# Case for Sustainability in Strategy and Operations: Overcoming the Challenges of Product Design in Creating Competitive Advantages in Circular Supply Chains

By

**Niraj Dalmia**

Bachelor of Commerce
St. Xavier's College, University of Calcutta, 2005

Master of Business Administration
Saïd Business School, Pembroke College, University of Oxford, 2013

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Signature of Author: Signature redacted
MIT Sloan School of Management
May 9, 2014

Certified By: Signature redacted
Matthew Amengual
Assistant Professor
Institute for Work and Employment Research
MIT Sloan School of Management
Thesis Supervisor

Accepted By: Signature redacted
Michael A. Cusumano
SMR Distinguished Professor of Management
Program Director, M.S. in Management Studies Program
MIT Sloan School of Management

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## Abstract

The previous industrial revolutions coupled with long-established business models have created a lock-in towards a linear 'take-make-dispose' model of production and consumption – products are manufactured using non-renewable sources and raw materials, manufacturing wastes are discarded as unusable, product is sold through the supply chain often creating more disposal of wastes, the final product is used by the end consumer till a less than optimal end-of-life, and then disposed or incinerated as landfill. The effects are clear and unsustainable – rapid spikes in resource prices, dangerous price volatility in the economy, discomforting signs of resource exhaustion and a trend towards business uncertainty and disruptions that can derail economic and social growth. The need for an alternative business model is becoming paramount, compelling organizations to find solutions to advance resource performance by reusing, remanufacturing, refurbishing and recycling products and parts to restore non-renewable resources, essentially 'closing the loop'. The management thinking behind creating this circular or 'cradle-to-cradle' supply chain rather than a linear or 'cradle-to-grave' model addresses the various aspects of revamping a business model from product design to recycling methods. This thesis focuses on overcoming challenges of product design in achieving that end. The paper is structured around four chapters. Chapter I opens the paper with an analysis of the circular supply chain model as compared with the linear consumption model, its impact on sustainability and management practices, the emergence and necessity of closing the loops, and the progress so far and limitations of the model. The role of product design in creating circular supply chains, and the variables associated with the challenges are explored in Chapter II. Based on these variables we analyze two case studies to check how our findings apply to two important product life cycle strategies. We also analyze the impact of these strategies on competitiveness and sustainability to demonstrate the business case for circular supply chains. This allows us to demonstrate important links between these variables to highlight overarching criteria to satisfy effective product design in Chapter III.


Thesis Supervisor: Matthew Amengual
Title: Assistant Professor, MIT Sloan School of Management

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"Nothing in the world can take the place of persistence. Talent will not; nothing is more common than unsuccessful men with talent. Genius will not; unrewarded genius is almost a proverb. Education will not; the world is full of educated derelicts. Persistence and determination alone are omnipotent. The slogan, 'press on' has solved, and always will solve, the problems of the human race." - Calvin Coolidge

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Finally, I owe everything I have to my family. Thank you for your unconditional love, and making me who I am today. In the vastness of space and immensity of time, it is my joy to spend a planet and an epoch with you. As a small token of my gratitude I dedicate this work to you.

At the end, thanks to you, reader. If you are reading this line, you at least read one page of my thesis.

By faith my walls of Jericho fell, after I had marched around them for seven days. To all those who lead monotonous lives, in the hope that they may experience at second hand the delights and dangers of adventure.

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# Contents

# Introduction

"An invasion of armies can be resisted but not an idea whose time has come." Advocates of the circular economy quote Victor Hugo's classic adage[1]. Let us better understand that idea. The linear supply chain model is one of 'take, make, dispose' way of running organizations, also described as the 'cradle-to-grave' approach which has been a fundamental premise on which our economy is established. In this linear world, organizations follow the modus operandi of extracting raw materials and non-renewable resources, utilizing them with a yield factor to convert them into a sellable product, selling them in the marketplace to the most immediate consumer (for example, wholesalers selling to retailers) who sell it to another consumer until the end-user of the product buys and uses the product till its end of life (or earlier), discarding it to landfill or the likes when the product fulfills its utility function. In 2010 around 65 billion tons of raw materials entered into the economic system, and in 2010 it has been forecasted to reach around 85 billion tons[2]. This has had the effect of increased resource prices and supply disruptions due to resource scarcity, thereby significantly increasing risk exposure.

With increased realization that the linear model belongs to the past, some organizations have taken to usher in a supply chain model that is restorative and regenerative, and an idea that can decouple business growth from resource exhaustion – the circular supply chain or 'cradle-to-cradle' idea. A circular supply chain is a model that replaces the end-of-life rule with restoration, encourages the use of renewable energy for restoration, eliminates the use of toxic chemicals and pollutants that hamper reuse or return to the biosphere, and aims for waste purging through superior design of materials, products, systems and business models[3]. It is also worth noting that this concept includes business ideas

[1] Ellen MacArthur Foundation book: circular economy thinkers set out views, The Guardian, Oliver Balch
[2] Towards the Circular Economy 1: Economic and Business Rationale for an Accelerated Transition; January 2012, Cowes, Isle of Wight: Ellen MacArthur Foundation.
[3] Towards the Circular Economy: Accelerating the scale-up across global supply chains; January 2014, Ellen MacArthur Foundation and McKinsey & Company

such as shifting from an ownership model to a service model to enable material and product tracking and return, with the end result of mitigating product disposal and waste. There are several enablers and challenges that lie within creating and implementing this idea. In this research we will focus on product design as an enabler and its challenges in building circular supply chains.

Product design can be vital in achieving a successful circular strategy – from designing products with materials that can be disassembled or reassembled for remanufacture to incorporating product durability and standardization in the design to increase end-of-life for reuse and repair. However, there exists several challenges due to certain market inefficiencies and dearth of processes that prevent designing products within circular chains at scale. Even then, based on our research we find that they are not insuperable. By exposing the variables around product design we demonstrate the linkages that exist amongst these variables and product design strategies to counter those challenges. Some of these challenges have been partly or fully mitigated by organizations, while some are currently being dealt with.

In this paper we will attempt to answer the following research questions: What are the important variables (enabling factors) and strategies of product design to achieve circular supply chains? What are the linkages that exist amongst these variables and how do they relate to criteria for effective product design in circular supply chains? Through case analysis we will also demonstrate competitive advantages created in the process that impact sustainability and business growth, in an attempt to show business case for circular supply chains at scale.

Based on our research and analysis argue that the necessary conditions for product design to achieve a circular supply chain at scale are:

1) Government Support
2) Information Sharing

3) Standardization

4) Certification system

5) Credible measurement mechanisms

The focus of the research covers the intersection of:

- Variables of product design process in pursuit of circular supply chains (and not specific to a specific value generating process within the supply chain such as procurement, production, packing, transport, distribution, retailing, consumption or marketing)
- Sustainability, defined as the three pillars of environmental (such as resource management and pollution prevention, reduced emissions and climate impact and environment reporting/disclosure, social (such as workplace diversity, health and safety, labor-Management relations, human rights, product integrity, product safety, product quality, emerging technology issues, community impact, community relations, responsible lending, corporate philanthropy and governance impact (such as executive compensation, board accountability, shareholder rights, reporting and disclosure)[4]
- Competitive advantages created within strategic and operational management, defined as core and peripheral competencies creating an advantage over competitors in the same industry

[4] Technology, Globalization and Sustainable Development – Transforming the Industrial State (Nicholas A. Ashford, Ralph P. Hall), pg. 2

# Chapter 1. What has been the impact of circular supply chains on organization's operations?

In this introductory chapter, we will analyze the impact of circular supply chains on organization's operations. We will start by providing a brief background of the linear supply chain model and its impact on sustainability and competitiveness (Part A). We will then set the context for the emergence of industrial ecology and circular supply chains by juxtaposing it against linear supply chains, critically discussing the existing debate. We will also illustrate the impact of circular supply chains and the need to make the transition. This discussion will exemplify how closed-loop models have prompted changes in organization's processes and management's practices, to carve out the links to product design (Part B). We will end the chapter by taking a step back and summarizing the progress and hurdles of circular supply chains. We will see the clear downsides of the linear model and the upsides of the circular model, and that substantial progress has been made towards closing the loops, but limitations exist specifically in the product design arena (Part C).

## 1.A The cradle-to-cradle world today: the tension between growth and resource exhaustion

### 1.1.1 The impact of linear consumption model on sustainability

The global economy has largely used a linear supply and consumption model for the past 150 years, bringing industrial and technological advancements, growth in terms of global production, and rapid innovation. However, this has put immense pressure on global resources, effectively creating an imbalance of non-renewable resources extracted and regenerated. The narrow-minded target of achieving high GDPs coupled with high consumption and price-sensitive consumers crafts a precarious scenario for the future of our economy, environment and society. Further, global population is estimated to grow rapidly with the middle class set to reach five billion people by 2030[5], demonstrating the most rapid rise in disposable income we have ever seen. The World Bank describes the demand-side trend as a "potential time bomb[6]". The effects have been put at the center stage at leading summits such as the 2014 Davos summit and the World Economic Forum, and by leading businesses, global foundations, governments and policy makers. "A linear economy simply can no longer provide the growth to sustain rising living standards across a global population which continues to expand apace[7]"

We must stress that the impact on sustainability deals with business continuity (economic effect) as much as it deals with the environment and society – Resource exhaustion brings with it the imbalance in the environment together with increased exposure to business risks and uncertainties. We explore these impacts in the following section. Also, we must be cognizant that these negative impacts are an outcome of several practices and not solely an outcome of the linear economy.

### 1.A.1.a Resource prices

Natural resources are used by almost every organization in producing goods and services. Global trends until 20th Century shows declining real prices including fossil fuels that were key in driving economic growth. Therefore, the linear model seemed to work – closing the loop was argued to not be the interest of the business (even though the harmful effects on the environment and society have been well documented in multiple sources, the effects on business continuity were relatively less apparent) as extracting/buying and disposing resources was easier and cost efficient rather than using reverse

[5] Could the circular economy be the new Copernican revolution?, The Guardian, Frans Van Houten
[6] Towards the Circular Economy: Accelerating the scale-up across global supply chains; January 2014, Ellen MacArthur Foundation and McKinsey & Company, pg. 22
[7] Going for Growth, A practical route to circular economy, Environmental Services Association – David Palmer-Jones, Chairman, ESA

logistics to reuse them. Since the turn of the century commodity prices increased by nearly 150%[8] from 2002 to 2010, effectively negating all the real price declines.

