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Circular economy, permanent materials and limitations to recycling: Where do we stand and what is the way forward?

When achieving the ambitious quantitative recycling targets set by the European circular economy package for year 2030, the qualitative characteristics and the existence of a market for recycled materials must be addressed, as higher recycling rates imply that more and more hardly recyclable materials will end up together with the easily recyclable ones.

There is no doubt that, when dealing with resources and waste management, societies are urged to move from a linear approach to a more circular one, but the narrative behind the circular economy concept tends to oversimplify some aspects that actually need to be taken into account. Material recycling should certainly be encouraged and significant targets have already been reached in many developed countries. However, this comes at a cost. More complex materials put in the market require recycling schemes and technologies able to deal with such complexity and that may precipitate the generation of non-negligible streams of residues. Such quantitative losses in the sorting and recycling schemes are coupled with qualitative losses, owing to changes in the inherent properties of materials, that affect the different materials to various extent, and are not limited to the traditional evidence of typically down-cycled materials, such as plastics, paper and wood.

When focusing on packaging materials, the respective industries have been very active in addressing this issue, by citing the potential recyclability for a better positioning in the market. As an example, the metals and glass industries have recently introduced and defined the concept of 'permanent materials'. According to Conte and colleagues (2014):

> a material is defined as permanent if its inherent properties do not change during use and through solid-liquid transformation, it can revert to its initial state. This is the case when the material consists of basic components, which are either chemical elements or robust chemical compounds, making repeated use and recycling possible without change of inherent material properties.

Beyond the strictly technical/scientific definition, the concept of material 'stewardship' was also defined, meaning that 'the material use must be legally compliant in order to prevent the unintended promotion of material applications having the properties and availability to be permanent but which may result in harm to humans or the ecosystem'. A third crucial point is that the use of recycled materials needs to bring an added value compared with the use of virgin ones. Such added value can be 'on the economic, social and/or environmental level'. Here the point of discussion relates to the fact that the use of recycled materials instead of virgin ones is perceived (and generally is) a more sustainable option compared with the extraction of raw materials from nature. This point goes beyond the mere technical aspects, since it must be supported by proper communication strategies, as well as environmental labelling, such as FSC (Forest Stewardship Council) for wood and paper products, to inform the customers that they are purchasing a recycled product, trying to encourage their 'pro-environmental behaviour'.

Based on such considerations, the report comes to the conclusion that aluminium (except for its use in explosive applications), steel in all different uses, glass (for bottles), copper and manganese are in full compliance with the Concept of Permanent Materials (CPeM). The same does not apply to paper and plastics, since they fail to comply with the definition mainly because of the technical limitations of their recycling, affecting the actual possibility of repeated recycling.

Although the conclusions of the abovementioned study might encourage establishment of a boundary between the 'good' permanent materials and the 'bad' non-permanent ones, again the picture is more complex and variegated. Take for example paper, a material which has some additional and peculiar characteristics, that make it even more flexible when it comes to its management as a waste. Paper is in fact a renewable and biodegradable material, which makes it suitable for a number of different recovery pathways, not limited to material recycling, but including renewable energy recovery, both via combustion or biological anaerobic degradation, as well as its degradation during biological aerobic processes. Whatever the disposal pathway is for paper, it will contribute in terms of material or energy recovery, or at least it will degrade, with limited or negligible impact on the environment (uncontrolled landfilling being obviously an exception).

On the other hand, there is mounting evidence that limitations to recycling apply also to permanent materials. For example, in order to guarantee certain properties, alloying elements are added to the pure metal to tailor its characteristics for a specific application. Furthermore, during preparation of scrap material for recycling in a subsequent system, contamination with unwanted elements may occur. The mix of different alloy types and the presence of contaminants may reduce the material spectrum substituted by recycled materials, and will certainly decrease market value of that recycled waste as a raw material.

