothing. Accordingly, most recycled clothing is downgraded to cleaning cloths, mattress stuffing or insulation materials. However, while the constituent fibres in clothing lose their integrity through use, the molecules that make up the fibres do not. We will always want such molecules, either to make new polymers for the manufacture of new textiles of for other applications. Our question is "can we recover the molecules from waste textiles (and indeed most types of waste) in a way that is environmentally sound and economically viable"? Up to now, the answer to that question has normally been "no" : virgin products are too cheap and so-called chemical recycling methods are too energy-demanding, expensive and/or reliant on hazardous processes. Waste disposal is usually inexpensive and an easy option for many producers and local authorities. How can we change that? We can only get out of this linear economic trap by a combination of new policies and new technologies, and the good news is that we are seeing the early signs of both. Recent policies that require the use of recycled plastics in some products, have massively affected the market, with recycled PET for example, costing significantly more than the virgin material – this can become a major economic incentive to produce recycled materials. The recycling process needs close analysis – almost all consumer goods are complex materials containing multiple components: almost any item of clothing for example, will contain two or more synthetic and/or natural polymers (including polyethylene terephthalate, PET, nylon, cotton, wool, etc) along with a plethora of added "small molecule" chemicals to impart colour, sheen, flame resistance, stain resistance, etc. These complex materials must be separated into the constituent polymers and other chemicals if anything like their true value is to be realised. Articles are rarely designed with separation in mind – indeed the opposite can apply – carpet tiles, for example, are constructed using powerful adhesives designed to hold the various material layers together even under long-term stress. Thus a practical waste textile molecular valorisation process would have the stages shown in Figure 1

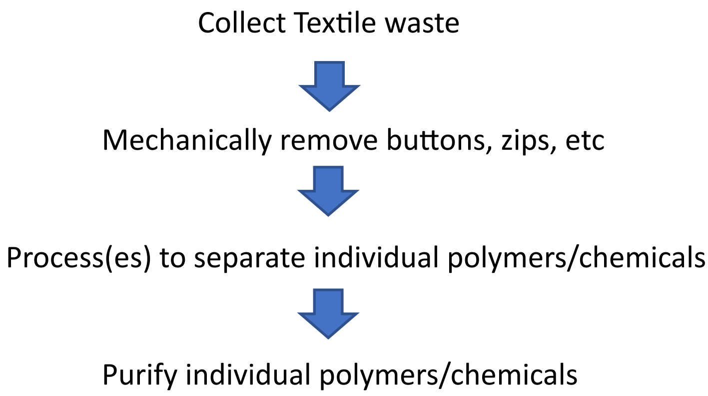

Figure 1. Stages in a possible waste textile molecular valorisation process

The green chemistry challenge is to enable the second critical step, i.e. the growth in green chemical technologies (mostly developed for the chemical and allied manufacturing industries) which is very encouraging (Clark, 2017). For example, solvents which have also been recognised as vital in almost any chemical process, but have generally been fraught with inherent hazards including toxicity, have been subject to intense academic and industrial research with the result that new “green” solvents are emerging on the market (Clark and Hunt, 2017). These solvents can be used for example, to selectively dissolve certain polymers greatly aiding separation. In terms of energy consumption, more efficient microwave-based processes have been developed. Clearly more work is needed – we need a “green chemistry toolkit” including a good number of genuinely safe solvents that can be applied to almost any waste textile situation.

Implications

The molecular valorisation strategy is applicable to any waste stream but it will rarely be easy and there will always be a trade-off between the undoubted benefits including reducing the demand for (increasingly scarce) virgin resources and diverting waste from landfill or incineration, and the costs and environmental footprint of the separation processes. Following the eco-design approach, we could significantly reduce the level of difficulty by a “benign by design” approach whereby the original article is better designed for separation, for example avoiding powerful irreversible adhesives, and ensuring the components have usefully different properties such as solubilities. The potential presence of hazardous chemicals such as synthetic dyes in textiles discourages their reuse and leads to dumping on a very large scale.

We argue that demonstrating the practical viability of these waste valorisation processes combined with policies to encourage them can have a real impact on public behaviour and attitude towards waste. The first step in any waste valorisation programme must be effective collection programmes ideally incorporating first stage physical separation (glass, metals, food, fabrics, etc). Simultaneously, chemical companies must be seen to be active in applying green chemical technologies to this valorisation process. Public engagement with this is vital if we are to significantly move towards a circular economy.

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Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: