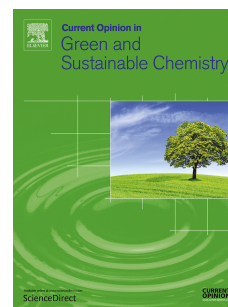


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From Linear to Circular Economies: The importance and application of recycling and reuse

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## From Linear to Circular Economies: The importance and application of recycling and reuse

Vijay Kumar Thakur, Raju Kumar Gupta and Avtar Singh Matharu

For all the good that Chemistry has given us it now brings many challenges that impact the future of our society. Chemistry, chemical engineering and allied subjects have given modern-day society unprecedented access to chemicals, materials (articles) and energy predominantly derived from crude oil. From the period 1970-2010, global material use has tripled, with annual global extraction of materials growing from 22 billion tonnes (1970) to 70 billion tonnes (2010). As global population is set to increase from 7 billion (2018) to 9 billion (2050) we will require about 180 billion tonnes of materials annually by 2050. Significantly, many of these materials have been designed, engineered and manufactured to be long-lasting, one use only and not designed for re-use or recycling. They operate within the principles of a linear economy that take, make, use and abuse materials, which at end of life (EoL) end up as waste, i.e., cradle to grave. As a society, we generate too much waste as recently exemplified by waste plastics, which is very much visible and in the public domain. We now need to change this paradigm and move from linear to circular economies that respect resource, environment and society, i.e., cradle to cradle, through practice and delivery of United Nations Sustainable Development Goals so as to effect a sustainable 21<sup>st</sup> Century.

“Recycling and Reuse” is an important area of research that provides second life to retired materials at EoL, thereby, keeping resource in the loop or value chain and minimizing waste. This section of *Current Opinion in Green and Sustainable Chemistry* focusses on “Recycling and Reuse” bringing together 12 important articles covering a range of topical resources for example, from elemental sustainability (critical elements), construction materials, paper, food waste, carbon fibre reinforced polymers (CFRP), electronic waste (E-waste or WEEE, Waste Electrical and Electronic Equipment) and to plastics.

Elemental sustainability and critical elements has been a serious topic of debate over the last 10 years as increasing amounts of rare earth elements (REE) are now used in modern day 'clean technology' applications and devices. The supply, demand and accessibility for these elements has both geopolitical and societal connotations. Thus, new measures and improvements of recycling and reuse of REEs is very important as at present recycling rates are as low as 1%.

Jowett *et al.* (<https://www.sciencedirect.com/science/article/pii/S2452223617301256>)

overview recycling of rare earth elements as raw material for permanent magnets, fluorescent lamps, batteries, and catalysts. Summary has been made over (i) rare earth elements and their common uses, (ii) main barriers towards effective recycling of e-waste, (iii) potential sources of REE during recycling, (iv) recycling potential of the REE and the applicability to the REE. Future developments required for REE cycling are clearly brought out in their article.

Similarly, many critical elements are found in E-waste commonly associated with LCD televisions, mobile phones, laptop computers. A modern-day electronic smart phone can comprise up to 60 elements of the Periodic Table. The re-manufacturing and recycling of WEEE is becoming highly significant than any other waste materials. E-Waste is the fastest growing waste stream on the planet, with an annual growth rate of 3–4%. E-Waste generation is estimated to reach 52.2 million tonnes per annum by 2021. In 2016, after Asia, which generated 18.2 million tonnes (MT) E-waste, the European Union (EU) produced the second largest amount of E-waste (12.3 MT). Sahajwalla and Gaikwad

(<https://www.sciencedirect.com/science/article/pii/S2452223618300452>) discuss the present and future of e-waste recycling. Notable and emerging technologies like micro factories employed for e-waste plastics are reviewed. The limitations and the advantages of e-waste plastics recycling is discussed. The research required for improving the usage of recycled e-waste plastics for various applications is explained. Also, microfactory inputs and value-added products (supercapacitors, steel industry, silicon carbide, polymer composites and 3D printing filaments) are discussed.

