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EDITORIAL

Taking the Circularity to the Next Level

A Special Issue on the Circular Economy

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Interest in the circular economy (CE) has grown remarkably in recent years. Viewed as a concept by some, a framework by others, the CE is an alternative to a traditional take-make-dispose linear economy. A CE aims to keep products, components, and materials at their highest utility and value at all times. The value is maintained or extracted though extension of product lifetimes by reuse, refurbishment, and remanufacturing as well as closing of resource cycles—through recycling and related strategies. An alternative strategy for extension of product lifetimes may be to use products more efficiently through sharing them or making them multifunctional. All these strategies may be facilitated through changes in ownership relationships, such as leasing and product-service systems (PSSs). Some accounts of the CE distinguish between biological cycles, that is, flows and cycles of materials from biological sources that can safely be returned to natural systems and technical cycles containing synthetic materials intended to be used repeated with limited loss in value. Businesses ranging from Google to Unilever to Renault have become conspicuous advocates, and governments, including the European Union (EU) and several in Asia, have made it an important element in their environmental policy. Environmental advocacy groups have embraced the CE with enthusiasm, and a sizable consulting industry has emerged.

. . . circular economy proponents argue that it is the integration of previous strategies and concepts where the framework can and should make its greatest contribution. This prompts the question of how the circular economy can learn from the methods and findings of industrial ecology, and what new ideas—or combination of ideas—the circular economy is bringing to industrial ecology.

Now that the concept of the CE has gained traction across these varied domains, critical questions emerge. When do CE practices lead to net environmental benefits? Under what social, economic, or political conditions are CE strategies likely to succeed? If viable strategies are identified, how should they be scaled? How can we engender significant structural changes in the way we use resources and move beyond incremental improvements in rates of low-grade recycling and waste minimization? How can more advanced CE strategies, beyond recycling, be adopted by business (Bocken et al. 2017)? Advancing the discussion of the CE to the next level requires that we come to a shared understanding and common language (Blomsma and Brennan 2017) and grapple with the complexity and trade-offs involved in this popular framework. We assert that the conversation must include the following aspects: (1) the viability and value of increasing the scale of circularity efforts beyond individual case studies, that is, identifying when replication and scaling circularity makes sense and when it does not; (2) careful evaluation of the environmental benefit in the context of material flows, resource use, and product design; and (3) efforts in innovative business models, institutional change, and informed policy actions.

Industrial ecology (IE) is uniquely positioned to continue this careful and systematic investigation of the CE. Ever since

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the publication of "Strategies for Manufacturing," the seminal article by Frosch and Gallopolous (1989) often identified as marking the beginning of IE as a research field, IE has been quantifying the flow of materials and energy in industries, supply chains, facilities, cities, nations, and the globe. The field has worked to provide systematic evaluations of environmental impact using such tools as life cycle assessment (LCA). And, notably, IE began its journey with a focus on closing and slowing resource cycles, looking to natural systems for insights about closing loops and increasing resource efficiency. The goal of this special issue is to engage the questions that arise as the pursuit of a CE contends with the inevitable dilemmas of an evolving field.

The articles in this special issue advance the discussion along several dimensions. We begin with a discussion of the evolution of the concept of the CE to draw lessons from rich historical experience. We then provide examples of CE-related product design and material flows, that is, elements in circular strategies that let us examine initial conceptions of this framework. Then, the contributed articles describe the role of the institutions in supporting circularity, coupled with conceptual and practical challenges in bringing about the CE. By tracking developments in the concepts and institutions that can guide our products and materials toward or away from circularity, we can continue to probe, elaborate, and refine this emerging framework.

We want to thank Deloitte, a leading global consultancy, and Eileen Fisher, a highly regarded and progressive women's clothing company, for financial support for this special issue. We particularly appreciate their willingness to support scholarly, peer-reviewed research on the CE. Although such research does not always grab headlines, it provides a foundation for careful and thoughtful examination of new strategies and frameworks. Neither Deloitte nor Eileen Fisher had any role in the content of this issue and their funding does not imply endorsement of any of the analysis, findings, or recommendations presented in this issue—only a willingness to participate in the further development of discussions about the CE.

