Chemical recycling
Helping to provide a better recycling future for consumers[**]

Bronwen Jameson[*]

Recycling Technologies[***]

Undoubtedly the world is facing a severe problem with respect to plastics (synthetic organic polymers). On the one hand they are extraordinarily useful in daily life, especially for packaging, where their substitution by other materials is probably overall less sustainable in almost every case. On the other hand their reckless disposal in the environment has already resulted in more or less detrimental ecological consequences worldwide, to counter which the UK and other European countries are leading the development of technologies to divert used plastics away from ultimate disposal in landfill or incineration. Mechanical recycling is already well established and being developed to tackle the challenges of the multiplicity of commercial plastics and their contaminated state post-use, but may never completely overcome them. The latest development is chemical or feedstock recycling, in which thermal treatment converts the polymers back into monomers or even the building blocks of the monomers. A modular, hence flexible and scalable, commercial system is due to come onstream in 2021. The robust tolerance of the technology to input of mixed and contaminated polymers removes a major barrier to the efficient collection of used plastic from individual consumers, namely the detriment they suffer through compliance with onerous sorting and washing requirements. Furthermore, the output of chemical recycling is a valuable material that can be used as feedstock for the production of virgin plastics.

1. Setting the scene

Recently, the world was alerted to the impacts of microplastics in our oceans by Richard Thompson.[1] He helped to achieve the UK ban on plastic microbeads in toiletries.[2] His work on

* E-mail address: Bronwen.jameson@rtech.co.uk *** Website: www.recyclingtechnologies.co.uk
** This paper was first presented at the *Balancing Resource Efficiency and Climate Change* (BRECC) conference, 26 November 2019, London (UK).
1 Professor of Marine Biology at Plymouth University, Devon, UK.
2 Introduced on 19 June 2018 https://www.gov.uk/government/news/world-leading-microbeads-ban-comes-into-force#:~:text=From%20today%2C%20retailers%20across%20England,soaps%2C%20toothpaste%20and%20shower%20gels

Nanotechnology Perceptions **16** (2020) 331–335
Received 29 September 2020; *accepted* 30 November 2020

doi: 10.4024/N19JA20A.ntp.16.03

ocean pollution examines the negative effects on the marine world of our current “make, use, dispose of” linear economy, in which we use materials, sometimes for very short periods of time, then throw them away. During a 2019 interview on the BBC Radio 4 programme “The Life Scientific”,[3] Prof. Thompson highlighted the need to use plastics more responsibly and argued that while using plastics in body scrubs and face wash is obviously profligate, when it comes to applications such as packaging the utility value of plastics often makes it the best material for the job. Hence, the answer is not to get rid of plastic, but to *design it* in ways to encourage material reuse and recycling, thereby moving towards a more circular and sustainable plastic economy. Recycling companies are presently faced with significant challenges; Thompson suggested that more can be done at the packaging design stage to standardize polymer choice and indeed to “design packaging for recyclability”. This will make it easier, and therefore more economically attractive, for materials to be separated (sorted) and processed back into the production system to be used again, achieving a circular or cyclic flow of materials.

In the realm of the consumer, it is difficult for shoppers to make the “right” choice when it comes to packaging. In a shop or market, we may be tempted to opt for a dessert packaged in glass or reach for a paper bag for some vegetables, believing we are helping the environment because we can reuse, repurpose or recycle these materials at home. However, a study has shown that a paper bag has 3.3 times more carbon dioxide embedded in it than a conventional plastic bag.[4] Glass bottles and metal cans have significantly higher CO_2 emissions associated with their manufacture than their plastic equivalents. In many situations, replacing plastic does not help the environment at all—quite the contrary.[5] Another study in the UK looking at consumer attitudes to packaging has demonstrated that consumers face a plastic dilemma.[8] They recognize the importance of plastic packaging to protect goods in transit and prolong shelf-life, which helps to prevent food waste, but are increasingly unwilling to accept that it comes at the expense of the environment. “In the long term, the consumer should not be faced with this ethical challenge every time they go into a shop of which type of packaging is better or worse than another. We as consumers ought to be able to rely on the packaging on the shelves in the supermarket having the minimum environmental footprint necessary, and that this homework has been done for us” (Thompson).[3] He also spoke about a future where over 80% of plastic packaging will be genuinely and widely recyclable in practice, and where it will be much simpler for us all to identify the right thing and do it accordingly.

