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CHAPTER 10. BUSINESS AND PRODUCTION SOLUTIONS: CLOSING LOOPS & THE CIRCULAR ECONOMY

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ABSTRACT

Traditional production frameworks and business models are now being challenged by alternatives that are informed by biology. The alternative paradigm, based on ecosystem models, argues that shifting from linear modes of production to a circular system can address material and energy efficiency by reducing the total volume of raw materials needed when manufacturing consumer products. This chapter introduces frameworks that apply closed-loop models at the product level namely; the Performance Economy, Cradle-to-Cradle*TM* design, The Blue Economy and the Circular Economy.

We discuss the historic development of these ideas and their main contributions. Through the use of examples we explore both practical challenges associated with realising circular strategies as well as their business model implications. We conclude by highlighting some of the theoretical challenges associated with adopting closed-loop models advocating for a critical approach to sustainable resource management which includes circular strategies as part of a toolbox of options.

10.1 Introduction

It is likely that humanity will be resource and carbon constrained in the future, which, with the current state of technology, is likely to affect modern consumption and production patterns. At the very least, we will have to create value for a growing and more affluent population emitting far fewer greenhouse gases, reducing the over-exploitation of natural resources and restoring biodiversity whilst ideally generating no waste in the process. Firstly, this requires significant changes in the way that we manufacture today: including radical efficiency gains, new materials and new production processes. Secondly, and more profoundly, this requires new business models, informed by appropriate social and moral foundations that change the way we think about and interact with products. Without these changes humanity faces ecological overshoot with potentially catastrophic consequences for the biosphere and society as we know it.

In search of models of production that recognise their embeddedness in the natural world, this chapter explores the use of ecosystems as guides for the reconceptualization of industrial production systems. We focus in particular on the application of closed-loop and circular frameworks at the product level. Implementing these ideas has the potential to change our relationship to manufacturing and to goods. However, like all models, these ideas are only representations of reality: understanding both their strengths and weaknesses is important.

Resource scarcity and constraints

From food to machinery, the manufacture of products requires factors of production that include raw materials, energy, water, finance and labour. It is likely that by 2050 and beyond, the scarcity of or restrictions due to emissions on the use of the first three factors, will act to constrain the products that can possibly be manufactured (Tennant, 2013).

Global population is projected to reach around 9 billion people by 2050 (OECD, 2012). Under a business-as-usual scenario the global population will be richer than today, moving towards a more affluent lifestyle powered mainly by fossil fuels, resulting in an average global temperature rise of between 3°C – 6°C by 2100. Concomitant industrialisation will see an increase in demand for food, energy, water and raw materials, with the World Wildlife Fund (WWF) (2012) predicting that humanity will be using 2.9 planets' worth of resources by 2050. Allwood et al. (2011) suggest that the demand for metals is predicted to double by 2050 and while it is unlikely that raw materials will run out in the near future, high-grade ores will become increasingly difficult to extract economically pushing up prices for both commodities and products.

If the global north wishes to maintain their current standard of living while also allowing newly emergent economies to enjoy a similar standard, new ways of making raw materials go further will have to be found.

Ecosystems as models for sustainable production systems

A defining characteristic of biological systems is the cycling of materials as old structures are decomposed and assimilated into new, which ensures continuing systems evolution. This has long been seen as an attractive alternative for current more linear manufacturing processes, epitomised by the paradigm of 'take, make and discard' or 'cradle-to-grave' production systems (Lifset and Lindhqvist, 2001).

A production system guided by nature aims to cycle materials when they reach their perceived end of life. This questions the very idea of waste, as in this context waste is always the feedstock for a new cycle and, as such, resources are never wasted. The re-framing of waste as a valuable resource has been applied predominantly at the industrial level by industrial ecology scholars (Graedel and Allenby, 1995, Ayres and Ayres, 2002) however, more recently, application at the product level has been re-emphasised (Stahel and Reday, 1981, McDonough and Braungart, 2002, Pauli, 2010, EMF, 2012).

This chapter begins by exploring ideas that underpin contemporary circular frameworks. Section 10.3 outlines four product-level frameworks: *The Performance Economy; Cradle-to-Cradle*^{TM} design, *The Blue Econom*y and the Ellen MacArthur Foundation's *Circular Economy Framework*. Section 10.4 highlights the practical challenges associated with trying to realise and implement circular strategies. Sections 10.5 addresses the business model implications of adopting circular strategies. In Section 10.6 we raise the theoretical challenges associated with adopting circular models arguing for a critical approach to circularity and advocating for a sustainable resource management approach which includes circular strategies as part of a variety of tools. Lastly, Section 10.7 summarizes this chapter by looking at the future of circular models.