An Evolving Circularity Framework

Some critics suggest that the CE is old wine in new bottles, whereas others emphasize it as a powerful new metaphor giving fresh inspiration to further old ideas (Potting and Kroeze 2010). It is true that the concept of the CE has many variants and a rich set of historical antecedents. In "Strategies for Manufacturing," Frosch and Gallopolous (1989) analogized industrial ecosystems to biological ecosystems. The set of ideas based on a biological analogy in varying degrees and forms has been examined, elaborated, and increasingly adopted in many guises. These include, but are not limited to, Boulding's essay on "The Economics of the Coming Spaceship Earth" (Boulding 1966), Commoner's "Four Laws of Ecology" (Commoner 1971), notions of closing and slowing loops (Stahel and Reday-Mulvey 1981; Bocken et al. 2016), the CE (Pearce and Turner 1990), industrial and socioeconomic metabolism (Ayres 1994; Fischer-Kowalski and Hüttler 1998), biomimicry (Benyus 1997) and biomimetics (Bhushan 2009), and cradle to cradle (McDonough and Braungart 2002).

Policy antecedents include the influential first Netherlands Environmental Policy Plan "To Choose or to Lose" in 1989 that was centered around closing cycles and, later, Germany's "Closed Substance Cycle and Waste Management Act" enacted in 1996, and Japan's 2002 "Basic Law for Establishing a Recycling-Based Society." In some cases, the adoption of a CE approach primarily signals a reinvigoration of the 3Rs—reduce, reuse, recycling—and in others it is a shift from a focus on waste management toward one on a more efficient use of resources motivated by concerns over resource availability and price stability. Other significant policy activities have emerged in China's 2009 "Circular Economy Promotion Law of the People's Republic of China" and the European Commission's (EC) 2015 Circular Economy Strategy.

In this special issue, McDowall and colleagues provide a detailed comparison of CE policies in China and Europe (McDowall et al. 2017). These researchers find that the Chinese perspective on the CE was developed around issues of pollution and in the context of China's rapid growth, whereas for Europe the focus is on business opportunities along with resource efficiency implications. The article identifies lessons from these international perspectives that can be used to advance the CE discussion and refine CE initiatives. For example, the breadth of the experimentation in policy and planning in China (geared toward identifying and then upscaling success) may be a useful example for Europe. On the other hand, Europe's emphasis on design, incentives for repair, and product labeling requirements may help China to move beyond recycling as the economy continues to grow.

Recent momentum has been catalyzed by the Ellen MacArthur Foundation (EMF), a British charity established in 2010. EMF has played a pivotal role in engaging the business community, and its *butterfly figure* has been instrumental in visualizing a hierarchy of circularity strategies (reuse, repair, refurbishment, remanufacturing, repurpose, and recycling). On the other hand, recent studies suggest that CE business initiatives predominantly focus on recycling (Allwood 2014; Potting et al. 2017).

But whether the ideas that make up the CE are novel or not is, in many ways, less important than ensuring that lessons from past attempts are fruitfully exploited in the current efforts. Further, CE proponents argue that it is the integration of previous strategies and concepts where the framework can and should make its greatest contribution. This prompts the question of how the CE can learn from the methods and findings of IE and what new ideas—or combination of ideas—the CE is bringing to IE.

Aiming for Product Circularity

The contributions in this issue around product design and the CE highlight the need for specific indicators and methodologies that integrate policy goals with business pursuits to understand whether product circularity is occurring and whether it is beneficial. The set of articles on this topic accomplish this through terminology refinement, and indicator and metric development, as well as through case studies.