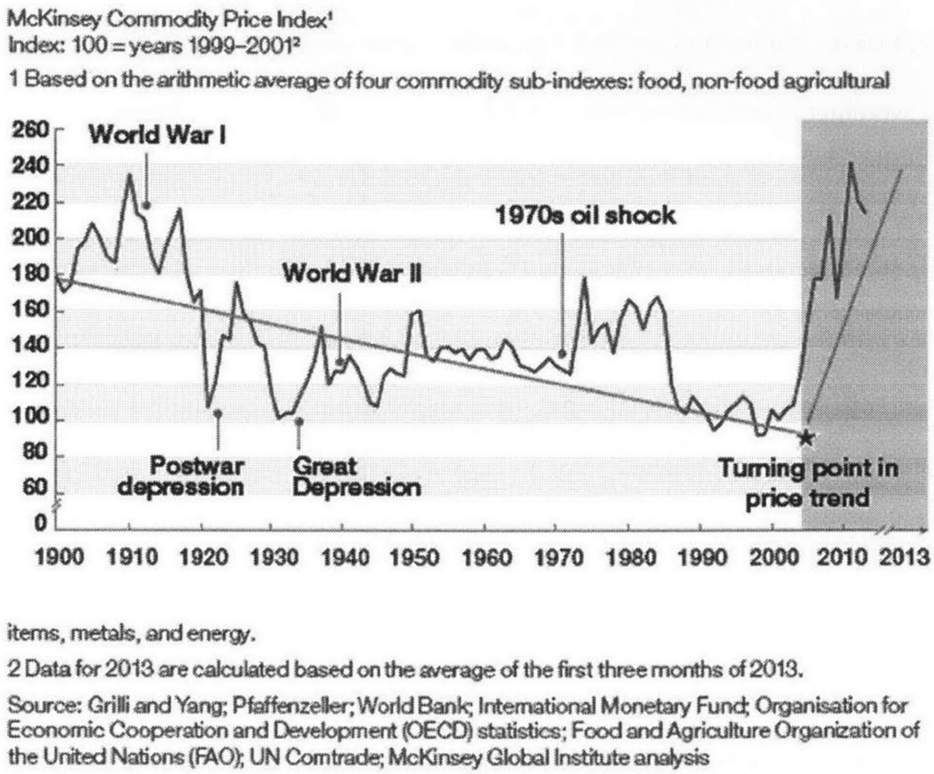


***Fig. 1.1*** *Price trends*

With this new price trend, the cost to extract/buy resources has distorted the long-standing economic models of organizations, forcing them to look at alternative supply chain models. Circular supply chains are now becoming more explicit to business profitability – it is cheaper to retrieve the product, dissemble it, extract expensive materials and reuse them, rather than to procure or extract them.

[8] Towards the Circular Economy: Accelerating the scale-up across global supply chains; January 2014, Ellen MacArthur Foundation and McKinsey & Company, pg. 21

### 1.A.1.b High price volatility

Price rise of commodities has not followed a gradual pattern, but rather a highly volatile upswing and downswing movement that has introduced business uncertainty and risks. Businesses that are highly resource dependent (specifically, price volatility of food, metals and non-food agriculture output has been the highest in the first decade of the 21st century than in any single decade[9]) are most vulnerable, making material planning and inventory management impotent. These businesses withdraw growth investments in volatile times and become risk averse, further stifling economic mood. A linear supply chain model cripples these organizations when continuous material yields are not achieved to convert into demanded products. According to the McKinsey Global Institute, this high dependence of non-renewable resources couple with dangerous price volatility is forcing organizations to look at alternative ways to tap into a secondary market for their resources – enabling reverse logistics and secondary/used products market creation. More importantly, this realization is building a making business' evaluate possibility of using closed loop supply chains and rethinking product design to deleverage risks in resource recovery.

### 1.A.1.c Poor inventory management and insecurity

On one hand linear supply chains provide organizations with the flexibility and onus of getting the product to the customer and not having to invest in the product once the ownership has passed, and on the other hand it limits the organizations capability of keeping a track of their sold product and its usage. Without this information and developed competency, organizations are highly dependent on resource extraction sources. Depleting resources has already caused organizations to disrupt their inventory management capabilities and business models. Studies (though debatable) have shown that with the current and future project extraction, the use of resources gold, silver, Indium, Iridium, Tungsten and

[9] Resource Revolution: Meeting the World's Energy, Materials, Food, and Water Needs, November 2011, McKinsey Global Institute.

several other elements may be depleted within five to fifty years[10]. According to the Ellen MacArthur Foundation, this has had the effect of increase in costs of exploration and mining coupled with increase in political risk in mining areas with resources that have high potential of depletion.

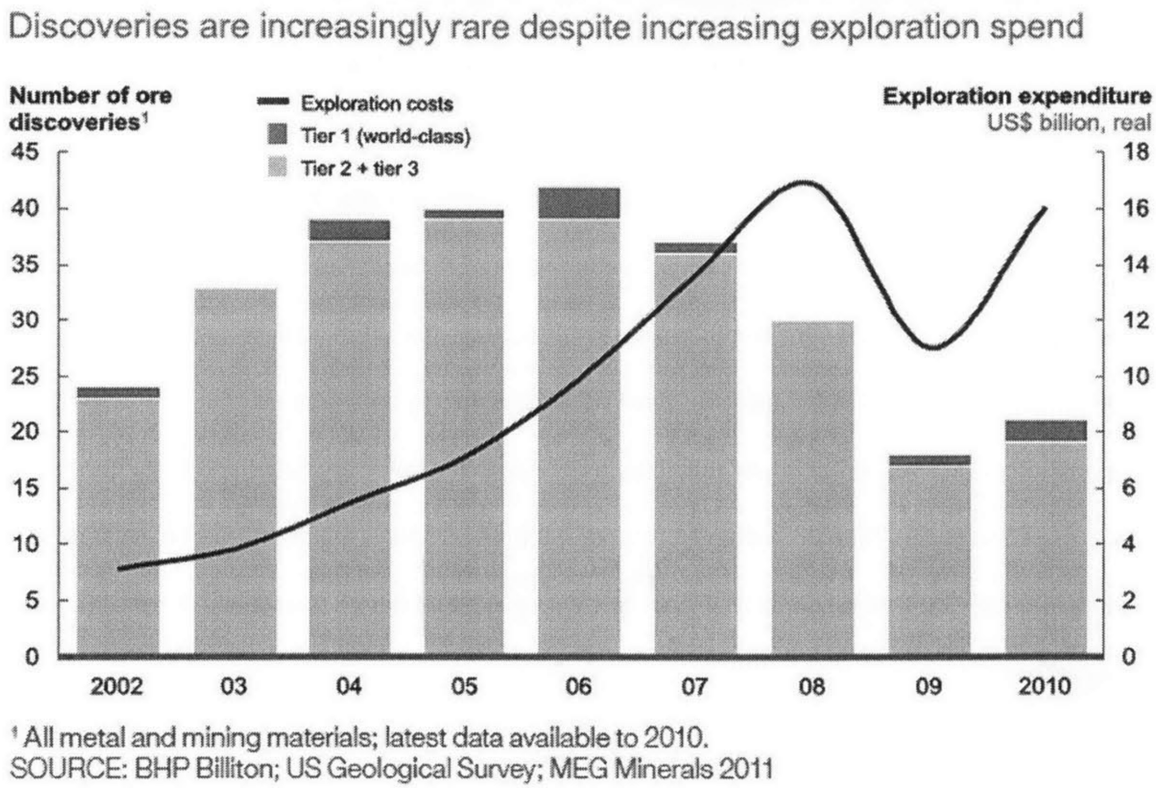


***Fig. 1.2.*** *Exploration cost trends*

Further, with investments in commodities such as mining and food products, the correlation between commodity prices and the price of oil as an index has increased[11], implying a snowball effect where shortage and price spikes in one resource could easily effect price volatility in another resource. Thus a linear supply chain dependency has the effect of increased business insecurity and poor supply management.

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[10] Hunt, A. J. (ed.), Element Recovery and Sustainability, RSC Green Chemistry Series, Cambridge, 2013

[11] Towards the Circular Economy: Accelerating the scale-up across global supply chains; January 2014, Ellen MacArthur Foundation and McKinsey & Company, pg. 22

### 1.A.1.d License to operate

With a linear supply chain model, the onus of a product's treatment at the end of life (dispose to landfill, re-sold in a secondary market, etc.) is not on the producer of the product. Without a profit-making business case, this creates a systemic issue where the producer is willing to have operational open loops and not be concerned about sustainability. Once this model is adopted by an industry, it creates a license to operate where one favors low prices and easily accessible goods over minimum waste and resource use. We argue that it has the potential of creating a lock-in to the linear model and a slippery slope where resources are exhausted and prices rise to a level where the industry is incapable of shifting to the circular model and is forced to dip into a low growth recession or even completely shut down.

### 1.1.2 Setting the context for industrial ecology: understanding the emergence

Industrial ecology has no standard definition but with several research works around the subject, Raymond Cote, at Dalhousie University (Halifax, Nova Scotia) compiled the definitions from early literature[12]. It points at three key elements[13]:

1. It is a systemic, comprehensive, integrated view of all the components of the industrial economy and their relations with the biosphere.

2. It emphasizes the biophysical substratum of human activities, i.e. the complex patterns of material flows within and outside the industrial system, in contrast with current approaches which mostly consider the economy in terms of abstract monetary units, or alternatively energy flows.

[12] Cote, R. P., The Industrial Ecolouv Seminar: Princioles. Topics for Discussion and Dictionary. School for Resource and Environmental Studies, Faculty of Management, Dalhousie University, Halifax, Nova Scotia, Industrial Park as an Ecosytem Project, December 1995

[13] Industrial ecology: an historical view, S. Erkman, J. Cleaner Prod., 1997, Volume 5, Number 1-2, pg. 1

3. It considers technological dynamics, i.e. the long term evolution (technological trajectories) of clusters of key technologies as a crucial (but not exclusive) element for the transition from the actual unsustainable industrial system to a viable industrial ecosystem.

Several attempts at implementing this concept have been made over the past 40 years, mostly all being fruitless, except in Japan[14]. Industrial ecology appears in the literature as early as the 1970s[15] referring to different things – from regional economic environment of companies to a 'green' slogan by industrial lobbies in reaction to the EPA. A paper on industrial ecology was then presented in 1977 by an American geochemist, Preston Cloud[16], inspired by the importance of matter and material flows in the human economy in a thermodynamic perspective. With the United Nations Environment Program and UN Conference on Human Environment in Stockholm laying importance on this subject, its popularity gained even more momentum. The concept then found new meaning when a collective work called L'Ecosysteme Belgique. Essai d'Ecologie Industielle was published in Brussels that filled a gap that prevailed in left-wing economic thinking – providing an overview of the Belgian economy based on materials and energy flows rather than monetary units[17].

The basic principles were laid:

*'To include industrial activity in the field of an ecological analysis, you have to consider the relations of a factory with the factories producing the raw materials that it consumes, with the distribution channels it depends on to sell its products, with the consumers who use them. In sum, you have to define industrial society as an ecosystem made up of the whole of its means of production, and distribution and consumption networks, as well as the reserves of raw material and energy that it uses and the waste it*

[14] Industrial ecology: an historical view, S. Erkman, J. Cleaner Prod., 1997, Volume 5, Number 1-2, pg. 1
[15] Ibid., pg. 2
[16] Ibid., pg. 2
[17] Ibid., pg. 3

*produces. .A description in terms of circulation of materials or energy produces a view of economic activity in its physical reality and shows how society manages its natural resources.'*

Japan took to this subject even earlier in the 1960s[18] with the Ministry of International Trade and Industry (MITI) commissioning for an alternative to high environmental cost of industrialization. The outcome was a thinking that the economy could be oriented towards information and knowledge rather than on consumption of materials. After several research initiatives by MITI, a report recommended a new policy be developed on the industrial ecology principle with accent on energy aspects[19]. After the oil shocks, Japan took it upon them to operationalize the academic work by advancing energy technology with the basic principle to replace material resources with technology – focusing more on the technological dynamics of industrial ecology.

In the 1990s, the subject started to gain traction when industrial engineers connected to the National Academy of Engineering[20] began talking more about the term (creating a buzzword effect) due to questions posed by the UN conferences and the Rio Summit to provide a practical solution for sustainable development. However, the solution itself was already being operationalized. For example[21], the city of Kalundborg in Denmark is built upon the idea of resource reuse and closed loops systems for the last four decades.