10.2 A brief history of Industrial Ecology

Industrial Ecology (IE) can be described as looking at biological ecosystems as 'models for industrial activity' (Lifset and Graedel, 2002:3). The term *ecosystem* refers to organisms, the interactions between them and the abiotic environment in which they are situated (Virginia and Wall, 2013). Observations of material and energy flows, at both the level of an organism's metabolism as well as at the level of species in biological food webs, are the basis for the concepts of *closing the loop or loop closing* (Lifset and Graedel, 2002).

Seminal thinkers

Ecosystem analogies have been used across multiple disciplines over the last 150 years suggesting there are a vast number of thinkers that have contributed to the evolution of the field of IE (Fischer-Kowalski, 2002). In Table 10.1 we provide an overview of the seminal thinkers whose ideas are the precursors to the emergence of contemporary circular frameworks. However, five thinkers are particularly worth highlighting due to their contributions to the field: systems thinker and evolutionary economist Kenneth Boulding (1966); physicist Robert Ayres and economist Allen Kneese (1969); and engineers Robert Frosch & Nicholas Gallopoulous (1976).

Boulding proposed the "closed spaceship economy" as an alternative to the "open cowboy economy" which he argued represented the lack of acknowledgement of the physical resource limits of a finite planet (Boulding, 1966:7). He argued that society on earth may become like a spaceship where there are limited sinks for pollution or stocks for extraction and that

> *"...man must find his place in a cyclical ecological system which is capable of continuous reproduction of material form even though it cannot escape having inputs of energy"* (Boulding, 1966:8).

He emphasised the importance of maintaining the quality of our capital stocks and highlighted issues of planned obsolescence and poor quality of consumer goods and introduced the concept of *durability* (Boulding, 1966:12).

Ayres and Kneese (1969) introduced the concept of an *industrial metabolism* which is based on the analogy of biological metabolism. Industrial metabolism can be described as drawing the analogy between "*…firms, regions, industries or economies with the metabolism of an organism"* (Lifset and Graedel, 2002:6). Industrial metabolism analysis aims to quantify the -

"*…energetic and material exchange relations between societies and their natural environments from a macro perspective*" (Fischer-Kowalski, 2002:15).

Frosch & Gallopoulous' (1989) paper *Strategies for Manufacturing* popularised the concept of an *industrial ecosystem*:

> "*In such a system the consumption of energy and materials is optimized, waste generation is minimized and the effluents of one process (…) serve as the raw material for another process*" (Frosch and Gallopoulos, 1989:144).

Key to their description of an *industrial ecosystem* is the principle of by-product exchange between firms whereby the waste output of one firm becomes an input for another firms' process.

These *industrial metabolism* and the *industrial ecosystem* analogies underpin the contemporary field of IE. While the metabolism analogy has a different departure point based on the observation of the metabolic processes at the level of an individual organism, it can also be interpreted as an ecosystem analogy applied at a lower system level, as the ecosystem analogy includes the metabolic processes of more than a single organism.

Table 10.1: Overview of Seminal IE Thinkers

Thinkers	Concepts/Frameworks	Level of Application	Seminal Work
Peter Lund Simmonds	Observations of industrial waste being used as a resource- practices we would now call IE.	Industrial system	Simmonds (1862/1876) Referenced by: Desrochers (2002) Murray et al. (2013)
Kenneth Boulding	Open cowboy economy versus a closed spaceship economy.	Industrial system/National	Boulding (1966)
Robert Ayres & Allen Kneese	Industrial metabolism	Industrial System	Ayres and Kneese (1969)
Barry Commoner	Ecological principles used to structure national economy.	National	Commoner (1971)

Thinkers	Concepts/Frameworks	Level of Application	Seminal Work
Walter Stahel	Circular or loop economy through product life-extension and the Performance Economy.	Product Design	Stahel and Reday (1981) Stahel (1984) Stahel (2010)
Robert Frosch & Nicholas Gallopoulous	Industrial ecosystem	Industrial System	Frosch and Gallopoulos (1989)
Karl Henrik Robért	Cyclic industrial era and the cyclical principle. Informed The Natural Step Framework.	Industrial System	Eriksson and Robèrt (1991) Robèrt et al. (1997)
Paul Hawken	Circular economy, restorative economy.	Community	Hawkens (1993)
John T. Lyle	Regenerative Design	National	Lyle (1996)
Thomas Graedel	Earth system ecology – studying biological and industrial systems from a synthesised perspective.	Industrial System	Graedel (1996)
Janine Benyus	Biomimicry Design framework – mimics form, function and processes in natural systems.	Product Design	Benyus (1997)
Gunter Pauli	Coined the term upcycling and the Blue Economy.	Product Design	Pauli (1998) Pauli (2010)
William McDonough & Michael Braungart	Cradle-to-Cradle (C2C) design: technical and biological metabolisms and eco-effectiveness.	Product Design	McDonough and Braungart (2002) Braungart et al. (2007) McDonough and Braungart (2013)

