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EDITORIAL

Circular economy: Is there anything new in this concept?

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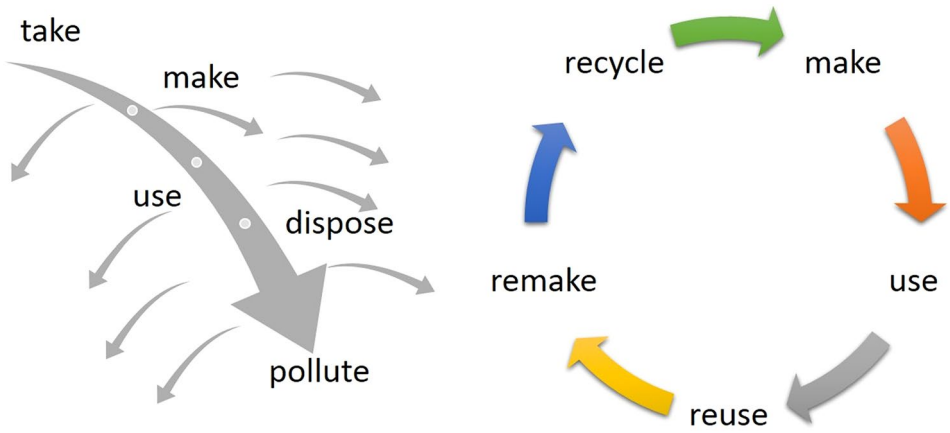
The term, Circular Economy, is beginning to be seen with some frequency in technical journals. The term originated in the field of inquiry known as environmental economics. Only a year ago, the concept was officially promoted by the World Economic Forum, which in 2018, in collaboration with several governments and non-governmental organizations (NGOs) such as World Resources Institute (WRI) and Ellen MacArthur Foundation, published a document called Platform for Accelerating the Circular Economy (PACE) to stimulate developments that adopt the principles of Circular Economy. Several multi-national corporations are also participants in implementing PACE. At the political level, this idea of development is now included in the European Union Horizon 2020 strategy. Several standards agencies in the European Union are also engaged in preparing guidance documents for implementation. The concept is illustrated in the figure below (https://en.wikipedia.org/wiki/Circular_economy).



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The figure contrasts the features of the so-called linear economy with those of circular economy. Linear economy is used to describe systems that produce products and wastes, all of which ultimately result in disposal and pollution in the environment, which are detrimental to human health and the environment. In circular economy, on the other hand, wastes from all ventures are used up in follow-up ventures to produce beneficial artifacts for human use. The process of production/recycle/reuse is, according to this principle, repeated *ad infinitum*. It must be pointed out at the outset that it is only material resource that undergoes this virtuous cycle. Energy is an essential ingredient of any venture, because just bringing materials in contact with one another serves no useful purpose. It requires energy to make things happen. Quantitative energy recycle and reuse, however, cannot be a feature of a circular economy, as it would run against the wall of the second law of thermodynamics—an inviolate law of science. The figure above can be appreciated as a simple illustration of two extremes. Linear economy may accurately describe practice at the very early stages of industrial revolution, reminiscent of scenarios

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depicted in Dickens's Oliver Twist; it is not a true descriptor of today's practice. Likewise, the circular economy is an idealized version of what the proponents have conjured up for the future. This journal has published an editorial[1] and several technical papers on the applications of circular economy ideas [2,3,4]. We have also allowed an upcoming special issue on the topic. It is evident that the concept is taking hold in technical circles in Europe and elsewhere, and it would take its roots in North America as soon as government agency funding becomes inevitably available for research.

Ellen MacArthur Foundation defines circular economy thus: "A circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles" (https://www.ellenmacarthurfoundation.org). The underlying goal of this concept is transition to renewable energy sources from the current domination by fossil-based sources and is supposed to achieve three aims: (1) eliminate waste and pollution generation at the design stage, (2) keep recycling and reusing materials and products, and (3) regenerate natural systems.