We must also note that there also existed a debate between waste prevention altogether (through mitigation techniques) and waste usage. The advocates for waste prevention promote cleaner production approaches, supporting the end-of-life philosophy[22] (also referred to as end-of-pipe

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[18] Industrial ecology: an historical view, S. Erkman, J. Cleaner Prod., 1997, Volume 5, Number 1-2, pg. 4
[19] Ibid., pg. 4
[20] Ausubel, J. H. and Sladovich, H. E., Technology and Environment. National Academy of Engineering, National Academy Press, Washington, DC, 1989
[21] Gertler, N., Industrial Ecosystems: Developing Sustainable Industrial Structures. Massachusetts Institute of Technology,Technology and Policy Program, Cambridge, MA, 1995, 141 pp
[22] Industrial ecology: an historical view, S. Erkman, J. Cleaner Prod., 1997, Volume 5, Number 1-2, pg. 2

approach) to an extent. Whereas, the industrial ecology sponsors voice the fact that waste prevention and clean production have limits. Moreover, certain production methods such as making cheese are dependent on milk that is regarded as waste or a by-product[23]. Hence, it is nearly impossible and perhaps also discouraged to eliminate all waste, but rather in the absence of cleaner production methods, advised to search ways in which the waste could be reusable. Therefore, the idea is to integrate end-of-life approaches and prevention methods together with closed loop systems to ensure resource reuse, limiting the impacts of linear models as explained in the previous section.

By the turn of the 21st century companies such as Renault, Unilever, GAP and Phillips; and think-tanks such as the Ellen MacArthur Foundation and the Cradle-to-Cradle Institute began operationalizing the concept specifically by creating circular (also called, full or partial closed-loop) supply chains to replace the linear supply chain method due to the impacts of the linear method as described in the previous section.

However, several gaps and challenges exist in building an efficient closed-loop system within an organization's business model, starting from sourcing appropriate materials for ease of extraction to designing products conducive for disassembly to using wastes and by-products in useful ways (which gave birth to creation of eco-industrial parks[24]) to optimizing material flows within the supply chain to increasing resource yield and reducing overall consumption (also called, dematerialization[25]) to revamping business strategy to selling services instead of products. In the following sections we focus on the argument for shifting to circular supply chains and the role of product design in making it happen.

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[23] Industrial ecology: an historical view, S. Erkman, J. Cleaner Prod., 1997, Volume 5, Number 1-2, pg. 2
[24] Lowe, E., Eco-Industrial Park Design Concept. Indigo Development, Oakland, Ca, 1993.
[25] Kanoh, T., in Science and Sustainability (Selected Papers on IIASA 20th Anniversary), ed. IIASA. IIASA, Laxenburg, 1992, pp. 63-94.

## 1.2 The emergence of circular supply chains for sustainability

### 1.2.1 The commentary on sustainability and supply chains

Concerns around sustainability issues have gained significant impetus over the last decade where organizations have begun to research on the impact of sustainability issues on their businesses' continuity. Mark E. Ferguson and Gilvan C. Souza (2010) claim that issues regarding energy usage, access to clean water, carbon dioxide emissions and climate change have received majority attention, however, the effect on the increasing rate of land-filling with manufactured products made of depletable raw materials and resources has now come to the forefront[26]. This not only deals with exhaustion of non-renewable resources but also the diminution of land available for product disposal. For example, based on 2006 numbers, in the United States each person generates approximately 4.6 pounds of waste per day with a cumulative of 251 tons of solid waste[27]. This is either incinerated or disposed to landfills every year. Shockingly, 16%[28] of this waste is durable goods manufactured mostly from nonrenewable resources and only 18.5% of the materials used in 40.2 million tons by weight of durable goods sold in the United States are recovered[29]. This activity and its effects have been realized at least since 1972 – the publication of a Club of Rome's report called, The limits to Growth (Meadows et al., 1972).

Initially, it was thought that resource conservation is an exercise that is inconsistent with profit and shareholder value maximization. This is demonstrated by the following profit maximizing equation (Baptiste Lebreton et al., 2007):

$$\max \pi = (\sigma - k) \times X,$$

where $\pi$ is profit, $(\sigma - \mathrm{k})$ is marginal cost and X is the number of units required to sell.

[26] Closed-Loop Supply Chains, New Developments to Improve the Sustainability of Business Practices Edited by Mark E. Ferguson and Gilvan C. Souza, Auerbach Publications 2010, pg. 1
[27] Ibid., pg. 2
[28] Ibid., pg. 2
[29] Ibid., pg. 2

Therefore, if R is the non-renewable resources required to make the product at a consumption rate of $\alpha$, we can say $\alpha \times X = R$, implying that to maximize profit we need to maximize resource use:

$$\max \pi \Rightarrow \max R$$

This argument is the premise behind the case that resource exhaustion is contrary to the fundamental fiduciary duty of a company (public) to increase shareholder value. However, with the realization that resource exhaustion leads to the impacts mentioned in the previous section (price rise and volatility, poor supply management, and raw material insecurity), businesses have started to look at alternative solutions and business models such as the closed-loop supply chain. In this model, to reduce the $\alpha$ coefficient, resource consumption can be reduced within the supply chain or by reintegrating already consumed resources back into the supply chain[30], hence closing the loop. By breaking down the consumption rate $\alpha$ to production throughput rate $\gamma$ and resource integration rate $\mu$, we see that when resource integration rate tends to 1 or production throughput rate tends to 0, consumption rate tends to 0 (Baptiste Lebreton et al., 2007):

$$\alpha \to 0 \Leftrightarrow \gamma \to 0, \mu \to 1$$

Even though there have been examples (Schmidt-Bleek, 1998 and von Weizsacker et al., 1995) to improve material intensity per service unit to reduce production throughput rate, these improvements are not sufficient to balance the impact on non-renewable resources R[31] (Porter and van der Linde, 1995 and Romm, 1999). Therefore, the focus shifts to reintegration rate $\mu$ or the impact of closed-loop supply chains – reuse, repair, remanufacture, cannibalize and recycle – on the reintegration rate, to build a business case for sustainability. In Chapter 2 we will also extend this theory based on our research to

[30] Strategic Closed-Loop Supply Chain Management, Baptiste Lebreton PhD, Springer Berlin Heidelberg, 2007, pg. 4
[31] Ibid., pg. 4

show how X (number of units sold) can be decreased to reduce negative impact on resource consumption R while mitigating negative impact on profitability $\pi$.

### 1.2.2 Transitioning from linear to circular

Closed-loop supply chains supplement the forward flow of materials from suppliers to the end customers through reverse flows of products back to the manufacturer. Hence, returns from customers are essential, taking the form of 'no questions asked' returns, end-of-use returns or end-of-life returns[32]. Once returned, they can be treated by recycling, parts harvesting, reselling, internal reusing, remanufacturing or refurbishing.

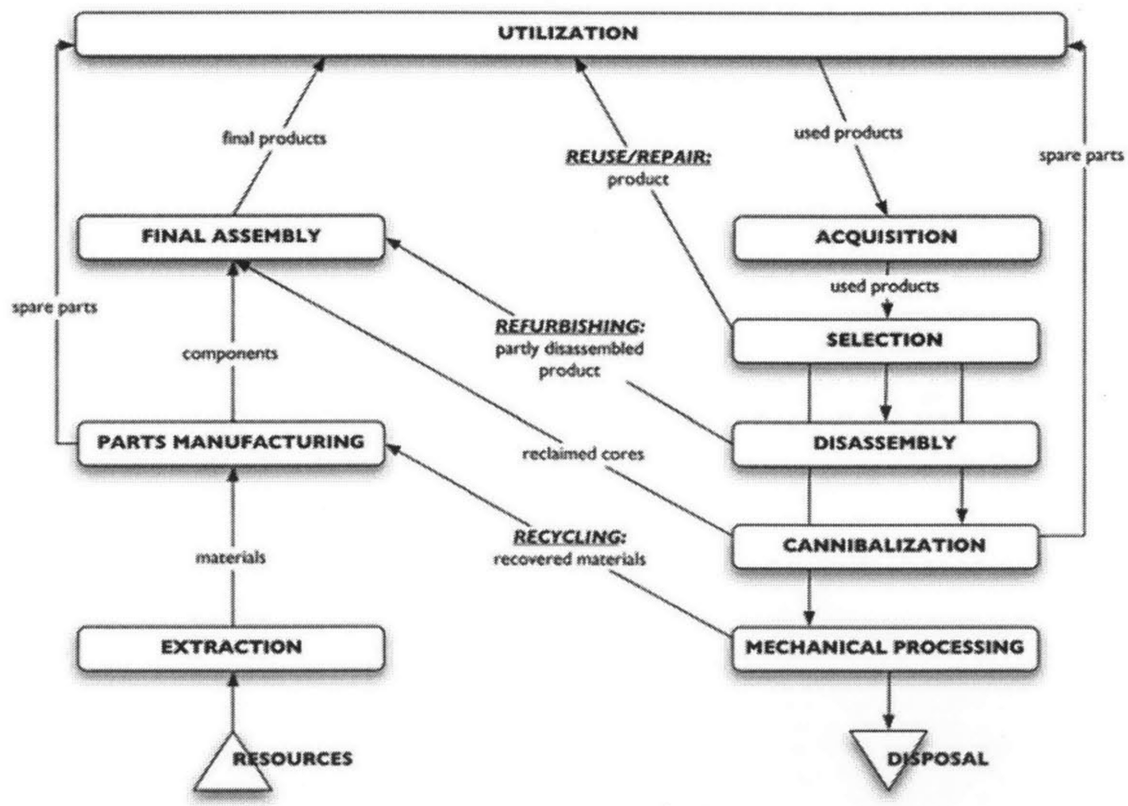



***Fig. 1.3.*** *Circular supply chain illustration (modified from White et al. 2003)*[33]

[32] Strategic Closed-Loop Supply Chain Management, Baptiste Lebreton, Springer Berlin Heidelberg, 2007, pg. 4 – 5
[33] Ibid., pg. 5

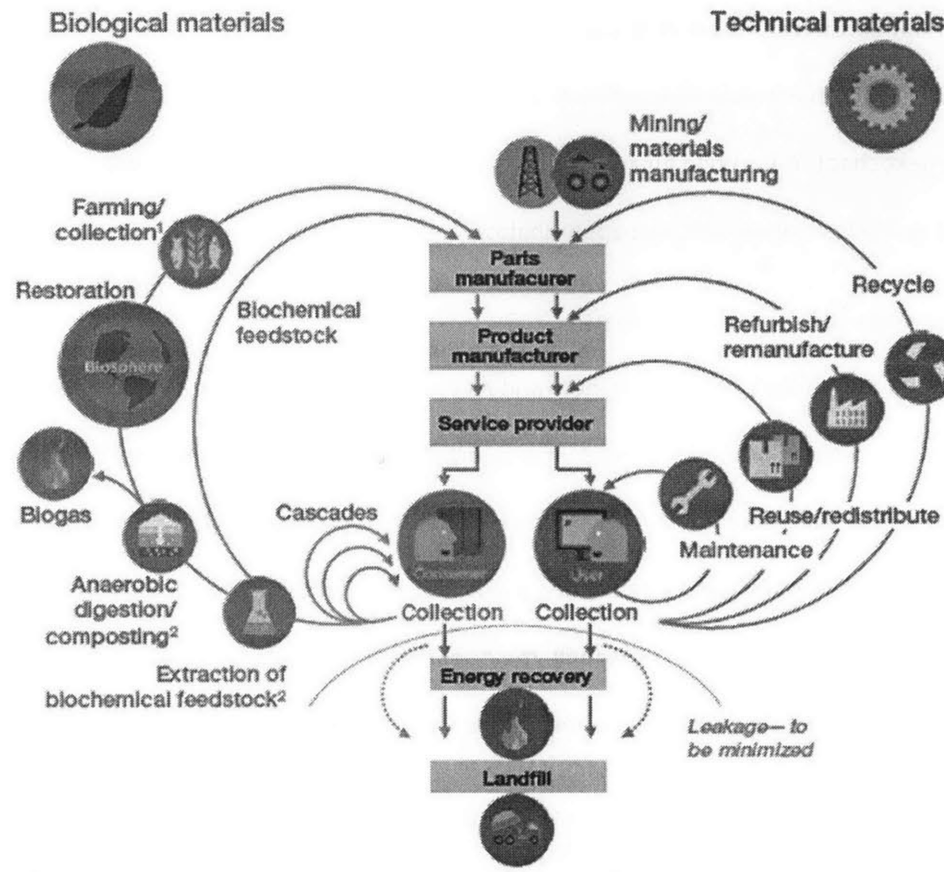
Ellen MacArthur Foundation, one of the largest think-tanks on circular economy has published a report in January 2014[34] that draws out three principles that lay the basis for leveraging circular supply chains.