Application of IE

Industrial ecology has predominantly been implemented at the macro-level of the industrial system with the formation of over 60 industrial symbiosis networks since the 1970s (Chertow and Ehrenfeld, 2012). Kalundborg Symbiosis Network in Denmark is the pre-eminent example of industrial symbiosis, a place-based approach to industrial ecology, whereby firms within a specific geographic location exchange waste from their production processes turning them into inputs or resources (Kalundborg, 2013). However, industrial symbiosis is just one application of the ecosystem analogy within a narrowly defined system boundary at that.

IE has also influenced national waste management and recycling policy particularly in Japan and China. In 2000 Japan introduced the '*Fundamental Law for a Sound Material-Cycle Society'* (Moriguchi, 2007) and China introduced the '*Law for a Circular Economy*' in 2008 (Park et al., 2010). More recently these ideas have gained traction in the European Union with the 2012-2014 *Resource Efficiency Platform* and subsequent adoption of a Circular Economy package (EC, 2014).

The impact of IE's ideas has largely been at the production process and policy level, however, products have always had an important role to play in an industrial ecosystem where nothing is wasted. This is highlighted by Graedel & Allenby's assertion that IE "…*is a systems view in which one seeks to optimize the total material cycle from virgin material, to finished material, to component, to product, to obsolete product, and to ultimate disposal*" (1995:9).

Our brief discussion demonstrates that closed-loop and circular ideas have a long history and there are varying interpretations of the underlying ecosystem analogies with wide ranging application. There is an extensive body of literature within the field of industrial ecology, which we have not had space to cover, and refer the interested reader to Ayres and Ayres (2002), Boons and Howard-Grenville (2009) and Lifset and Boons (2012).

10.3 Circular frameworks

In this section we introduce four contemporary circular frameworks that are influencing circular product design, highlighting their characteristics and commonalities. Recognising that these frameworks are broad in scope, the following discussions will be limited to the aspects related to circularity.

Product-life extension & the Performance Economy

In the late 1970s Walter Stahel, a Swiss architect and economist, outlined the job creation and waste reduction benefits that could be created from shifting to a cradle-to-cradle or closed-loop economy in *Jobs for tomorrow: the potential for substituting manpower for energy* (Stahel and Reday, 1981). Expanding on these ideas in *The Product-Life Factor,* he referred to a *self-replenishing economy*, based on a loop system that results in the circulation of materials through sequential product-life extension activities (re-use, repair, reconditioning/upgrades, remanufacturing and recycling) (Stahel, 1984). These works underpin Stahel's argument for the *Performance Economy* which emphasises designing long-lived or durable products, ensuring product life extension strategies occur, and advocating for the sales of the service of a product rather than the physical product itself (Stahel, 2010).

Selling the function, use or the performance of a product as a service is now commonly referred to as a product-service system (PSS) and Stahel is recognised as one of the pioneers of this concept (Tukker, 2013). Stahel argues that selling performance results in both the efficient cycling of materials as well as increased innovation because it is in the service provider's profit interest to adopt strategies which prolong the life of the resources which form the material basis of the service (Stahel, 2010). Stahel also maintains that a shift to a *Performance Economy*, which he equates with a circular economy, will lead to an increase in job creation in local economies as labour is required to keep resources and goods in productive loops (Stahel, 2010).

Cradle-to-Cradle*TM* (C2C) design

American architect William McDonough and German chemist Michael Braungart developed a design framework called *Cradle-to-Cradle*TM (C2C), which applies ecosystem analogies to the design of products and the built environment. Their framework, which originated in *The Hannover Principles* they produced for the German city in 1992, was developed and popularised through their books *Cradle to Cradle: Remaking the way we make things* (McDonough and Braungart, 2002) and *The Upcycle* (McDonough and Braungart, 2013).