Blomsma and Brennan (2017) contend that indicators and other assessment methods will play a key role in generating a deeper understanding of the CE concept and how it integrates earlier related concepts. Den Hollander and colleagues (2017) argue that there is a fundamental distinction to be made between eco-design and circular product design. Through this distinction, they articulate a set of new concepts and definitions, including the redefinition of *product lifetime* and introduction of terms such as *presource* and *recovery horizon*. Leveraging Stahel's inertia principle to develop a typology of approaches, they label "Design for Product Integrity"; the work informs the discussion on the role of product design in a CE. By outlining gaps in the current terminology, this contribution highlights that new opportunities may arise as we continue to probe the usefulness of the CE framework.

Linder and colleagues (2017) respond to a lack of standardized methods for measuring the circularity of products by proposing a single value economic metric calculated as the ratio of economic value of the recirculated materials to the total product value, using value chain costs as an estimator. Fernandez Mendoza and colleagues (2017) bring together eco-design principles and backcasting to support new business model development and product design in a CE, through an example of a vacuum cleaner. They introduce an "iReSOLVE framework" building on the EMF's ReSOLVE framework to map solutions related to the case study ranging from product-related to systemic changes. Niero and colleagues (2017) present a framework combining LCA and Cradle to Cradle® certification for the development of continuous loop packaging systems, specifically for aluminum cans and the Carlsberg Circular Community. This results in a list of prioritized actions to promote the most eco-efficient and eco-effective *upcycling* strategy for beverage packaging. Each of these contributions emphasize that in order to take the CE to the next level, we need to dynamically evaluate circularity and eco-design as these products, and the systems in which they exist, continue to evolve.

Two articles focus discussions on electronics at end of life (EoL). Given the ubiquity of electronics-containing products and finite reuse opportunities, continued attention should be paid to this topic. Talens Peiró and colleagues (2017) offer findings relevant to the objectives of the EU CE package for a case of disassembly criteria related to battery packs in computer devices. They provide a framework to identify design features that facilitate disassembly for batteries when reuse or refurbishment is not practical. Richa and colleagues (2017) present a framework for evaluation of EoL management for lithium-ion batteries from electric vehicles (EVs). As the market share of EVs grows, the management of the use of spent batteries will become increasingly important, raising issues of which sort of circular strategy is best. The analysis covers a broad set of options, including: same-product reuse in EVs; so-called cascaded reuse in stationary applications; recycling; and landfill. Putting their findings in the context of waste policies, the researchers find that the environmental benefits of reuse, though significant, rely on the size, form, and chemistry of batteries, as well as the nature of incumbent versus future battery systems. These contributions emphasize the need for careful evaluation of product and materials management for EoL and the importance of not assuming reuse is always preferable.

Baxter and colleagues (2017) approach product circularity from another angle by exploring the barrier for product circularity from what they label *contaminated interaction* stemming from variations in the perceived state of a material within a product. Because the CE derives much of its value from maintaining pure material flows, such (perceived) contamination poses important challenges to the CE. Focusing on decision making by individuals in consumer and business to business environments, they show three ways in which contaminated interaction acts as a barrier to the CE: downcycling; premature disposal; and hindered circulation. Their emphasis is on products developed with transferable design—products that can move between users and uses without negative consequences.

Taking Steps Toward Material Circularity

As we see from the discussion of the contribution by Baxter and colleagues (2017), discussions about product circularity inevitably lead to discussion of recycling the materials that constitute these products. Several contributions focus on the opportunities and challenges faced in achieving material circularity.