- Design products to eliminate waste through disassembly and reuse optimization

- Differentiation between consumable and durable components of products – consumables must be designed using biological components that are non-toxic and can be safely returned to the biosphere, whereas durables are made of technical components that are not suitable for the biosphere and must be designed for reuse (through lease, rent and share based programs)

- Energy required to close the loop (for example, to extract materials and remanufacture) must be renewable so that we are not shifting the burden from one system to another.

[34] Towards the Circular Economy: Accelerating the scale-up across global supply chains; January 2014, Ellen MacArthur Foundation and McKinsey & Company, pg. 15




[1] Hunting and fishing
[2] Can take both postharvest and postconsumer waste as an input
Source: Ellen MacArthur Foundation circular economy team drawing from Braungart & McDonough and Cradle to Cradle (C2C)

***Fig. 1.4.*** *Circular economy illustration (Ellen MacArthur Foundation)*

Based on the above illustration, the inner circles of maintenance, reuse/redistribute and refurbish/remanufacture aim to reduce material use by assuring that the product and/or its materials go back into the hands of the user who requires the product. The recycle circle aims to firstly increase the life cycle of the product so that it is in use longer and secondly, aims to increase material yield by using it again. Other possibilities include using a final product that is no longer needed by the user, in another industry where the product might be valued more. For example, cotton clothes are resold in the second-hand market, then acquired to be used in the furniture industry as fiber-fill, and then reused in stone wool insulation for construction[35]. In all these techniques it is of utmost importance that the product be designed in such a way that it uses sustainable materials and is compatible to reuse, refurbish and/or recycle. In the next chapter, we build an analysis on how product design can be effective in doing so. We also highlight the key benefits of circular supply chains:

### 1.2.2.a Cost savings and new opportunities

As long as collection of products from customers and its integration into the value chain is less expensive than selling new products or products with new parts, organizations will incur lower unit and marginal costs. The Ellen MacArthur Foundation estimates that a circular economy could result in material cost savings of $706 billion annually[36] in the consumer goods industry. Also, with increasing expenses in managing wastes through incineration or landfill, the opportunity cost of remanufacturing is reduced[37]. Further, there exists several new business opportunities that can create innovative revenue streams[38]:

- Setup of downstream businesses that use wastes and by-products from primary business – for example, CHP plants can feed waste heat to tomato greenhouses[39] and Biogas plants feed waste heat to fish farming in Germany[40].
- Collection and reverse logistics - for example, DHL's Envirosolutions initiative[41] provides waste management services to its clients.
- Opportunities for the financial sector to fund corporations undergoing the transition from linear to circular supply chain.

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[35] Towards the Circular Economy: Accelerating the scale-up across global supply chains; January 2014, Ellen MacArthur Foundation and McKinsey & Company, pg. 15
[36] Towards the Circular Economy: Opportunities for the consumer goods sector; 2013, Ellen MacArthur Foundation, pg. 86
[37] Strategic Closed-Loop Supply Chain Management, Baptiste Lebreton, Springer Berlin Heidelberg, 2007, pg. 77
[38] Towards the Circular Economy: Opportunities for the consumer goods sector; 2013, Ellen MacArthur Foundation, pg. 84
[39] Ibid.
[40] Ibid.
[41] Ibid.

- Waste exchange and second-hand goods platforms – for example, Waste Producer Exchange[42] and eBay.

### 1.2.2.b Customer loyalty

By closing the loop through customer returns, circular supply chains enhance customer interaction. Renault claims to have increased customer loyalty by making old parts available that might have been discontinued from production, through customer returns[43]. This can create a long-term relationship with the customer increasing loyalty and retention.

### 1.2.2.c Information access

Within a circular supply chain, organizations spend increased resources to collect information about product use to better understand return rates. This enables them to gain better insights into customer behavior leading to more targeted product characteristics, promotion techniques, price setting and distribution channels, furthering customer satisfaction.

### 1.2.2.d Competitive advantage

Circular supply chains can create competitive advantages in the shape of robust security of raw materials as customer returns provide a key source of supplier diversification, and through reduction in exposure to swift price fluctuations. As Jean-Philippe Hermine at Renault remarks: 'By reusing material, you disconnect from market price volatility and secure supplies'[44]. For example, a cost of a garment is roughly composed of 9% material costs. As natural and synthetic fibers have a strong correlation with energy prices, there exists a high business risk of cost uncertainty[45]. Similarly, cost of fertilizers account for a significant cost of agriculture produce. With fertilizers being transported large distances, their costs

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[42] Ibid.

[43] Source: http://www.renault.com/en/capeco2/laisser-moins-de-traces/pages/fin-de-vie.aspx

[44] Towards the Circular Economy: Opportunities for the consumer goods sector; 2013, Ellen MacArthur Foundation, pg. 85

[45] 'Soaring polyester puts squeeze on fashion', FT, April 2011, and 'Cotton prices surge to all-time high', FT, Feb. 2011

depend on commodities such as natural gas, making their prices volatile. A circular supply chain would enable a business to have a cost advantage by reducing volatility, thereby decreasing business disruption risk and gaining an advantage over competitors who might struggle with cost uncertainty.

### 1.2.2.e Recycling industry growth

The recycling industry is approximately a $77 billion[46] industry. Circular supply chains are creating opportunities for companies in this industry to expand their operations by adding new regions and materials to their portfolio. For example[47], Tomra is supplying its collection technology as a service, enabling a 20% growth of their business per annum. The demand for recycling could be enabling these companies to achieve high recycling yields, lowering cost of operation and increasing research and development in separation and collection methodologies.

### 1.2.2.f Impact on environment

With decreased landfills of 340 million tons[48] of waste per annum, the burden of waste treatment costs on public taxes can potentially be reduced. Total emissions in the UK itself can be reduced by 7 million tons of $CO_2$[49]. Apart from this, scarce natural resource use can be significantly lowered. It is estimated that one-third of food production is wasted. By using this waste, pressure on land use for growing new agricultural produce can be reduced, and land productivity and yield maintained[50].

### 1.2.2.g The service model advantage

A technique to achieve circular supply chains is to build a service-based business model rather than an ownership-based model. This can enable customers to have a better choice at an affordable price,

[46] Institute of Scrap Recycling Industries, Inc.
[47] Towards the Circular Economy: Opportunities for the consumer goods sector; 2013, Ellen MacArthur Foundation, pg. 85
[48] Ibid., pg. 87
[49] Ecoinvent: The ecoinvent database, version v2.2, 2012
[50] Source: http://msue.anr.msu.edu/news/compost_increases_the_water_holding_capacity_of_droughty_soils, July 20, 2012, M. Charles Gould, Michigan State University Extension

increasing their utility. Idle-capacity that is built after end-of-use is eliminated as the product goes in the hands of another user who has a higher utility function for that product. For example, car and home sharing programs have gained significant momentum and success using this model. Also, we see cost of ownership reducing significantly. For example[51], according to Coca-Cola's Mexican bottler, Fesma, 'On average, a refillable package is priced 18% less than the same size non-refillable package'[52].

## 1.3 Major hurdles of circular supply chains

Given that the benefits have the potential to counter some of the implications of linear supply chains, we now analyze the challenges of creating circular supply chains.

### 1.3.1 Costs of disposals as a common good

The economic and environmental costs of product disposal are paid by society as a whole but (due to public solid waste disposal) are not directly attributed to either producers or consumers. This externality of product disposal leads to a number problems including the overproduction and underpricing of the difficulty to dispose of goods, and incomplete incentives to pursue options such as remanufacture or recycling which would reduce product disposal[53]. This affects the entire economic system, rendering creation of closed-loops and reduction of waste much harder and a systemic issue.

### 1.3.2 Incentive complications

Flapper (2003) explains that incentives are important for collecting products back from customers. Customers will only return the products back if they cannot sell it in the secondary market at a higher price than the buyback reward offered by the manufacturer. However, a manufacturer in that case would have to offer an incentive higher than what it could have spent on buying the product at the

[51] Towards the Circular Economy: Opportunities for the consumer goods sector; 2013, Ellen MacArthur Foundation, pg. 92

[52] WRAP, Refillable glass beverage container systems in the U.K., 2008

[53] Determining the value of remanufacture in an integrated manufacturing-remanufacturing organization, Mark W. McIntosh and Bert Bras, 1998, pg. 2

secondary market price. He also argues that even a deposit fee incentive would have similar flaws as the customer would sell the used product to the secondary market if the residual value is higher than the deposit fee[54]. Further, "a key question is how to align incentives throughout the supply chain so that, from the design stage to customer engagement, companies actively consider the use of sustainable materials and features such as durability and reparability at the core of their product strategy. This incentive problem poses a huge challenge for manufacturers to reliably collect back product returns[55]".

### 1.3.3 Cost of recovery vs. cost of new procurement

A manufacturer will only find it economically beneficial if the cost of recovery of the product and/or its materials is lower than procuring a similar/same product or material respectively. Even as advancements in recovery processes and methodologies are taking place, yet product design is becoming more complicated and expensive.

### 1.3.4 High level of inter-departmental and inter-organizational coordination and complexity

As stated by Baptiste Lebreton (2007), "the decision implies coordination between procurement (how many parts are required to match the demand?), inbound logistics (is there any part on stock?), marketing (is there currently a demand for the final product?), and service (is there a demand for the recovered spare parts?). The ability to manage this information flow becomes a core competency for an OEM". Further, entire supply chains that involve multiple producers often geographically spread have to restructure their operations to facilitate information and material flow[56] forward and reverse to enable a closed-loop supply chain. This involves high transaction costs and delays in negotiations. Also as John Barton has observed, businesses are more likely to collaborate where they do not directly compete (for instance, electricity distribution companies that operate in separate areas) or if they focus on different

[54] Strategic Closed-Loop Supply Chain Management, Baptiste Lebreton, Springer Berlin Heidelberg, 2007, pg. 6
[55] A Global Redesign? Shaping the Circular Economy, briefing paper, Felix Preston, Energy, Environment and Resource Governance, March 2012, pg. 15
[56] Ibid., pg. 15

sectors[57]. Solutions for intellectual property sharing would need to be developed. As such, it involves high organizational and technical complexity.

### 1.3.5 The lock-in problem

The current development model is highly dependent on fossil fuels and linear manufacturing models, and there are no off-the-shelf models to follow even though there is a realization that a less-intensive model of development is needed[58]. This creates a lock-in effect where capital and labor resources are committed to the traditional linear supply chain model and the infrastructure required to transition to a circular supply chain requires a systemic change within several constituents and stakeholders in the value chain, creating a significant barrier to the circular movement. Further, to move away from this lock-in to the linear model, organizations will need to incur business risks and high up-front costs - retooling machines, relocating whole factories, building new distribution and logistics arrangements, and retraining staff[59]. Moreover, manufacturers have historically dealt with designing products with the understanding that their concern and responsibility of the products end at point of sale[60]. McIntosh (1998) and McIntosh and Brar (1998) have explored how this mindset has thrown a number of challenges and new ways of thinking for producers, imposing a significant lock-in effect.

### 1.3.6 Political hindrances

For the market to respond effectively, subsidies that encourage excessive use of resources will need to be removed and all 'externalities' should be incorporated into the price of resources and energy[61].