Braungart and McDonough argue that zero-emissions is the incorrect goal for industry to strive towards, for "…*existence creates emissions…*" (Braungart et al., 2007:1342), meaning that generating emissions is fundamental to life. Rather, they see the problem as one of "materials-in-the-wrong-place", where these wrong and out-of-place materials cause serious negative human and environmental health impacts (McDonough and Braungart, 2013:211). As a solution to this problem they distinguish between two types of metabolism and two important groups of nutrients - materials that can safely be returned to the biosphere, called *biological nutrients,* which should flow within a biological metabolism; and man-made compounds that cannot be broken down and safely absorbed by biological systems, or *technical nutrients,* which should flow in the technical metabolism (McDonough and Braungart, 2002, Braungart et al., 2007). Cradle-to-Cradle*TM* is based on the idea that products can be designed in such a way that their constituent materials can cycle in either the biological or technical systems indefinitely using renewable energy sources to sustain these cycles (McDonough and Braungart, 2002).

Within Cradle-to-Cradle*TM* waste is reconceptualised as healthy waste, or *waste equals food,* where waste from one process is used as food for another (McDonough and Braungart, 2002). This notion departs from eco-efficiency strategies like waste minimization and zero waste strategies. This new strategy they termed eco-effectiveness and, like Stahel's *Performance Economy*, its goal is to "…*maintain resource quality and productivity through many cycles of use, rather than seeking to eliminate waste*" (Braungart et al., 2007:1338). They argue that materials that cannot be feasibly cycled either within biological systems or as a technical nutrient should be phased out of products (McDonough and Braungart, 2002).

The Blue Economy

Gunter Pauli founded the open source Zero Emission Research & Initiatives network (ZERI) in 1994. His 2010 report to the Club of Rome outlined the concept of the *Blue Economy*, which focuses on providing for people's basic needs, such as food, access to energy and work, whilst staying within ecological boundaries to do so:

> "…*Blue Economy industries, capable of generating employment for all, are on the horizon. They are based on how nature uses physics and biochemistry to build harmoniously functioning whole systems, cascading abundantly, transforming effortlessly, and cycling efficiently without waste or energy loss*" (Pauli, 2010:12).

Despite the emphasis on basic needs, the Blue Economy offers interesting insights into what circular products are and how they come into being. For example, the Blue Economy, like Cradle-to-Cradle^{TM}, does not see waste as an issue *per se*, but is concerned with what to do with it (Pauli, 2010:7). The Blue Economy is aimed at generating maximum value from waste in order to be able to do more with less. The means to achieving this is maximising the value of a resource as it cascades from one use to another (Pauli, 2011:15). One example is the farming of mushrooms on coffee waste, where the continued use of coffee grounds for producing edible food is seen as an extra way to generate value from a resource beyond its primary use for brewing coffee (ZERI, 2013). An important enabler of resource cascades is the redesign of materials and processes so that they are biocompatible ensuring that materials are safe and non-toxic.

The Circular Economy by the Ellen MacArthur Foundation

The application of circular ideas at the economy-wide level has received renewed attention since the launch of the report *Towards the Circular Economy* by the Ellen MacArthur Foundation (EMF) at the 2012 World Economic Forum (WEF). They estimate that the successful implementation of a circular production system across the EU could result in net material savings of up to US$630 billion per annum (EMF, 2012).

EMF's *Circular Economy Framework* combines Stahel's Performance Economy (product-life extension activities that cycle materials: re-use, repair, reconditioning/upgrades, remanufacturing and recycling) with Cradle-to-Cradle^{TM} (distinction between biological and technical nutrient cycles) and the Blue Economy (generating value from multiple cascades) (EMF, 2012, EMF, 2013). The Ellen MacArthur Foundation advocates four principles for increasing resource productivity: the returning of a product to a use-able state in the shortest cycle possible, prioritising re-use over reconditioning, remanufacturing or recycling referred to as the "the inner circle"; maximising the number of consecutive cycles and length of cycles "circling longer"; re-using materials at different points in the value chain "cascaded use" and the fourth principle emphasises the importance of uncontaminated material streams through "pure circles" (EMF, 2012:7).

Bakker et al. (2014) highlight the parallel between the EMF's Circular Economy framework's emphasis on prioritisation of re-use over reconditioning, reconditioning over remanufacturing and remanufacturing over recycling and the principles of the European

Union's Waste Hierarchy, a legislative framework that attempts to guide the reduction of the impacts of waste using the *3 R's - reduce, reuse, recycle* (EC, 2008). Within the Waste Hierarchy framework *reducing* the absolute amount of materials and products in the economy is seen as having the greatest effect on reducing environmental impact and is given priority over *reusing* the product after some repair, refurbishment or remanufacture. Reuse is in turn prioritised over *recycling* with the final option of *recovering* embodied energy (EC, 2008).