Much of the discussion of the CE is couched in terms of material flows. In their commentary, Fellner and colleagues (2017) take a complementary perspective, one that is increasingly studied in IE—quantification of stocks of materials. They look at a theoretical economy where all waste is turned into secondary materials and show that, because a significant share of commodities is still used to build up our infrastructure and thus accumulates in societies´ material stock, the overall potential for reducing primary raw material consumption and accompanying impacts is limited. Moreau and colleagues (2017) also conclude that dissipative uses absorb the largest material and energy flows in the economy, and point to the need for material recovery, because "reduce" strategies are largely insufficient to reduce such flows as, for example, anthropogenic carbon or nitrogen. Cullen (2017) argues, in a short commentary, that the quantity and quality of recovered materials must be taken into account in the formulation of CE strategies. He points out that a growing economy cannot rely solely on the recovered postconsumer materials, simply because the amount of available material is necessarily smaller than the raw materials inputs required attributable to increasing stocks. Even more important, cycling resources only makes sense when environmental impacts from energy use are integrated into the assessment of value. The discussions put forward by Fellner and colleagues (2017) and Cullen (2017) both point to the continued need for primary materials (i.e., extracted from mines, forests, and agricultural land). There is a need therefore to consider the circularity of a conventional mine—a concept that may seem in direct contradiction to the premise of a CE. Lèbre and colleagues (2017) acknowledge our continued dependence on primary extraction and provide a framework for circularity evaluation at a mine level. They develop material flow indicators and explore the impact of mine lifetime in the context of an Australian mine example. The article raises an interesting question: Acknowledging that we will still need resource extraction, can we have circularity in the mining industry?

On the other end of the life cycle, Haupt and colleagues (2016) engage a familiar topic—recycling of municipal solid waste—and bring detailed empirical analysis and rigor to something that many know intuitively, but not in systematic or quantified terms. Using material flow analysis (MFA), they quantify the difference between open- and closed-loop recycling and the difference between what is collected for recycling in Switzerland and what actually gets to end-user industries. For example, official collection rates for paper and cardboard are very high (97%), whereas they found collection rates of 74% and 89% and recycling rates of 59% and 81% for paper and cardboard, respectively. Their results raise questions about the actual flow of available secondary resources to industry.

Haupt and colleagues' work is complemented by a global analysis of waste treatment and waste footprints by Tisserant and colleagues (2017). They use environmentally extended input-output analysis to estimate the world-wide generation and recycling of solid waste in 2007. They develop a harmonized multiregional solid waste account, covering 48 world regions, 11 types of solid waste, and 12 waste treatment processes using a physical layer of the EXIOBASE2 multiregional supply and use tables. The study calculates that 3.2 billion tonnes (gigatonnes; Gt)[1] of solid waste is generated globally every year: 1 Gt was recycled or reused; 0.7 Gt was incinerated, gasified, composted, or used as aggregates; and 1.5 Gt was landfilled. In contrast, the EU needs to increase recycling by approximately 100 million tonnes per year (megatonnes; Mt/yr)[2] and reduce landfilling by approximately 35 Mt/yr to meet CE 2030 targets set in the EU Action Plan. Although patterns of waste generation differed between countries, with solid waste footprints found to be strongly correlated with affluence, significant potential for closing material loops still exists in both high- and low-income countries.

Schiller and colleagues (2017), in their work on the German building sector, propose a new MFA methodology for directly linking material inflow and outflows to the use phase of buildings. This is applied to bulk nonmetallic mineral building materials in the German building stock, with a focus on aggregate recycling from concrete building elements. The analysis finds little opportunity for closed-loop recycling of concrete aggregates. The recycling process incurs an estimated 20% loss in material capture and a further 40% loss in processing, resulting in only half of the demolition outflow meeting the requirements for high-quality recycling material. Further, even with improvement in capture and processing yields, only approximately one third of the material content of concrete could possibly be replaced by recycled aggregates attributed to technical limits in the German building standards. Another specific example of a particular material's potential circularity within a particular sector can be found in the contribution by Ueberschaar and colleagues (2017). They provide a detailed experimental analysis of recovering tantalum from the capacitors and printed circuit boards within a range of electronic devices, including phones, computers, monitors, and servers. The researchers find that, although recycling is possible, complete separation of tantalum from the device is near impossible and the process also leads to the loss of silver. The researchers place their results in the context of trends in the industry around products, components, and also based on the location of the recycling activities. This contribution serves as a case study for the limitations of the CE and points out that certain elements do not lend themselves to circularity. These targeted contributions echo the concerns of Fellner and colleagues (2017) and Cullen (2017), all together highlighting the potential limitations for significant material circularity.