[57] Barton, J. (2007), 'IP and Climate Technology' (Chatham House), www.chathamhouse.org/sites/default/files/public/Research/Energy,%20Environment%20and%20Development/161107_ipclimate.pdf

[58] A Global Redesign? Shaping the Circular Economy, briefing paper, Felix Preston, Energy, Environment and Resource Governance, March 2012, pg. 14

[59] Ibid., pg. 15

[60] Determining the value of remanufacture in an integrated manufacturing-remanufacturing organization, Mark W. McIntosh and Bert Bras, 1998, pg. 2

[61] Hawken, P., Lovins, A. and Lovins, L.H. (1999), Natural Capitalism: Creating the Next Industrial Revolution (New York: Little, Brown and Company)

Politics and special interest groups create delays and often permanent barriers in introducing regulations to bring systemic impacts – notably carbon pricing[62]. Clear, strong and predictable policy frameworks are vital in moving away from the lock-in barrier[63].

### 1.3.7 Stakeholder acceptability and standardization

Given the multiple stakeholders (suppliers, producers, waste collectors, regulators, customers) involved in closing the loop, the circular supply chain requires acceptability and willingness to adopt. Apart from looking for incentives, there seems to be poor standardization of methodologies, one that can be applied across countries, high cost of quantification of resource consumption, and absence of a globally recognized and acceptable certification institution for circular supply chains[64].

### 1.3.8 Innovation

Product design can be at the center of closing loops to minimize wastes and increase yields from non-renewable resources. However, innovation and customization introduces significant problems for the remanufacture loop. In remanufacture, it is desirable to have a large return supply of the same components for extended periods of time. Parts proliferation (caused by both innovation and customization) has become a major problem for remanufacturers as demonstrated in surveys of remanufacturers such as those conducted by Hammond et al., 1998. Furthermore, rapid innovation has led to shorter technology life spans for components (Ishii, et al., 1995) thus decreasing the window of opportunity for remanufacture[65]. However, advancements in new materials must continue at a strong pace and be accessible to the developed and developing world as this would trigger easier separation and disassembly methods. Further, technical advancements are also needed in smart infrastructure and

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[62] A Global Redesign? Shaping the Circular Economy, briefing paper, Felix Preston, Energy, Environment and Resource Governance, March 2012, pg. 14

[63] Ibid., pg. 15

[64] Ibid., pg. 15

[65] Determining the value of remanufacture in an integrated manufacturing-remanufacturing organization, Mark W. McIntosh and Bert Bras, 1998, pg. 2

tracking technology[66] to support reverse logistics. Hence, innovation must be guided to be in the correct areas that support the circular concepts.

Having now studied the impact background and impact of linear supply chains on sustainability, and the emergence, challenges and benefits of circular supply chains, we will move our focus to addressing these challenges through product design.

[66] A Global Redesign? Shaping the Circular Economy, briefing paper, Felix Preston, Energy, Environment and Resource Governance, March 2012, pg. 15

# Chapter 2. How does product design play a part in creating circular supply chains?

According to a briefing paper[67], moving to a circular economy "would mean a radical shift in how materials are used throughout the economy. With the right incentives, innovation will deliver more sustainable materials – plastics, for example, would increasingly be derived from plants rather than fossil fuels. Nanotechnology and biotechnology have the potential to deliver materials with increased strength, reduced weight and other useful properties. At the end of the product's life these materials would biodegrade or could be easily separated so that they could be reused". This entails revamping the entire value chain of a manufacturer's operations – from its value proposition to product design to material procurement to conversion processes to distribution methodologies to product pricing and conditions to reverse logistics. Moreover, once the product is collected, several options are available:

***Fig. 2.1.** Recycling options*

| Structural Change | Description of recycling process | Examples | Type of recycling |
|---|---|---|---|
| No change | The product is transferred from one application to another. | Reuse of bottles, second-hand sales of books and clothing, modular construction/deconstruction. | Direct reuse |
| Superficial | Changes are made to the surface of the product only. | Toner removal from paper, refurbished cardboard boxes (label/print/tape removal), molten-salt processing, thermal cleaning, ultrasonic sound waves, non-abrasive blasting media. | |
| Deformative | Alterations are made to the form of the product without addition or subtraction of material. | Bending metal beams, reforming steel columns, re-folding of cardboard boxes, re-rolling of steel plate (Indian ship salvage). | Non-destructive recycling |
| Subtractive | Material is removed from the original product. | Dye-cutting of used cardboard, removal of oxide coating, cutting new shapes from used steel plate. | |
| Additive | Products are joined together e.g. by welding or gluing. | Cold bonding of aluminium, welding processes (selective recasting, friction welding, laser cladding, wire-arc spraying), gluing of plastics/paper. | |
| Destructive | Breaking down a material so it can be used as feedstock in conventional production processes. | Melting of plastics and metals, re-pulping of paper/board. | Conventional recycling |

Source: Allwood, J., Ashby, M., Gutowski, T. and Worrell, E. (2011). 'Material Efficiency: A White Paper', *Resources, Conservation and Recycling* 55, Table 3.3, www.fraw.org.uk/files/economics/allwood_2011.pdf.

[67] A Global Redesign? Shaping the Circular Economy, briefing paper, Felix Preston, Energy, Environment and Resource Governance, March 2012, pg. 7

As such, product design's script in the circular supply chain ambition is significant, one that can allow altering the life cycle of products, enabling modularization, remanufacturing and component reuse and reducing material use[68]. Hence, several organizations have paid attention to product design to be the catalyst for closing the loops.

With a target of 30%[69] of its revenue from green products, Philips is attempting to redesign light bulbs to be easily recyclable – doubling collection, recycling amounts and materials by 2015[70]. Similarly, the carpet industry has already reaped benefits from circular concepts and is now implementing it in scale. According to a Sustainability Managing Partner at Deloitte USA[71], the carpet industry is widely adopting the closed-loop supply chains, a well-suited process for the industry that uses complex and expensive materials. For example, at Desso old tiles are processed to separate the yarn which is de-polymerized into new yarn. Further, the bitumen from tiles is cascaded to the cement industry where it is used for road repairs and cycle paths[72]. According to Desso's CEO, the strategy has increased profit margins despite the global economic crisis, indicating that customers are already willing to pay a premium for the greener product lines. Moreover, they claim that in three years the price premium will be no more than 5% over the traditional approach, down from 15% today[73].

Similar, by redesigning their products, Caterpillar claims that it is remanufacturing its machines and saving 59,000 tons of steel, 91 metric tons of cardboard and 1,500 tons of wood products with an end of

[68] Allwood, J., Ashby, M., Gutowski, T. and Worrell, E. (2011), 'Material Efficiency: A White Paper', Resources, Conservation and Recycling 55, pp. 362–81, www.fraw.org.uk/files/economics/allwood_2011.pdf
[69] A Global Redesign? Shaping the Circular Economy, briefing paper, Felix Preston, Energy, Environment and Resource Governance, March 2012, pg. 9
[70] Ibid., pg. 9
[71] Interview conducted on 28th February 2014
[72] Centre for Remanufacturing and Reuse, www.remanufacturing.org.uk/reuse-repair-recycle.lasso?-session=RemanSession:3EFDC4B21b3fb0D8DCoSY32D3BF1
[73] Desso website, http://www.desso.com/Desso/EN; The Guardian, 'Cradle to cradle: how Desso has adapted to birth of new movement', 1 September 2011, www.guardian.co.uk/sustainable-business/cradle-to-cradle-desso-carpet-tiles-innovation

life return rate of over 90%[74]. Patagonia is targeting to redesign its product range including shoes and bags to make them compostable or recyclable and more durable[75]. Japanese firm Kyocera has redesigned its toner cartridges such that they can be easily refilled instead of the traditional cartridges that aim to prevent refills through the secondary market, thus manufacturing a complex product with high material use. This has reduced costs by 50% and wastes by 90%[76].

These examples might be impressive and show the value of moving to circular supply chains, however, redesigning products for circular supply chains entails changing long-standing business models and stakeholder relationships. This requires systemic change embodying partnerships and a network of suppliers, intermediaries, manufacturers and institutions that operate within the supply chain[77]. Given the central role product design plays in the circular economy, in this chapter we will explore the role of product design in enabling circular supply chains by scrutinizing the key strategies that come with it or in other words the major considerations or 'variables' an organization considers to counter circular supply chain challenges and bring about a possible transition away from the linear lock-in. This will allow us to emphasize these variables in Chapter 3 by exploring the linkages between them to arrive at conditions for effective product design in enabling circular supply chains.

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[74] Caterpillar (2010), 'Sustainability Report', http://www.caterpillar.com/cda/files/2838620/7/2010SustainabilityReport.pdf

[75] A Global Redesign? Shaping the Circular Economy, briefing paper, Felix Preston, Energy, Environment and Resource Governance, March 2012, pg. 9

[76] Ibid., pg. 8

[77] Socolow, R. et al. (1994), Industrial Ecology and Global Change (Cambridge University Press)

## 2.1 Role of product design in giving life to cradle-to-cradle

## 2.2 Understanding the challenges in using product design as a lever for circular economies

According to a research paper by Mark W. McIntosh et. al. (1998)[78], remanufacturing efforts that will have the largest economic and environmental impact will be those with carefully planned product design, implying that original equipment manufacturers' important role in remanufacturing as they can design-in remanufacture and determine conditions. According to Bras (2007), the remanufacturing activity involves various processes. Product design must take into account each of these processes. A survey conducted by Hammond et al. (1998), reveals that automotive manufacturers find inherent design problems in remanufacturing, making part replacement, and cleaning and refurbishing costly operations. Based on our interviews, there are several strategies that an organization must consider when transitioning from linear to closed-loop systems, based on the industry, geographic location, process complexity, product type, and market structure. In the following section we will attempt to summarize the critical strategies and variables in product design to enable circular supply chains and the challenges associated with it, based on our interviews, literature review and application of strategic tools. This will allow us to apply these variables and build a framework to bring more clarity on how circular supply chain challenges can be overcome through product design.

[78] DETERMINING THE VALUE OF REMANUFACTURE IN AN INTEGRATED MANUFACTURING-REMANUFACTURING ORGANIZATION, Mark W. McIntosh and Bert Bras, 1998, pg. 1

## 2.3 Identifying the variables in product design

### 2.3.1 Product Life Cycle Analysis – recycle more vs. longer useful life

According to professor Conny Bakker and researcher Marcel den Hollander of Delft University of Technology, although recycling has received much attention, increasing the useful life of products is more impactful than recycling as it intervenes at product level and slows down the rate at which products are put through recycling loops (focusing on the inner loops rather than the outer ones in figure 1.4). According to them, "Business models based on the 'sell more, sell faster' principle, which have dominated our linear Western economies since the Industrial Revolution are not suited to accommodating longer-lasting products and their services. The success of a circular economy depends on new business models that are able to truly capitalize on longer product lifespans over time[79]".

As such, an important variable to consider is the combination of more recycling or longer lasting products. As these are conflicting characteristics, an organization must adopt a strategy that fits best with their industry, product, target audience and business model. Five models have been identified[80] by professor Conny Bakker. We use this concept to map them in figure 2.2 based on two important characteristics – recycling rate and useful life.