10.4 Design considerations

While the above circular frameworks provide general conceptions based on the potential for closed-loop cycling and product longevity, they do not describe the technical operations that are needed to implement them. Implementing the majority of the strategies that facilitate material cycling requires product design changes that should occur at product conception so that the potential to extend their useful life is locked in rather than an afterthought. However, fundamental changes to products or processes may require large capital investment and thus be unattractive to businesses that spend little on research and development or new infrastructure. This section outlines the methods available to upstream actors, for example brand designers and original equipment manufacturers, highlighting some of the practical challenges encountered when trying to implement these models. Moreover, it emphasises that there are always trade-offs to be made and that the appropriate solution will be context-dependent.

Reduce: material composition and product life cycle

There are a number of practical challenges associated with product design that stem from material properties and the current state of technology in processing these materials. Discussed next are the trade-offs associated with durability and light-weighting and the difficulties associated with hazardous materials.

Durability and light-weighting

Increasing a product's durability means that it is able to withstand the rigours of use for longer, enabling product-service systems and the sharing economy which allow the owner to extract more value from it. This is in contrast with planned obsolescence, where products are made with a set lifespan in order to encourage replacement purchases. Increasing a product's durability is associated with strengthening the weak points in a product and can be achieved by using shock and wear resistant materials or more robust shapes, either through changing the geometry or adding more material. One has to also consider the impact of material choice on both biodegradability and recyclability. These all have implications for aesthetics and consequently for sales: if a consumer perceives value to be based, in part, on clean design and minimalism, then adding bulk and changing design may affect profits negatively.

However, there are cases particularly with electronics, where durability is not always the best solution from an environmental point of view, as the energy-in-use phase of an inefficient product may outweigh any potential material savings (Gutowski et al., 2011, Bakker et al., 2014). Bakker et al. (2014) argue that an *"optimal product lifespan"* exists (Bakker et al., 2014:12). However, they argue the main challenges are determining both this optimal lifespan and "…*when* to apply *which* product life extension strategy" to a particular product (Bakker et al., 2014:15).

Light-weighting is another method to reduce overall material use which has been applied in a number of sectors particularly aerospace, automotive and packaging (WRAP, 2010, Allwood, 2014). In the case of cars, lightweight design has been enabled by the advancement of composite materials, but composites come with their own challenges as they are difficult and energy intensive to separate and recycle (Bjørn and Hauschild, 2012, Yang et al., 2012). However, despite this trade-off, light-weighting is an important short-term strategy to adopt in this particular case because the weight of a car has a significant impact on fuel consumption.

Furthermore, while up-weighting for durability and light-weighting could be seen as potentially contradictory methods, they can be used in a complementary manner. For example if one were to adopt a *onion model* of design whereby the core was up-weighted and designed for extended life the outer-layers can be light-weighted and designed so they can be easily replaced (Allwood and Cullen, 2012).

Designing out hazardous materials & non-substitutes

It seems strange that products or materials that could be hazardous to health would be designed in the first place. Initially this occurred due to the ignorance of the hazards, for example, the use of ozone-depleting gases in refrigeration units which were subsequently phased out. However, today we still use chemicals and materials which are hazardous to life because there are no adequate substitutes. One example is brominated flame-retardants which are used in plastics and textiles for their safety properties. In an ideal world brominated additives would be designed out but, there are no substitutes with similar safety profiles and so they remain in products, requiring capture at the end of their life so that they cannot enter the biosphere.

Dealing with non-substitutable materials at the end of a product's life is a sensible option, but relies on capital investment and the ability to generate revenue over the long-term to offset the on-going costs of end-of-life management. This can be problematic when cash reserves are tight resulting in sub-optimal or no cycling within the technical system. However, new materials can and are being designed where substitutes do exist for example Ecover's use of biocompatible materials in their detergents.

Re-use: design for maintenance and reconditioning

Re-use is a strategy that attempts to retain or increase the value and in-use time of products by cleaning, maintaining, repairing, refurbishing and remanufacturing. These can be seen on a spectrum of activities that increase in complexity and often subsequent cost. Cleaning is usually the simplest intervention and remanufacturing the most complex.

Remanufacturing is where goods are returned to a guaranteed like new condition through disassembly, repair or replacement of parts and reassembly (Hatcher et al., 2011). If parts cannot be accessed to facilitate any type of maintenance it is likely that the value embodied within the product will be lost well before the theoretical end of its life cycle. This is seen in the many cheap consumer goods that are difficult, and consequently economically unattractive, to take apart and repair in most developed countries. However, product design is now recognised as impacting the ease and the success of all re-use methods and strategies. Increasingly 'Design for X' frameworks (Gatenby and Foo, 1990) which attempt to factor in re-use requirements at product conception, for example standardisation of components, modularisation and upgradeability, are implemented at the design stage of the manufacturing process (Allwood and Cullen, 2012).