Rising to the Challenge of Toxic Materials

Among the challenges faced in the advancement of the materials CE is the management of hazardous or potentially hazardous substances that become embedded in material cycles, what the EMF has dubbed *substances of concern* (WEF et al. 2016). The potential for continuing or enhancing exposure to problematic, or even toxic, substances through the closing of material cycles is widely acknowledged, and, in a few cases, tangible efforts are being made to address the problem.

Nonetheless, most discussions of this issue in the context of the CE are confined to exhortations, in part because removing such substances is difficult. In this issue, two contributions examine these challenges. Augustsson and colleagues (2016) examine the management of wood treated with chromated copper arsenate (CCA) in Sweden. They document how, despite overt attention to CCA wood waste since 2002, it remains both poorly tracked and improperly routed in the waste management with undesirable results, including contamination of incinerator ash, limiting possibilities for reuse of the ash. Goldberg (2017), executive director of the U.S. Northeast Waste Management Officials and a leader in efforts at toxics reduction, argues that some efforts at closing material cycles underestimate the potential for leakage and that the CE advocates need to connect better with long-standing, existing organizations working to reduce the use of toxic substances.

Tackling Conceptual Challenges and Exploiting Institutional Opportunities

Turning to the agents that are needed to bring about change toward circularity, a set of articles examine concepts and institutions. Circularity can be encouraged by business models such as PSSs and those moving away from ownership to selling usage or performance (Stahel 2010). PSSs can be particularly suitable given that they better align interests by breaking the link between profit and production volumes (Bocken et al. 2014). In this issue, Catulli and colleagues (2016) provide insight into sociocultural aspects of PSS-based consumption in consumer markets for a case of Harley Davidson and Zipcar. Through these case-study choices, they examine consumption with ownership versus consumption without ownership, pointing to the sociocultural barriers in PSSs for cases where identifying with a brand community is important. By acknowledging this challenge with PSSs, we may then identify ways for designers to overcome these difficulties.

The next levels of circularity strategies require social and institutional changes, as well as new business models and circular product design. If increasing circularity shifts focus away from changing downstream processes (i.e., waste collection and processing) to fundamental changes in upstream processes of production and consumption, actors through the whole product chain need to change their practices, and this needs to be enabled by related socioinstitutional changes. Borrowing the notion of *umbrella concepts* from sociology and organizational science, Blomsma and Brennan (2017) assert that the concept of the CE can catalyze a new perspective on waste and resource use, creating capacity that can be used as a basis for collective action and further highlighting the need for development in the social science aspects of IE. Moreau and colleagues (2017) point to the danger of considering mainly cost-effective opportunities within the realm of economic competitiveness. Such a limited approach to CE concepts may stop short of grappling with the institutional and social predispositions essential for setting the rules that distinguish profitable from nonprofitable activities. Moreau and colleagues (2017) show that reconsidering the role of labor is essential to tackling the large share of dissipated material and energy flows that cannot be recovered economically. In this respect, the social and solidarity economy, with its focus on equity with respect to labor and governance, provides an instructive and practical example that defies the constraints related to current institutional conditions and economic efficiency.

One place where institution meets circularity in the field of IE is the study of industrial symbiosis (IS) (Chertow 2000). Businesses achieving circularity across organizational boundaries, and thereby closing loops, are instrumental to reducing dependence on primary resources. Mulrow and colleagues (2017) explore IS possibilities within single facilities that include multiple firms. They provide three frameworks for facility-scale symbiosis: one leveraging an anchor firm; a second where there is a project organizer; and the third (most specific to facility scale) is a business incubator. In a case study around cement manufacture, Prosman and colleagues (2017) challenge the role of geographical proximity and external coordination in IS, offering thoughts for how existing IS exchanges could be improved. Another potential opportunity in IS, which connects with business model innovation, is offered by Siskos and Wassenhove (2016). They introduce the concept of a synergy management services company, a synergy contractor and third-party financing model, to overcome IS barriers related to economic concerns stemming from long payback periods and price fluctuation.