The manufacture and use construction materials will continue to increase due to population growth, industrialization and urbanization. However, as new buildings replace old then there will be a considerable amount of construction demolition waste (CDW) that may be considered

as potential recylate. Menegaki and Damigos

(<https://www.sciencedirect.com/science/article/pii/S245222361830018X>) discuss that globally about 35% of CDW is sent for landfill without any treatment, occupying land that can then no longer be used. They present an explanatory model and concept map based on global data available for reuse and recycling options for CDW. Similarly, marble is used at scale in India as a construction material. Air-borne marble particulate matter emanating from marble-rich waste sites is a serious environmental problem in densely populated countries such as India. Also, the challenges that need to be overcome are explained in detail. Implementation of good management practices and proper follow ups can help in forming a rational guideline for CDW recycling and reuse. Anil Thakur *et al.*

(<https://www.sciencedirect.com/science/article/pii/S2452223618300257>) review the use of recycled marble waste as a source of *sustainable* green construction products, discussing major mineralogical compounds present in the recycled marble wastes and their activity when used as building materials. In terms of materials with potential construction applications, carbon fibre reinforced polymers (CFRP) are gaining attention at industrial level as their uses include aerospace, structural engineering and energy. Verma *et al.*

(<https://www.sciencedirect.com/science/article/pii/S2452223618300427>) overview and summarize various processes for CFRP recycling, from mechanical through to chemical, which are effectively employed at industrial level. It also discloses the consolidated list of chemical reagents used for recycling of carbon fibres. It is concluded that economic recycling of carbon fiber is the need of the hour.

Adu *et al.* (<https://www.sciencedirect.com/science/article/pii/S2452223617301244>) discuss the reuse and recycling of paper waste, a high volume resource within the context of a biorefinery. It is a common mis-conception that paper can be recycled up to 7 times. In practice, across the EU paper is at best recycled up to 3 times as fiber length and quality deteriorate over successive re-cycles. Characteristics of CNCs prepared from various wastepaper sources are clearly brought out in the discussion. The use of recycled paper for high value applications such as production of cellulose nanocrystals, composite reinforcement, high performance electrical components and biofuels is reported.

Plastic usage has become part of day to day activities for many people. The damage caused by plastic waste on land and oceans have created chaos for people and marine life. Plastic waste is a major environmental threat for all the living beings and their recyclability is very challenging as discussed by Sourbh Thakur *et al.*

(<https://www.sciencedirect.com/science/article/pii/S2452223618300245>,

<https://www.sciencedirect.com/science/article/pii/S2452223618300233>). Bio-recycling mechanisms are clearly mentioned and a discussion of the opportunities and challenges of sustainability of bio-plastics is addressed. The importance of bio-plastics against the non-degradable plastics is opined. Ayre

(<https://www.sciencedirect.com/science/article/pii/S2452223618300634>) reviews recent advances in the recycling of plastic packaging materials, describing different routes for recycling of thermoplastics such as primary recycling, secondary recycling and, tertiary recycling including energy recovery via incineration. Discussions have also been included on how to improve and ensure the recycling in terms of providing incentives and education on a global scale.

Globally, 1.3 billion tonnes of food is wasted every year. Much of this is avoidable as '*spoilt food is in the eyes of the beholder*'. Rich Nations will reject ugly food out of cosmetic or aesthetic choice rather than necessity, whilst in poor Nations food waste is usually associated with spoilage post-harvest due to inferior storage conditions. Primary and secondary processing of food, from farm to fork (or table) generates approximately 30-35% unavoidable food supply chain wastes. The latter is rich source chemicals, materials and energy akin to the needs of a biorefinery as described by Pleissner

(<https://www.sciencedirect.com/science/article/pii/S2452223618300051>), Kumar and

Longhurst (<https://www.sciencedirect.com/science/article/pii/S2452223617301281>), and

Makris (<https://www.sciencedirect.com/science/article/pii/S2452223618300087>). Also, bioproduction of chemicals from food waste and bioconversion of food waste into chemicals having huge market potential and demand have been summarized.

To conclude, this special issue highlights the importance for an immediate need to recycle and reuse to stimulate development of potential urban and rural circular economies, protect the environment, improve welfare and societal needs.

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# Editorial overview: From linear to circular economies: The importance and application of recycling and reuse

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