In the recycling of end-of-life aluminium, product contamination by alloying elements may constitute a problem owing to the strict requirements on alloy composition. Two alternative reprocessing operations exist for aluminium recycling: remelting or refining. Remelting produces wrought alloys (alloy content up to 10 wt.%) for rolled and extruded products, meanwhile refining produces cast alloys (alloy content up to 20 wt.%) for shape-cast products and deoxidation aluminium (Cullen and Allwood, 2013). Nowadays, most of the mixed aluminium scrap is used to produce cast alloys (Paraskevas et al., 2013). Thus, recycling tends to cascade from wrought alloys to less pure shape casting alloy (Cullen and Allwood, 2013). Limits to the removal of impurity elements during aluminium remelting exist owing to chemical thermodynamics, except for magnesium and zinc (Nakajima et al., 2010). The concentrations of contaminants can also be adjusted to the desired target alloy by diluting the scrap with primary aluminium.

In steel recycling, post-consumer scrap is collected in different quality grades, sorted depending on the size and origin, which have different content of tramp elements and mineral materials. Decisive for steel quality, and therefore for the field of application, is the concentration of tramp elements. According to Yellishetty et al., 2011, copper, tin, nickel and molybdenum pose a great challenge and are very difficult to extract from scrap by metallurgical processes, which leads their concentration to increase during each recycling loop. When the contaminants occurring in secondary materials exceed the maximum content allowed for the target product, additional high purity materials must be added to 'dilute' the contaminant to an acceptable level (Nakamura et al., 2012).

When it comes to glass, the quality of cullet ready for the furnace is affected by the presence of elements like iron and chromium, that affect the colour, by the presence of organics (residues of sticking papers, glue, oil and grease on the glass fragments), which act as a reducing agent, affecting the redox equilibrium in the glass melt and by the presence of lead glass fragments (Favaro and Ceola, 2017).

What is lagging behind in this sort of competition between different materials is plastics, which shows clear limitations to recycling except for well selected and separated polymers. Energy recovery from mixed plastics can play a role, but with the limitation of releasing fossil CO_2 in the case of conventional combustion or co-combustion processes. And the major advantage of plastics, which is the possibility to manufacture very light items, particularly in the field of packaging, thus saving primary resources, is claimed to encourage the littering behaviour (Grosso, 2016).

All the abovementioned constraints are exacerbated when products are made by coupling different materials, such as in poly-laminated packaging, which might include paper, plastics and aluminium. But this is another story.

Waste Management & Research serves as a forum for exchanging research expertise and scientific ideas supporting the development and application of novel waste management options. Thus, *Waste Management & Research* invites researchers and practitioners to submit manuscripts focusing, among others, on the quality of recycled materials, on eco-design and on the development of new recycling processes able to overcome the obstacles and limitations briefly mentioned in this Editorial.

References

Conte F, Dinkel F, Kagi T, et al. (2014) Permanent materials – scientific background. Available at: https://carbotech.ch/cms2/wp-content/uploads/Final_PeM_Report_Carbotech.pdf (last accessed 20 July 2017).

Cullen JM and Allwood JM (2013) Mapping the global flow of aluminum: From liquid aluminum to end-use goods. *Environmental Science and Technology* 47: 3057−3064.

Favaro N and Ceola S (2017) Glass cullet sources and applications. *Encyclopedia of Glass Science, Technology, History and Culture*, submitted.

Grosso M (2016) Sound and advanced municipal waste management: Moving from slogans and politics to practice and technique. *Waste Management and Research* 34: 977–979.

Nakajima K, Takeda O, Miki T, et al. (2010) Thermodynamic analysis of contamination by alloying elements in aluminum recycling. *Environmental Science & Technology* 44: 5594–5600.

Nakamura S, Kondo Y, Matsubae K, et al. (2012) Quality- and dilution losses in the recycling of ferrous materials from end-of-life passenger cars: Input-output analysis under explicit consideration of scrap quality. *Environmental Science & Technology* 46: 9266–9273.

Paraskevas D, Kellens K, Renaldi R, et al. (2013) Sustainable metal management and recycling loops: life cycle assessment for aluminium recycling strategies. In: *Re-engineering Manufacturing for Sustainability. CIRP conference on life cycle engineering*, Singapore: Springer, pp.403–408.

Yellishetty M, Mudd GM, Ranjith PG, et al. (2011) Environmental life-cycle comparisons of steel production and recycling: Sustainability issues, problems and prospects. *Environmental Science & Policy* 14: 650–663.

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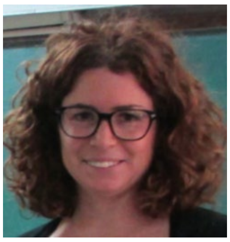

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