[79] Six design strategies for longer lasting products in circular economy, The Guardian, Conny Bakker and Marcel den Hollander, 16th December 2013
[80] Adapted from, Six design strategies for longer lasting products in circular economy (Products That Last poject), The Guardian, Conny Bakker and Marcel den Hollander, 16th December 2013

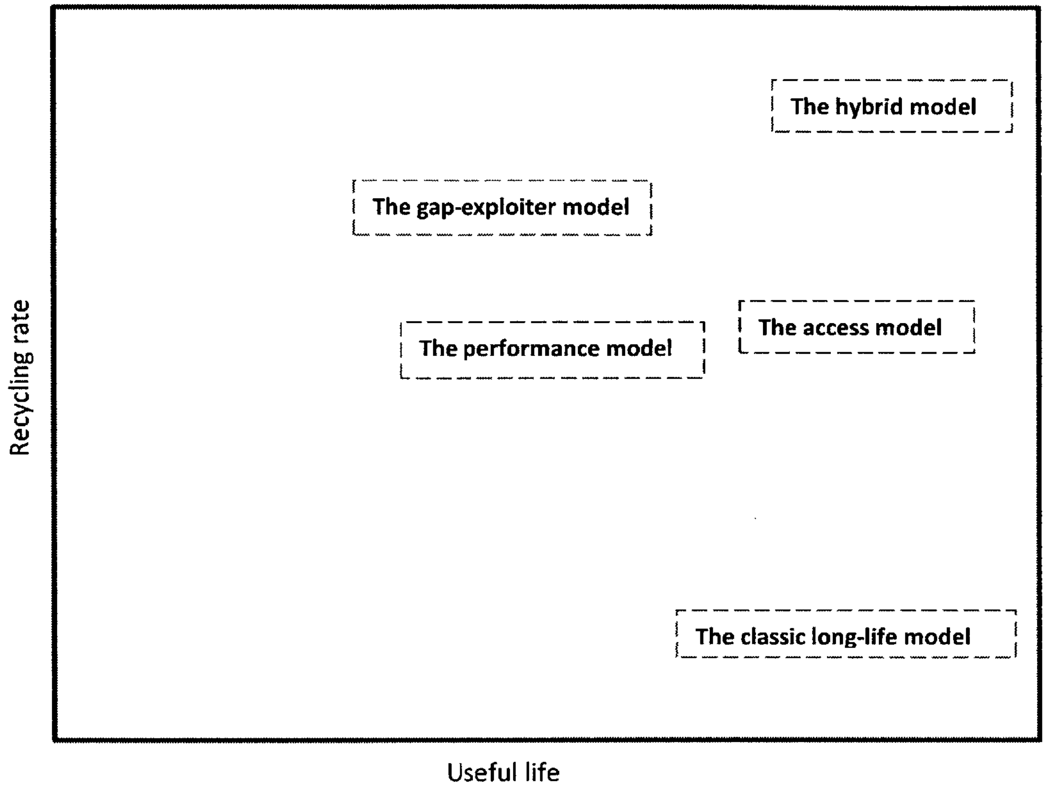


*Fig. 2.2. Recycle more vs. longer useful life*

It is important to note that the useful life and recycling rate of these models can vary. The above figure 2.2 only illustrates the models relative to each other.

**The hybrid model:** combination of a durable product and short-lived consumables. Main revenue stream comes from repeat sales of the fast-cycling consumables. It typically has a high useful life and recycling rate due to the product itself having a long life with the consumables designed for efficient recycling and reuse (For example, durable multi-purpose printers with cartridges that can be reused or recycled easily).

**The gap-exploiter model:** exploits 'lifetime value gaps' or leftover value in product systems. Main revenue stream comes from selling products, parts and services based on the mixed product life of components. It typically has a relatively medium useful life with a high recycle rate due to the product itself capable of being reused after its initial sale as there is a leftover value, and some of its components designed for easy replacement and recycle to extract the remaining value.

**The access model:** provides product access rather than ownership. Main revenue stream comes from payments for product access. It typically has a relatively high useful life and medium recycle rate due to the product designed for long-term durable use by multiple users, however, in that process reducing recycling/reuse capability as long-term use results in more wear and tear, and difficulty in design for recycling/reuse that might occur in the long-term.

**The performance model:** delivers product performance rather than the product itself. Primary revenue stream from payments for performance delivered. It typically has a medium useful life and recycle rate due to the product being designed for durable use but as the business model is dependent on performance, the design tends to not compensate performance for recycling and reuse potential.

**The classic long-life model:** primary revenue stream from sales of high-grade products with a long useful life. It typically has a high useful life with low recycle rate as the product is made as durable as possible. However, this tends to reduce the design's capability in incorporating high recycle potential.

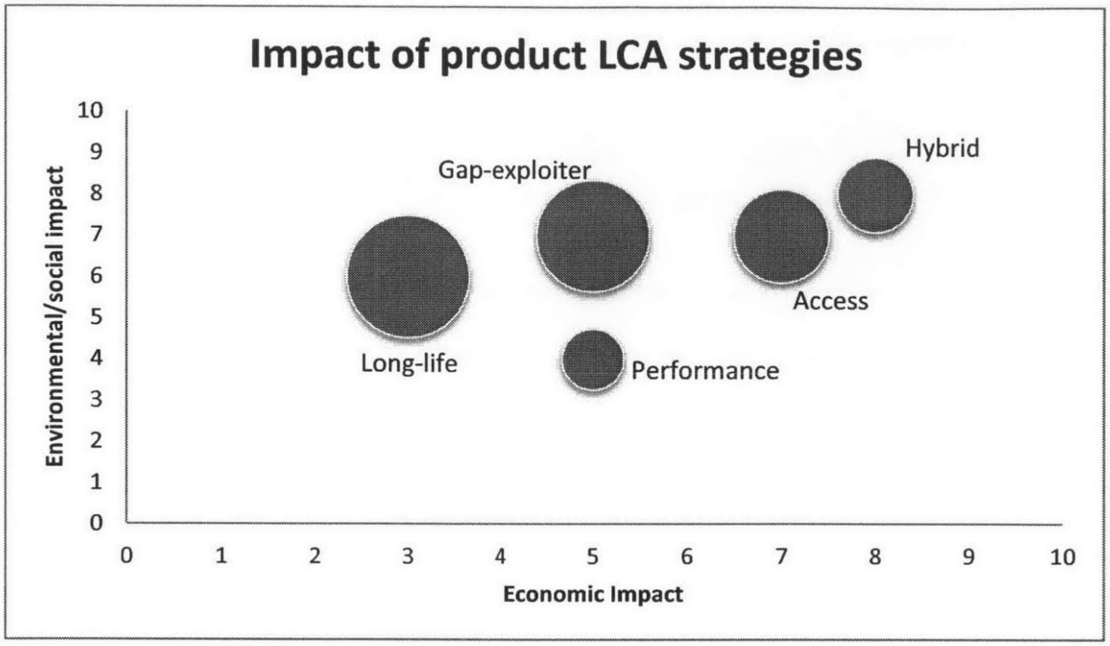


***Fig. 2.3.*** *Impact of product LCA strategies on environment and economy*

We conducted interviews[81] to rank the economic and environmental/social impact of these models. Interviewees were provided a scale of 1 to 10 to rank the outcome (Fig. 2.3). Also, the success of the model was ranked on a scale of 1 to 5 (depicted by the size of the bubbles in Fig. 2.3). We can see that Hybrid and Access models have relatively high environmental, social and economic impact (impact is defined here as an improvement on current conditions) (also evidenced in Fig. 2.2.). The Performance model has similar economic impact as the Gap-exploiter model but the Performance model has higher environmental/social impact due to higher recycling rates of the Gap-exploiter model (also evidenced in Fig. 2.2.). The Long-life model has relatively poor economic impact but substantial environmental/social impact. The effect of increasing product life has a direct influence on resource use and on profits. This was also evidenced by Philips who elaborated that, "we have had marked improvement in resource productivity and positively impacting our bottom line through supply of longer life products". We can

[81] Interviews conducted with Philips, Deloitte, PwC, M&S, Ellen MacArthur Foundation, Cradle-to-Cradle Institute, Gap, Nike, B&Q, Cisco, The Coca-Cola Company, Nestle, Renault, Vodafone

illustrate that by expanding on the equation established by Baptiste Lebreton et al. (2007) as described in Chapter 1:

$$\max \pi = (\sigma - k) \times X,$$

where $\pi$ is profit, $(\sigma - \mathrm{k})$ is marginal cost and X is the number of units required to sell (including repeat sales). Given that product life cycle is increased and assuming demand to be constant, the number of repeat sales will reduce, decreasing X. Again we know that, if R is the non-renewable resources required to make the product at a consumption rate of $\alpha$, we can say $\alpha \times X = R$, implying that to maximize profit we need to maximize resource use:

$$\max \pi \Rightarrow \max R$$

Hence, if X tends to 0, R will tend to 0 assuming consumption rate $\alpha$ to be the same. However, this will also mean that $\pi$ will tend to 0. This can be taken as a reason why the Long-life model struggles with economic impact. When the long-life product is combined with high recyclable consumables in the hybrid-model, even though X tends to 0, $\pi$ does not fall due to increase in consumable sales (Y):

$$\alpha \times X + b \times Y = R,$$

$$\max \pi \Rightarrow \max R,$$

where b is consumption rate of consumables. Similarly, access model has a relatively high impact on sustainability as it increases the life of the product without reducing X (defined in this case as sales from access use), by simply reducing idle-capacity of the product's value.

We also see that the success rate is relatively low for Hybrid and Performance models. The Hybrid model involves high disassembly and reassembly process requirement. As per Sustainability Managing Partner, PwC, "this is due to poor reverse logistics and component secondary market infrastructure in certain industries." The Performance model is currently being used only in limited high capital cost and product price industries such as the airplane industry where for example the engine is paid for based on its performance. According to Philips, customer adoption rate has been low for such models where they would rather prefer owning the product and paying a one-time price rather than a regular payment. Similarly, the Access model has the next lowest success rate due to the same reason of low customer adoption rate, even though its success has recently been highlighted in areas such as shared car use and house rental, indicating a growth in customer adoption of the Access model.

### 2.3.2 Design strategies

Based on my interview with professor Conny Baker of Delft University of Technology, Products That Last is a project that is currently being undertaken to help companies and organizations lead in sustainability and circular economy. Within this initiative, research is being conducted to better understand distinct design strategies. As per her research and company analyses, six strategies have been identified. We map these strategies on an organizational and technical complexity map (adapted from Prof. Sterman's lecture) using a bubble chart that also depicts the level of success (as defined by a strategy that has met or exceeded set target key performance indicator with regards to circular supply chain, such as % remanufactured and sold, % sales upgrades, % repeat sales) identified by companies based on our interviews. (We conducted interviews[82] where interviewees were provided a scale of 1 to 10 to rank the technical and organizational complexity).