---

3 hps://www.bbc.co.uk/programmes/m000674n

4 Life cycle assessment of supermarket carrier bags: a review of the bags available in 2006. Bristol: Environment Agency (2011) https://www.gov.uk/government/publications/life-cycle-assessment-of-supermarket-carrierbags-a-review-of-the-bags-available-in-2006

5 As pointed out by Stahel,[6] “doing without” is at the top of the sustainability hierarchy. If one creates the dessert oneself at home from raw ingredients, no packaging is required; similarly vegetables can be simply placed in a durable wicker basket.[7]

6 W.R. Stahel, The circular economy and intelligent decentralization, nanotechnologies and materials, metals and mining. *Nanotechnol. Perceptions* **16** (2020) 151–168.

7 http://lpahorticole.faylbillot.educagri.fr/index.php?page=presentation-cfppa#ae-image-2

8 Citizens’ attitudes & behaviours relating to food waste, packaging, and plastic packaging. Banbury: Waste and Resources Action Programme (WRAP) & London: Industry Council for Research on Packaging and the Environment (INCPEN) (2019) https://www.wrap.org.uk/sites/files/wrap/Citizen-attitudes-survey-food-waste-and-packaging.pdf

2. Recycling technologies

Thankfully, that future need not be intangibly far away. It is already technically possible to recycle virtually all plastics by coupling innovative chemical recycling approaches with existing mechanical recycling processes.[9] However, to accelerate the transition to what can be recycled in theory to what is recycled in practice requires investment in building recycling infrastructure and scaling capacity, for all modes of recycling.

In the UK, from the 5 million tonnes of plastic used each year, only 1.1 million tonnes is collected for recycling.[10] The rest is either not accounted for, or is landfilled or incinerated. Of the material collected for recycling, a proportion is recycled domestically in the UK, but almost two-thirds—over 600,000 tonnes—is exported, mainly to the Far East. This can sometimes lead to hugely damaging outcomes for the local communities receiving the waste, some of which "leaks" into the environment, such as rivers and lakes, or it is simply burnt, polluting the air. With demand for plastics globally showing no sign of slowing down (on the contrary, it is expected to double between now and 2040), more collection, sorting and recycling infrastructure must be built to keep pace with demand.

Traditional mechanical recycling has long been the predominant recycling approach for plastics and is economically and environmentally effective for recycling polyethylene terephthalate (PET) bottles and other rigid forms such as trays and high-density polyethylene (HDPE) bottles. Mechanical recycling comprises subprocesses for separating and sorting different polymers with a high degree of accuracy, thanks to spectroscopy-based automation. These sorted polymers are then washed and granulated for reforming into pellets for moulding applications. Advances in mechanical recycling enable ever-higher yields (purities) of post-use plastics. The aim of these systems is to provide quality, high-value recyclate for remanufacture. However, some sensitive product and packaging applications such as food and medicine packaging and healthcare products are required by regulation to use controlled levels of recyclate or even virgin polymers. Apart from PET and HDPE milk containers in the UK, these regulations make it extremely difficult to return post-consumer plastics back into the same food-grade application.

3. Chemical recycling

Emerging chemical recycling is poised to recycle residual plastics wastes that are residues of mechanical processes or difficult to recycle mechanically, such as plastic films, food bags and wrappers, laminated plastic pouches and packets, contaminated plastics, and small plastic objects. According to resource management specialist WRAP, the UK uses around 400,000 tonnes of flexible plastics every year.[10] In its *Pack Flow 2025 Plastic Packaging Flow Data Report*, WRAP reports that flexible plastics make up 26% of all consumer plastic packaging used in the UK, yet just 5% of this material is collected for recycling mechanically. By

[9] Note that from the molecular or nanoscale viewpoint, "chemical recycling" could equally well be called remanufacture. The terminology is still evolving. This could be an important distinction because remanufacture lies above recycling in the so-called "waste hierarchy", and is hence preferable.

[10] Plastics Market Situation Report 2019. Banbury: Waste and Resources Action Programme (WRAP) https://www.wrap.org.uk/sites/files/wrap/WRAP_Plastics_market_situation_report.pdf

embracing innovative approaches to recycling, the UK can prevent hundreds of thousands of tonnes of plastics from ending in landfill and incineration every year and achieve a circular pathway for many more plastics.