Whilst remanufacturing is already a common practice for vehicles and washing machines due to the high value of their steel and aluminium bodies, its suitability as a solution for other products is dependent on the rate at which technology or products evolve in a particular sector (Whitehouse, 2012). There is however, a growing trend in websites which provide free product information and repair manuals for example like ifixit.com, which are reducing some of the barriers to maintaining and repairing white goods and electronics.

Recycle

When products are recycled they may be up-cycled or down-cycled. Both methods usually refer to the repurposing of waste products and materials, where up-cycling increases the value of the material (Braungart et al., 2007), down-cycling decreases it because it results in a lower quality end-product due to the contamination caused during shredding, melting or crushing materials. For example, InterfaceFLOR's *Net-Works* project in the Philippines up-cycles discarded fishing nets into carpet tiles, creating value in the form of income for both the fishing villages and the company. However, Nike's *NikeGrind* initiative down-cycles the plastic from running shoes and uses it as the aggregate material for athletics tracks and playgrounds.

Whilst upcycling is a preferred strategy, whether products can be disassembled into their constituent parts safely so they can be up-cycled will largely depend on the materials in question. Modern composite materials are used extensively in advanced manufacturing processes and products, including renewable energy technologies, automotive and aerospace sectors. These materials are blended in ways that result in products with superior properties compared to alternatives but, due to their heterogeneous nature, it is difficult to separate the constituent materials for recycling (Yang et al., 2012). There is thus a tension between innovation and environmental impact: if innovation allows society to develop such things as renewable energy technologies, to what extent should we regulate the materials used in production?

10.5 Business model examples and implications

Each of the strategies and methods discussed in Section 10.4 have implications for how businesses can create value. Keeping a product in use for longer implies that direct sales of new products decrease, impacting on-going profits that could otherwise be made. This is both a challenge to mainstream business operations that rely on repeat purchases but can also represent new business opportunities.

Instead of selling an electric drill, for example, a retailer could rent it to customers and create a new revenue stream focusing on maintenance (Cheshire, 2011). While this seems an attractive proposition it could require capital outlay to set up a new business unit and train staff to undertake the work. This has positive social implications in the form of job creation, as argued by Walter Stahel (1981). However, we also need to consider the consequences of such action and, in particular, the effect that leasing and repair will have on manufacturers, who will also be impacted by falling sales volumes. Will it require new designs and, if so, who will pay for those? Will customers want to travel back and forth to pick up and take back a small appliance, or would they rather buy a cheap one that is used for a fraction of its potential?

Some manufacturers create durable products with no expectation of volume sales, but wanting to have as little environmental impact as possible. Vitsoe, a UK furniture manufacturer who operate in the US, Asian and European markets, aims to help people "*live better with less*" (Vitsoe, 2014). They promote sufficiency by making high-end products which are based on the minimum amount of furniture their customers need and their products have come to have symbolic value, meaning they are more than "just things" to be disposed of when no longer wanted.

There are also a growing number of business models oriented around leasing (InterfaceFlor Evergreen Lease; Muddjeans; Vodafone); remanufacturing (Caterpillar; Ricoh; Xerox); PSS or pay per use (Citycar; Michelin Tyres; Philips and Turntoo office space); secondary markets (Marks & Spencer Schwopping; Patagonia Common Threads Initiative; PGA Golf 'Play it on Pledge' eBay Trade-In Network) and collaborative consumption (ZipCar; WhipCar). All of which are challenging the way that businesses deliver value and make profit. However, understanding both the potential value generation opportunities and costs implications of adopting circular strategies is important.

For example, a number of these business models associated with cycling of materials also require reverse logistics. If products are to be remanufactured or recycled, for example, how are they taken back to the manufacturer or a third party? This requires transportation for collection and return to customers, as well as inputs of energy, materials or labour to get the material or products to the specification required for re-purposing, all of which attract extra costs. Furthermore, if markets for secondary goods or materials are not mature or reconditioned goods are perceived as being of lower quality than new, this can impact the ability of businesses to generate revenue. All in all, each of these strategies and associated methods cost money that must be recouped somehow. This has different business model implications, some of which are summarized in Table 10.2.