[82] Interviews conducted with Philips, Deloitte, PwC, M&S, Ellen MacArthur Foundation, Cradle-to-Cradle Institute, Gap, Nike, B&Q, Cisco, The Coca-Cola Company, Nestle, Renault, Vodafone

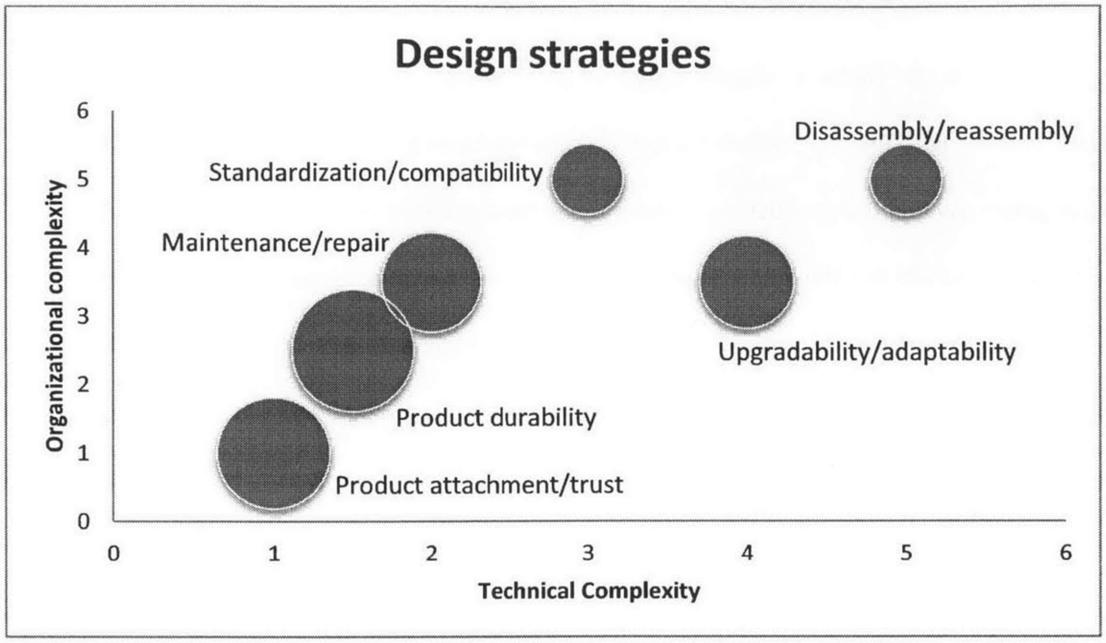


***Fig. 2.4.*** *Complexity and success of design strategies*

The following definition of each strategy is stated[83]:

**Design for product attachment and trust** – it is aimed at countering emotional obsolescence by creating products that will be loved, liked or trusted longer; for example the Patek Philippe watch.

**Design for product durability** – it is aimed at countering functional obsolescence by developing products that can take wear and tear; for example the Miele washing machine.

**Design for standardization and compatibility** – it is aimed at countering systemic obsolescence by creating products with parts that fit other products as well; for example the Vitsoe wall shelving.

**Design for ease of maintenance and repair** – it is aimed at countering functional obsolescence by enabling products to be maintained in tip-top condition; for example the Rolls Royce jet engine and the Philips pay-per-lux solution.

[83] Six design strategies for longer lasting products in circular economy, The Guardian, Conny Bakker and Marcel den Hollander, 16th December 2013

**Design for upgradability and adaptability** – it is aimed at countering systemic obsolescence by allowing for future expansion and modification; for example the Kitchen Aid mixer.

**Design for disassembly and reassembly** – it is aimed at countering systemic obsolescence by ensuring product parts can be separated and reassembled easily. For example the Océ-Canon document (re)production equipment and the Philips Healthcare refurbished systems".

We can see from the above figure that enabling product durability and attachment has seen more success relative to the other strategies and are relatively less complex to implement. Even though disassembly/reassembly as noted in the previous section enables the highest improvement on sustainability, it has seen low success due to high complexity and other limitations highlighted earlier in Chapter 1. This was also evidenced by Renault in our interview who elaborated that, "Renault recognizes the importance of disassembly and reassembly and is steadily working on developing the competency, but challenges lay ahead that we must overcome". These challenges were elaborated in Chapter 1. I It must also be noted that combinations of these strategies are also implementable.

We also conducted interviews[84] to analyze these strategies by success rate and level of importance (on a scale of 1 to 10, defined as the factor that most influences the decision to implement circular concepts).

Following were the results:

[84] Interviews conducted with Philips, Deloitte, PwC, M&S, Ellen MacArthur Foundation, Cradle-to-Cradle Institute, Gap, Nike, B&Q, Cisco, The Coca-Cola Company, Nestle, Renault, Vodafone

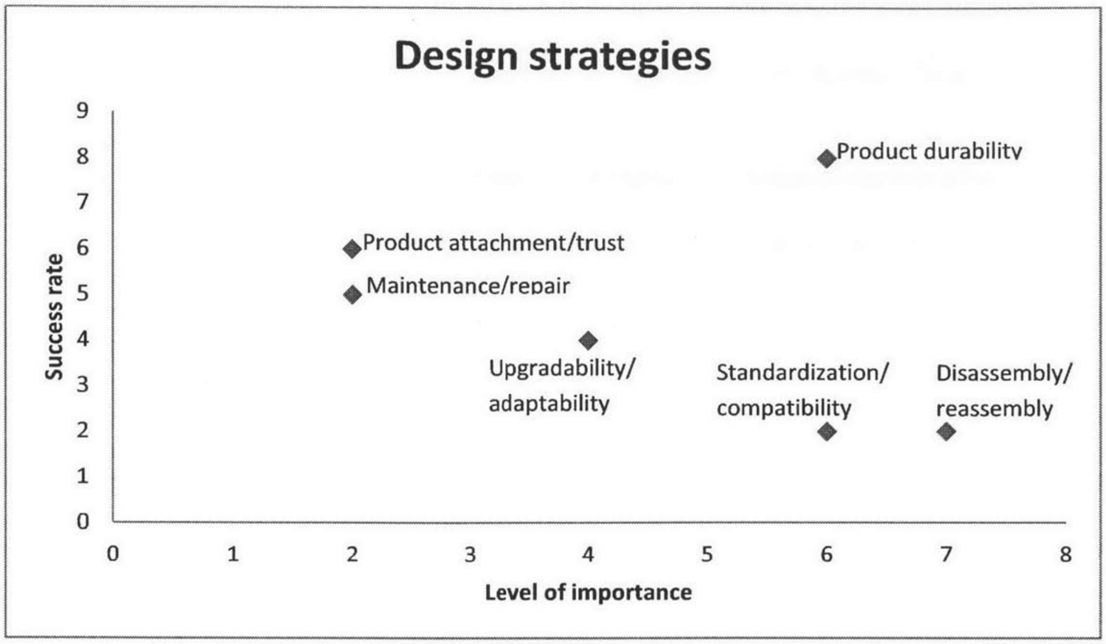


***Fig. 2.5.*** *Success rate and level of importance of design strategies*

We can see from the above figure see that standardization/compatibility and disassembly/reassembly are considered as important factors in considering circular concepts but their success rate in implementing it is relatively low, whereas, only product durability seems to be the factor that has high success rate with relatively high importance. This again confirms our hypothesis of the importance of meeting challenges to enable better disassembly/reassembly. Recommendations in Chapter 3 look to address these hurdles.

### 2.3.3 Product characteristics

Mark W. McIntosh and Bert Bras (1998) have summarized product design characteristics that a product designer must consider to make decisions that will affect closing the remanufacturing loop. According to them, the goal must be to create a product that is returnable, has the most possible reusable components and minimal disassembly requirements. In our interviews, we questioned the rate of success and complexity of these characteristics in an organization's product design decision making process to enable successful circular strategies. Similar to figure 2.4, the following bubble chart represents the results based on our interviews[85]. (We conducted interviews where interviewees were provided a scale of 1 to 10 to rank the technical and organizational complexity)

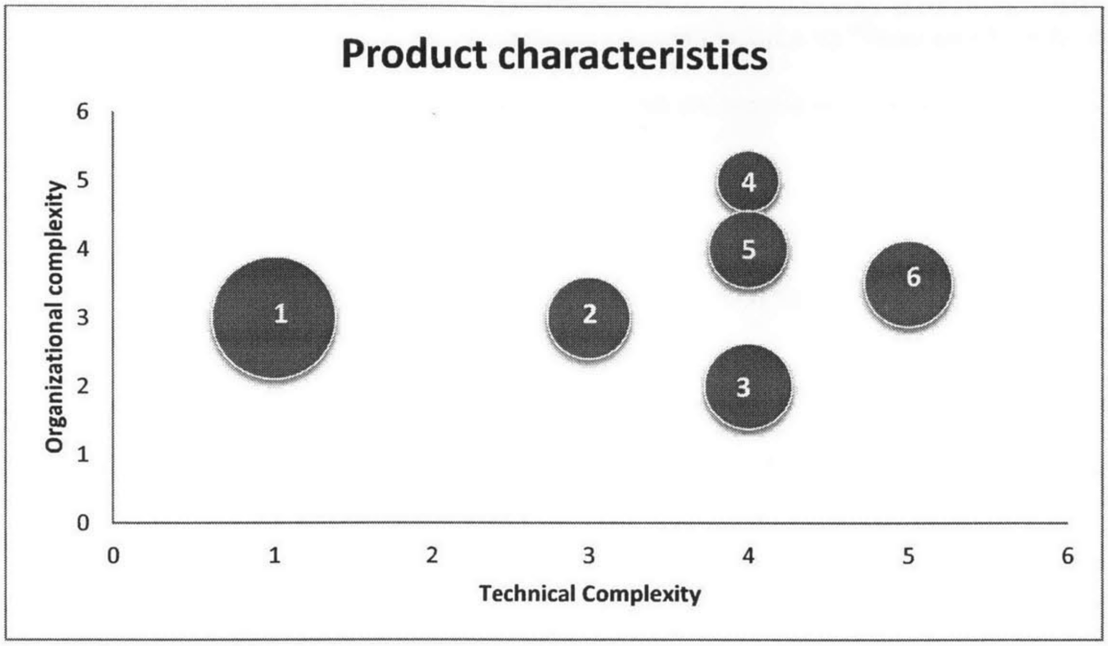


*Fig. 2.6. Complexity and success of product characteristics*

1. Design for Inexpensive and High Volume Product Retrieval
2. Remanufacture processes
3. Number of Components Intended and Designed for Reuse
4. Level of Disassembly Required for Remanufacture
5. Number of Components in Product Models
6. Ease of Component Disassembly

Design for inexpensive and high volume product retrieval was a focus for several organizations who found it to be a successful factor in decision making. It was also relatively less complex, representing a low-hanging fruit. Ease of component disassembly was closely followed as the second-most successful

[85] Interviews conducted with Philips, Deloitte, PwC, M&S, Ellen MacArthur Foundation, Cradle-to-Cradle Institute, Gap, Nike, B&Q, Cisco, The Coca-Cola Company, Nestle, Renault, Vodafone

factor. While it is relatively of higher complexity, with a high success rate, this characteristic was worth implementing to enable the circular concepts.

We also conducted interviews[86] to analyze these characteristics by success rate and level of importance (defined as the factor that most influences the decision to implement circular concepts). Following were the results:

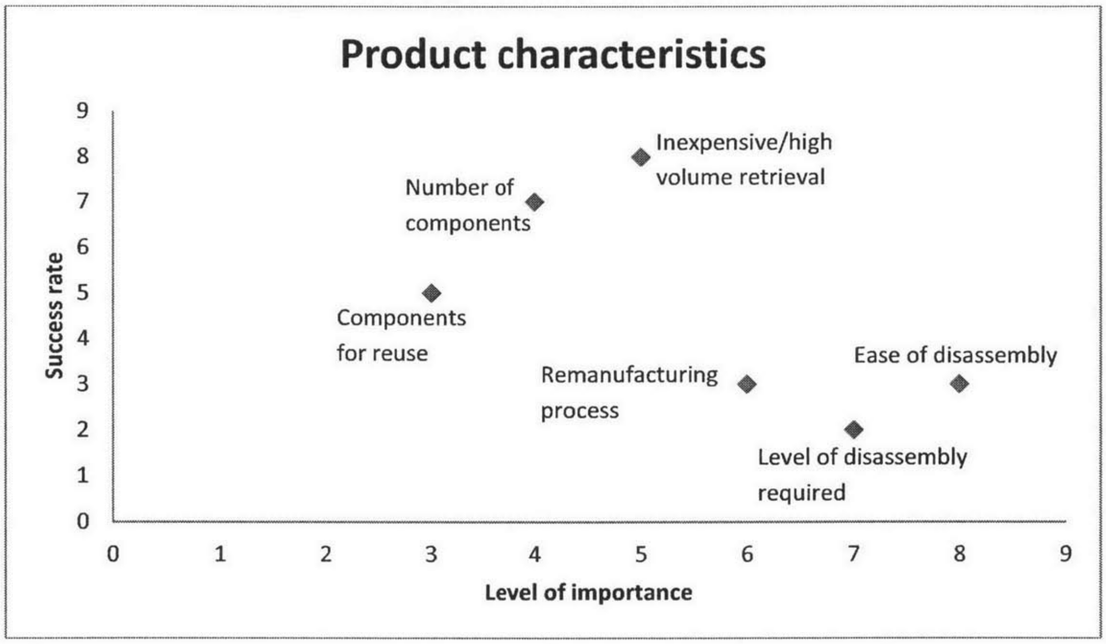


***Fig. 2.7.*** *Success rate and level of importance of product characteristics*

We can see that three important factors – ease of disassembly, remanufacturing process, and level of disassembly required have relatively low success rate. This was evidenced by Deloitte who mentioned that, "disassembly and remanufacturing capabilities need to be embedded within product design to provide impetus to the circular supply chain model of companies".