Chemical recycling is an umbrella term to describe a range of thermal conversion technologies that recycle plastic waste back into valuable oils and monomers that can be used in the petrochemical sector as feedstocks for new virgin-quality plastics production. These thermal conversion processes essentially comprise pyrolysis, gasification and hydrothermal treatment and are also known as "feedstock recycling".[11] Feedstock recycling processes create chemical feedstocks that can be co-fed into the petrochemical process with fossil-derived feedstocks to create new polymers with nominally recycled content that are nevertheless of virgin quality and therefore have the potential to be used in food-contact and medical applications. Tracing these feedstocks and attributing them to their final products can be achieved using mass balance accounting and accreditation by a third party. An example of this in commercial practice is the recent announcement by SABIC of its successful development of resins for the Unilever *Magnum* brand.[12]

Whilst some material output from chemical recycling is technically suitable as a fuel, fuel oil from plastic remains a fossil-based resource and, hence, using it thus is neither renewable nor sustainable and it obviously contravenes the goal to keep the outputs of chemical recycling within the circular economy. Chemical recycling can be repeated indefinitely and is therefore a truly long-term solution. In contrast, energy-from-waste recovery, which has also been proposed as a solution to the plastic waste problem, because it, too, is more tolerant of feedstock than mechanical recycling, can be carried out once only. Hence, it is unsustainable and cannot be part of the circular economy. Furthermore, energy-from-waste emits a large quantity of carbon dioxide.[13]

4. Implementation

UK-based Recycling Technologies is an example of a company that has developed and patented a feedstock recycling machine, the RT7000, that uses pyrolysis to thermally crack plastics into hydrocarbon vapour, which is distilled and fractionated into a range of chemical feedstocks called Plaxx®; noncondensable light hydrocarbon gas is reused in the system as an energy source. With equity investment and grant funding, including from the Scottish authorities via Zero Waste Scotland, the first commercial RT7000 machine to launch feedstock recycling in Perthshire will be in place in 2021, with more to follow.

The approach of Recycling Technologies is to mass-produce its modular RT7000, which is capable of processing 7,000 tonnes of plastic waste per annum, and to sell machines to waste operators around the world. This decentralized model can be quickly scaled up but it is designed to overcome the economic and environmental costs of transporting wastes to larger, centralized

[11] See also footnote 9.

[12] https://www.sabic.com/en/news/24118-magnum_launches_new_tubs_made_using_certified_circular_polypropylene

[13] Exploration chemical recycling—Extended summary. What is the potential contribution of chemical recycling to Dutch climate policy? Delft: CE Delft (2020) https://www.cedelft.eu/en/publications/download/2832

facilities. The liquid Plaxx® offtake has been contracted initially to Finnish energy company Neste, a world leader in its use of biofuels and waste oils in renewable diesels. Neste's aim is to use recycled feedstocks for its processes to meet demands from downstream customers—the brands and retailers—for more recycled content in new plastics. The company has an ambition to use one million tonnes of pyrolysis oil feedstocks in new products and chemicals by 2030.

These and other initiatives and collaborations across the emerging chemical recycling sector and plastic value chain are set to step-change the percentage of plastic that is recycled. Governments too have an important role and, in the UK, it has set out how it intends to stimulate recycling, infrastructure development and demand for recycled raw materials using a variety of interventions. Deposit return schemes (DRS), extended producer responsibility (EPR) schemes, statutory recycling targets, separate collection schemes and penalties are being strengthened or considered in the Westminster and devolved governments' waste and resources strategies. Indeed, in the recent UK Treasury budget, the Chancellor of the Exchequer confirmed the introduction of a plastics packaging tax in 2022. Under this, producers and importers of plastics packaging will need to have a minimum of 30% recycled content (which could be made up from chemical recyclate[14] like Plaxx) in their products or pay a tax of £200 per tonne of virgin material.

We need to make it easier for the consumer to be part of the step change and access recycling services that better capture valuable materials. So how do we make the system better? Scotland's code of practice aims to standardize domestic waste collections into three bins so that recycling services do not change from district to district. Residents in many continental European countries receive a single collection sack specifically for "Plastics, cans & cartons", which accepts virtually all plastic regardless of colour or type. The hope is that this will greatly increase rates of recycling by reducing confusion over what can be accepted and instigate a much simpler procedure for residents (i.e., "If you think it's plastic, put it in"). One system, one message, and consistently coded bins at home, in the office and in shopping centres and other public areas would empower the 9 out of 10 people who want to do the "right" thing.

I am confident that the pressure consumers have brought to bear on governments and businesses, many of which have staked their reputations on achieving ambitious targets for reducing waste and increasing recycling, will be rewarded with investment in new and better systems. In many countries, recycling is the number one community action for the environment. It is likely that for UK consumers too, acting for the environment can be best delivered via weekly kerbside recycling.

[14] I.e., that which has been recycled.