Table 10.2: Product Strategies, Methods and Business Model Implications Summary

Strategy	**Method**	**Design Considerations**	**Business Model Implications** *all: capital outlay for redesign*
reduce	Durability/ Up-weighting	can it retain its function and aesthetic? does more material have to be used?	volume sales model difficult additional cost
	light-weighting	can it retain its function and aesthetic? does less material compromise strength and durability?	consumer perception of fragility guarantees needed
	fewer hazardous materials	material choice	costs of new materials
	changing consumption patterns	social regulatory	business case for changing consumer behaviour cost of innovation
re-use	cleaning	can parts be accessed? can it be cleaned using non-toxic solvents?	proprietary solvents increase revenue
	maintaining	can parts be accessed? can parts be manipulated e.g. bolts tightened? can it be taken apart in order to facilitate maintenance?	new business units for servicing; stimulates new company growth
	repairing	can it be taken apart?	as above

Strategy	Method	Design Considerations	Business Model Implications
			all: capital outlay for redesign
		can parts be replaced independently of whole?	
	remanufacturing/ refurbishing/ reconditioning	can it be repaired and the function guaranteed?	as above; quality assurance/guarantee/insurance
recycle	upcycle	can it be reduced to its constituent molecular level?	research & development costs
		can those parts be constituted into something of more value than the original waste?	network coordination with other companies, including transaction costs; quality assurance; guarantees
	down-cycle	can it be reduced to lower value state e.g. by crushing, shredding? is the aggregate hazardous? can the aggregate be used for other applications?	network coordination with other companies, including transaction costs
	compost	is it hazardous to life? is it biological?	
recovery	AD	is it biological? is it hazardous to life?	
	incineration/ gasification/pyrolysis	are the emissions toxic?	
		can any toxic emissions be captured & destroyed?	research and development costs
landfill		is it hazardous to life over the long-term?	

10.6 Challenges for circular frameworks

Circular industrial strategies promise to transform the way we manufacture goods, significantly reducing impacts on the environment and, ideally, moving towards living within planetary boundaries. There are, however, a number of overarching issues that need to be acknowledged as part of this transformation: the appropriateness of using an ecosystem model; population growth and consumption; economy-wide rebound effects; and the importance of context.

Is the ecosystem model appropriate?

Metaphorically, ideas of cycles and *waste-as-food* or *waste-equals-food* are powerful concepts that have been appropriated directly to some degree into the Waste Hierarchy and each of the circular frameworks outlined. However, direct mapping of the biological concept onto industrial systems is not straightforward (Jensen et al., 2011).

Ecosystems aren't closed systems

Ecosystems are not closed in the same way that industrial systems are (Murray et al., 2013). The loops in natural systems extend over spatial and temporal scales and boundaries are fuzzy and overlapping. Industrial systems are engineered and the bounds are well-defined, or *closed*. Moreover, the idea of a closed-loop system is thermodynamically impossible: in order to implement any of the circular strategies listed above more energy, materials and/or labour have to be imported in order to return a product to a useful state (Bjørn and Hauschild, 2012, Allwood, 2014). Yet, the circular frameworks outlined in this chapter often under-emphasise the fact that the vision of closing loops in industrial systems is idealistic and there are always trade-offs to be made.

Health warning: biological materials

One of the beauties of biological systems is that they have evolved to be inherently circular. Unlike industrial systems they use materials that biodegrade or can be transformed with minimal energetic requirements and used again. However, the argument that *biological nutrients* are inherently "healthy waste" due to their non-hazardous and biodegradable properties requires two important qualifications (Reijnders, 2008).

Firstly, it depends on the context of the particular ecosystem where the biological nutrients would be returned because biodegradation has the potential for negative effects highlighted by the example of algal blooms which are caused by excess fixed nitrogen in water ecosystems. Secondly, one needs to bear in mind naturally occurring toxins which can be harmful to organisms including humans (Reijnders, 2008). Ironically, the example of cherry trees used by Braungart et al. (2007) fails to note that they contain a natural toxin harmful to humans (Reijnders, 2008). Thus naturally occurring materials need to be managed in ways that account for potential negative impacts (Reijnders, 2008).

Population growth & pace of flows

Circular frameworks imply a static picture of consumption: we continuously cycle what has already dug out of the ground and use that material to create all the manufactured products that we need in the future. Suggesting a precondition for circularity to work is that global demand for products need to stabilise (Allwood, 2014). However, as the global population increases it is unlikely that emerging economies will want to live in relative poverty compared to their Western neighbours. Consequently, demand for materials and products is likely to rise requiring an increased stock of products-in-use which defies the potential for solely using circular strategies (Bjørn and Hauschild, 2012, Allwood, 2014). Therefore, we argue a circular production system needs to be seen in the broader context of a system of sustainable consumption and production (SCP) which acknowledges that the pace of flows through the economy is as important as maintaining stocks and multiple cycles of products (Bjørn and Hauschild, 2012, Allwood, 2014).