Ness and Xing (2017) provide a synthesis of key principles associated with the CE and outline the benefits and shortcomings of existing concepts (e.g., closed loop, optimized use of assets). They develop a conceptual model and apply the principle to the built environment, in particular, developing a research agenda to advance the discussion of sustainable buildings beyond a focus on carbon neutrality and *greenness*. They offer a set of CE, IE, and urban metabolism principles and their application to the built environment. Their “conceptual model for a resource-efficient built environment” gives direction about the types of strategies and activities actors can adopt to collaboratively in the move to a circular built environment.

In a fundamental challenge to the CE, Zink and Geyer (2017) highlight how the rebound effect might also influence our ability to close material and product loops if our ultimate aim is to reduce primary production. The rebound effect, most widely studied in the context of transportation and energy efficiency, describes a situation where increased efficiency makes consumption of some goods relatively cheaper and, as a result, people consume more of it. Zink and Geyer provide insight into which mechanisms lead to rebound in the CE, such as limited substitutability of primary materials by secondary materials. This article addresses the challenge organizations face in increasing circularity while still finding profitable opportunities to grow. This article points out that the economic responses to circularity may be often overlooked and considers whether economic growth stimulated by circular strategies might undermine its resource and environmental benefits.

Final Thoughts

As pointed out by several articles, the CE can build on a large body of literature and a rich set of its historical antecedents; particularly, knowledge and insights from IE are emphasized. The articles in this special issue provide examples of both convergence and complementarity in the priorities identified to further the CE. They also hint at some emerging and challenging issues that must be addressed as CE discussions move forward. A first challenge is obviously to include environmental assessment in discussions of circular strategies on a systematic and ongoing basis. If, as several articles indicate, circularity can sometimes lead to negative environmental results, how should CE strategies take this into account? This leads to a more subtle, but significant, question. Are there circular strategies that do not generate net environmental benefits now, but might do so after they evolve? How do we identify which ostensibly counterproductive strategies fall into this category? Put another way, an analytical foundation is needed to manage a transition to a CE. This challenge is not unique to the CE. Many environmental endeavors are pursued with the expectation that poor environmental performance will give way to desired outcomes over time. For example, we currently promote EVs not because they lead to significant environmental benefits today, but in the hope that we will be better prepared to exploit a future decarbonized electricity grid. In the same way, transitioning to a more resource-efficient CE now means less renewable energy will be required for delivering products later. Perhaps there are lessons in those examples that can be applied to the CE, helping to distinguish desirable wagers on evolving practices from those that lead to a dead end.

Another implication of articles in this issue (Lèbre et al 2017; Fellner et al. 2017; Cullen 2017) is that economies cannot run solely on recycled materials. Primary resource extraction cannot be avoided. Although the concept of biological and technical materials indicates how types of materials might be appropriately matched to uses and resource cycles, little is said about sustainable management and extraction of raw materials and energy. Put in operational terms, materials could follow the dictates of the CE and still be responsible for significant environmental damage if natural resource management and extraction are ignored.

How should we look to the short- and long-term evolution of these outcomes to understand whether the CE is leading us in the right direction, that is, toward the higher strategies in the waste hierarchy of prevention and consumption reduction, or lower-ranked strategies of recycling (Allwood 2014)? Will it lead to rebound effects (Zink and Geyer 2017), or can it be compatible with slower forms of consumption and *sufficiency* (Bocken et al. 2016)? Will large global companies adopt the CE more widely, including the more *advanced* business strategies such as remanufacturing and *sharing models* (Bocken et al., 2017)? As the CE concept continues to evolve in the process of being adopted by businesses and implemented in national and regional policies, the IE community needs to play a pivotal role in ensuring that the discussion and implementation moves to the next level in a fruitful and rigorous way.

Notes

1. One gigatonne = 10^9 tonnes (t) = one petagram (Pg, SI) ≈ 1.102 × 10^9 short tons.
2. One megatonne (Mt) = 10^6 tonnes (t) = one teragram (Tg, SI) ≈ 1.102 × 10^6 short tons.

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