Concerns for the environment in the context of industrial and commercial developments have driven policy in some form since the Alkali Act in the nineteenth century and the efforts in combatting the ill-famous London fog in Great Britain. But an avalanche of government regulations started being issued to reign in the ill effects of manufacturing practices in the 1970s, particularly just before and after the formation of the Environmental Protection Agency in the USA. The initial efforts in this sense were described as control technologies intended to turn toxic and offensive emissions, discharges, and disposal into benign wastes. In parallel, the core idea of preventing pollution or waste creation was embodied in terms and programs that came in various monikers such as waste minimization, pollution prevention, design for the environment, industrial ecology, cradle to cradle, green chemistry, sustainable development, and resiliency. Inherently safe chemistry and inherently safe design are additional terms being used along the same line. Circular economy is just the latest prescription. In close examination, one would note that in the beginning the environmental mandates for improving the environmental performance of industrial processes and products did not concern about cost, at least from legal perspectives; in later evolutionary steps the prescriptions do pay attention to cost and profitability. Also, the early concepts and programs explicitly considered toxicity of emitted chemicals and their effects, but currently the most important determinant is the emissions of carbon dioxide and other greenhouse gases, though the deleterious effects of pollution on the human health and the environment are not ignored. Overall, however, one would be in pains to distinguish circular economy from pollution prevention or sustainable development.

In the 1990s, academic researchers toyed with the idea of "infinite recycle" from process modeling motivations. This idea, albeit in more limited scenarios, is very similar to the idea of circular economy. This author remembers having arguments with one such academic of considerable reputation about the soundness of the claim of achieving zero wastes through infinite recycle. Yes, in principle it is doable, and one can find an extremely simple case to justify the claim. In the large majority of chemical or related processes involving chemical transformations, however, infinite recycle is a pipe dream. Can circular economy be different? Let us look at the case of plastics recycle to illustrate the challenges.

In the June 16, 2018, issue of C&E News, there was a feature on the failure of plastics packaging recycle worldwide. Currently only 14% of plastics packaging material goes through recycle attempts, and only 2% gets reused in the same application. Out of the rest, 4% gets lost in the recycle process and 8% finds use in lower-grade applications. This dismal failure must be understood in the backdrop of noisy efforts and claims to make a difference over the last 30 years! Meanwhile, plastics in various forms are ending up in the stomachs of cows on land and whales in the oceans. The so-called microplastics are recognized to have a particularly pernicious impact on aquatic health. The failure is not the result of lack of efforts; the proposition is exceedingly difficult. There are at present no clear technical or policy ideas to make a big difference in plastics recycle.

What are the plastics recycle/reuse challenges to circular economy? Since almost no plastic product is made of 100% pure polymer and has many other ingredients such as other polymers, plasticizers, colors, and additives, any attempt to do zero-waste recycling needs to deal with the recycle/reuse of all these other ingredients as well. A more important issue is the chain length degradation of thermoplastics over time, making certain that a return to the original application is impossible. Inherent in this sequence is continued loss of properties over continued recycle. The only way out is to convert the polymer neatly to the monomers, which cannot be done without creating other complex wastes. These

[1] Varbanov PS, Walmsley TG (2019) Circular economy and engineering concepts for technology and policy development. 21(3):279

[2] Zhao Y et al (2019) An emergy ternery diagram approach to evaluate circular economy implementation of eco-industrial parks. Clean Technol Environ Policy 8:8–9. https://doi.org/10.1007/s10098-019-01714-z

[3] Van Caneghem J et al (2019) Waste-energy is compatible and complementary with recycling in the circular economy. 21(5):923

[4] Belaud JP et al (2019) A circular economy and industrial toolbox for developing an eco-industrial park: perspectives from French policy. 21(5):967

inherent problems will exist even if the fossil sources of the polymers were eliminated in favor of plant-based material. Biodegradable polymers have been in development in the last four decades. These have made some inroads in packaging but the record of their spontaneously degrading in the landfill in realistic time duration is spotty. These challenges therefore are monumental. Industry and academic research have looked for potential solutions for a long time. Invoking a new slogan is unlikely to make any difference to this grave problem. Lastly, from the global warming viewpoint, the energy used to make and recycle plastics has to be from renewable sources, be affordable, and be themselves carbon–neutral, which is another monumental challenge.

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