Given few precedents to guide us, we have to experiment with ways to manufacture more of the same products with the same amount of material whilst also being aware of the context we are operating in, or, alternatively, we have to produce fewer things. Techno-optimism tells us that the first is possible, and thus could be seen as part of a circular approach. The second, however, implies different strategies to avoid exhausting scarce resources. These strategies range from slow consumption (Cooper, 2005) to collaborative consumption, or the sharing economy, where products are shared and so used more intensely (Allwood, 2012). However, these both rely on changing attitudes to products, which may prove difficult in societies where ownership of more "stuff" is considered a sign of affluence and where novelty is prized. It also seems likely that businesses will also resist this change if it affects their profit margins.

Economy-wide rebound effect

The *rebound effect* is said to occur when an improvement in energy efficiency in one area is offset by an increase in energy use elsewhere (Sorrell and Dimitropoulos, 2007, Sorrell, 2009). An economy wide rebound can happen when:

> "*Cost-effective energy efficiency improvements will increase the overall productivity of the economy, thereby encouraging economic growth. The increased consumption of goods and services may in turn drive up energy consumption*" (Sorrell and Dimitropoulos, 2007:6).

If one were to extend this argument to the use of materials it can be argued that material cycling strategies may also increase economic growth as, in effect, supply is increased. Without regulation on the use of raw materials or economic price floors any material efficiency initiative may result in increased overall environmental impact. However, it is extremely difficult to quantify this economic rebound effect and more research on this is required.

Importance of context

The circular frameworks outlined in this chapter can be viewed as some of a number of tools that can be used to address the issues of unsustainability, which, in turn, contain a bundle of tools. Their call to design products and services which "do good rather than less bad" is an extremely important one. However, eco-efficiency strategies, which often result in relative, or incremental, sustainability improvements have a short-term role to play alongside eco-effective, or more radical strategies, which aim to achieve absolute sustainability improvements by re-designing entire product systems (Bjørn and Hauschild, 2012).

With so many considerations and trade-offs to account for, whatever strategies we choose, whether they entail reduction, reuse or recycling, rather than naively reading from a hierarchy of options or assuming biological materials are inherently "good" we need to make choices from a critical evaluative stance that acknowledges the context dependence of "positive impact". Consequently a constructive conversation about circularity requires clarification of the context of application and determining appropriate boundaries for the circular system under consideration.

10.7 The future of circular models

The circular economy, in its many variants, is a powerful conceptual tool that manufacturers, retailers and policy makers can use to help reduce the negative environmental impact of producing goods. It is, however, problematic in the context of a growing and more affluent population. Given finite resources it is likely that we will have to go beyond eco-efficiency strategies if we are to meet the needs of society in the near future. Demonstrating the difficultly of this it is calculated that the global rate of decarbonisation has been 0.8% since 2000 (PwC, 2012), but needs to increase to 5.1% *per annum* until 2050 to meet carbon reduction targets.

There are no practical precedents to guide us in this endeavour and so it is incumbent on industrial, business, finance and policy stakeholders to start to experiment with ways of producing goods differently. If our society is to be regenerative then industry must devote considerably more resources to research and development, with the aim of developing a manufacturing paradigm that has positive overall impacts on the environment and society. This will require new ways of doing business, from collaboration to accounting, which, in turn, will require supportive regulatory and policy infrastructure.

Of course, we could suggest that population growth is addressed, as this seems to be the "elephant in the room" with so many discussions about sustainability. Population growth *per se* is not the problem though: the poorest in society have very little impact on the environment (Satterthwaite, 2009). We need to address the consumption habits of the richest, of which there will be 3 billion more by 2030 (Kharas, 2010). Much better, we think, to harness the creativity of these individuals than to fight a battle that will act to divide interests, be politically imprudent and may act to derail the progress made already towards a notion of sustainability.

In conclusion, the purpose of this chapter has been to demonstrate that linear production systems based on the paradigm of "take, make, waste" are no longer sufficient to address the resource-constrained future ahead but equally, whilst closed-loop models or circular frameworks are better, they are not a silver bullet and should be seen as part of a suite of sustainable resource management strategies. Sometimes there are no ideal choices and experimentation in order to learn whether ideas work, or learn from failure, are the best options available to us. We have argued that in order to "do good rather than less bad", as circular frameworks rightly call for, a critical approach is required to decision making whereby the trade-offs of adopting one strategy over another are considered. This also requires being able to acknowledge the limitations of ideas in order to be able to identify when better ideas supersede others. We believe one of the most important contributions of the current circular economy meme is that it is providing rhetorical and practical inspiration for businesses to experiment with doing things differently.

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