[86] Interviews conducted with Philips, Deloitte, PwC, M&S, Ellen MacArthur Foundation, Cradle-to-Cradle Institute, Gap, Nike, B&Q, Cisco, The Coca-Cola Company, Nestle, Renault, Vodafone

### 2.3.4 Product Development Strategies

Mark W. McIntosh and Bert Bras (1998) have also enumerated several design management decisions that need to be considered for remanufacturing[87]:

1. Rate of Innovation (Technology Life Span of Components) – A strategy where organizations must consider the rate of innovation that alter products and its components to not make remanufacturing old products obsolete but at the same time innovate to be competitive. In other words, the strategy balances:
   Developing Adaptable Products vs. Standardization Across Generations (Ability to Innovate While Preserving Components Across Generations)[88]
2. The Level of Product Variety (Number of Product Models at Any Time) – A strategy where organizations must consider if increased product models will conflict with closed-loop supply chains where component interchangeability might become more difficult due to large product variety. In other words, the strategy balances:
   Developing Families of Products vs. Standardization Across Product Variety (Ability to Offer Product Variety while Standardizing Across Product Models)[89]
3. Volume of Each Product Model Produced – A strategy where organizations must consider the balance between the volumes of model produced vs. remanufactured.
4. The Time Horizon Considered for Remanufacturing Assessments – A strategy where organizations plan the remanufacturing time horizon to ensure inventory sufficiency while keeping flexibility of customer returns.

[87] Determining the value of remanufacture in an integrated manufacturing-remanufacturing organization, Mark W. McIntosh and Bert Bras, 1998, pg. 4
[88] Ibid.
[89] Ibid.

Mark W. McIntosh and Bert Bras (1998) also suggest that the rate of innovation and the level of product variety need more attention as rapid innovation and customization will increase product model and component variety, thereby decreasing interchangeability and reclamation[90]. Further, Ishii, et. al. (1995) explain the relationship between technology life spans and product life spans – "If a component's technology life span is shorter than the expected life span of its product, the component is not a candidate for reuse[91]". We expand on these suggestions by surveying the success rate and complexity of handling each of these strategies within the context of creating circular supply chains. We also attempt to further build these relationships based on our interviews (Chapter 3).

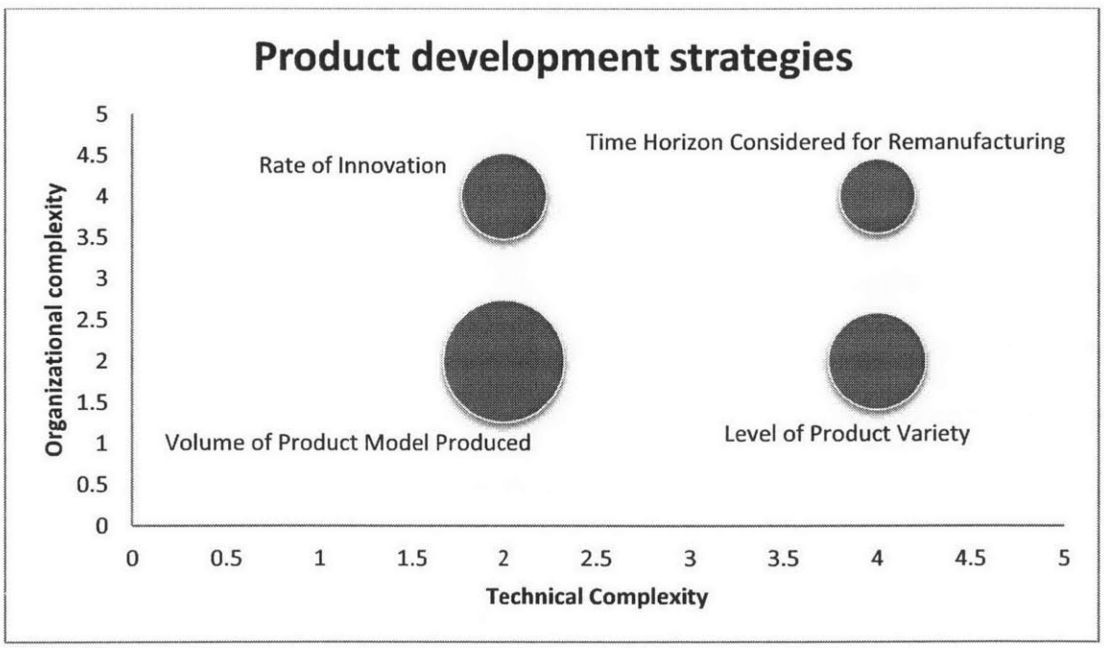


***Fig. 2.8.*** *Complexity and success of product development strategies*

In the above figure, we see that the strategy involving volume of product model produced has been successful and has a low complexity factor. Managing remanufacturing time horizon is most complex in terms of technical and organizational challenges given the lack of reverse logistics infrastructure and

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[90] Ibid.

[91] Determining the value of remanufacture in an integrated manufacturing-remanufacturing organization, Mark W. McIntosh and Bert Bras, 1998, pg. 4

hence has also had a low success rate. We also conducted interviews[92] to analyze these characteristics by success rate and level of importance (defined as the factor that most influences the decision to implement circular concepts). Following were the results:

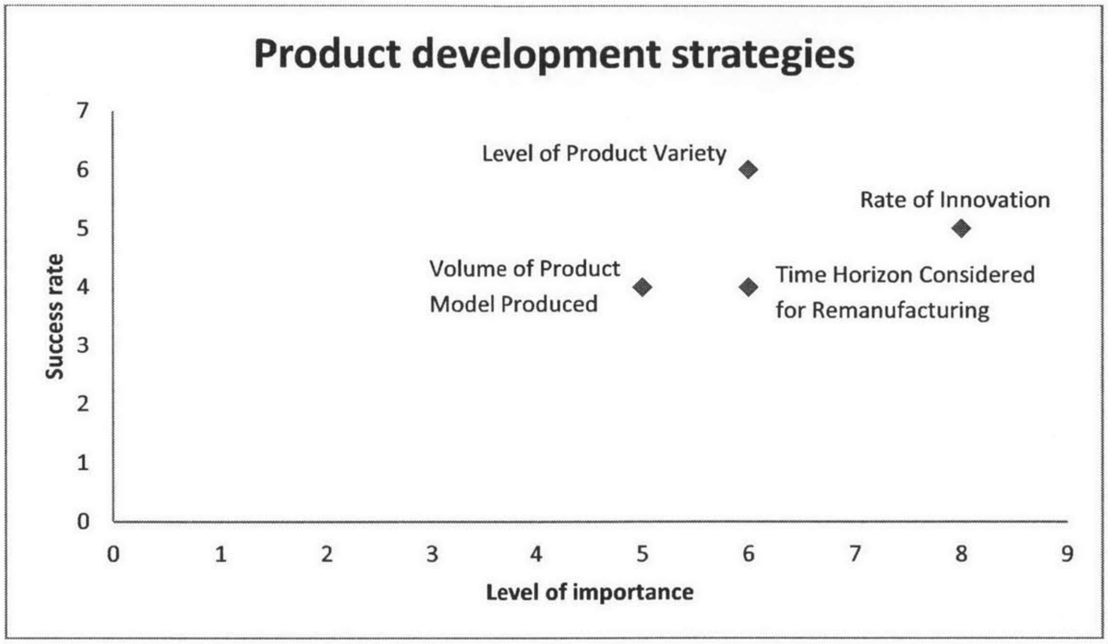


***Fig. 2.9.*** *Success rate and level of importance of product development strategies*

We can see from the above figure that Rate of Innovation and Level of Product Variety has relatively had a high level of importance and high success rate. This was also evidenced by Gap who mentioned that, "the driver to enabling circular concepts has been the ability to continuously manage innovation and product variety to counter returns that are obsolete". We will further demonstrate the links between these variables in Chapter 3.

### 2.3.5 Business conditions

Lastly, we list the business conditions that influence remanufacturing viability[93]:

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[92] Interviews conducted with Philips, Deloitte, PwC, M&S, Ellen MacArthur Foundation, Cradle-to-Cradle Institute, Gap, Nike, B&Q, Cisco, The Coca-Cola Company, Nestle, Renault, Vodafone

[93] Determining the value of remanufacture in an integrated manufacturing-remanufacturing organization, Mark W. McIntosh and Bert Bras, 1998, pg. 4

1. Cost to Reclaim Used Products – The cost to reclaim when incorporated into a decision analysis to remanufacture or not must not be large enough to not be economically viable. At times, due to geographical dispersion and technical difficulties in collecting used products, costs can spike, making remanufacturing unattractive.
2. Percent of Used Products Returned – Product returns are highly variable and dependent on several factors such as incentives, ease of returns, product characteristics, consumer habits, etc. This factor can dramatically change the economic viability of closed-loop supply chains.
3. Product Life Span (Time Before Products are Returned) – Similarly, the product return time plays a significant role in inventory management and remanufacturing processes.
4. Shifts in Technology and Consumer Requirements (Changes in Technology Life Span Beyond Designer's Control) – Large shifts can prevent maintenance of a product's design[94] despite efforts to build products incorporating the design characteristics mentioned in the earlier section.
5. Cost of Manufacturing New Components – This factor has been identified as crucial[95] since in order to be feasible, components must be reclaimed and remanufactured more economically than manufacturing them from scratch.
6. Prices Received for Scrap Recycling of Components – If prices received for scrap recycling of components is too low due to a poor market for those components, then that would discourage remanufacturing and recycling.
7. Cost of Labor and other Remanufacturing Process Costs – Generally, remanufacturing costs tend to be low as existing manufacturing and labor overheads are leveraged to take advantage of economies of scale (as seen in the example of Renault in Chapter 3). However, in certain

[94] Determining the value of remanufacture in an integrated manufacturing-remanufacturing organization, Mark W. McIntosh and Bert Bras, 1998, pg. 5
[95] Ibid., pg. 4

industries where remanufacturing involves a significantly different process and skillset, costs can spike sharply making it economically unviable.

8. Remanufacturing Process Setup Costs – Setup costs involve the initial capital outlay to establish the remanufacturing facility and logistics. This factor has been identified as one of the key lock-in challenges that industries face when looking to transition from linear to circular concepts.
9. Inefficiency When New Remanufacturing Processes Are Required – Remanufacturing processes are considered to be challenging and niche in certain industries[96]. There exists poor knowhow and standardization. This brings inefficiencies when new processes are required.
10. Government Policies (Incentives for Reuse or Recycling) – Government incentives are considered highly important in compensating for some of the business conditions mentioned above and making the business case for closed-loop processes.
11. Producer's Opportunity Cost of Capital - Mark W. McIntosh and Bert Bras (1998) also consider producer's opportunity cost of capital to have a big impact on remanufacturing since the decisions to whether to remanufacture will also be weighed against other investment opportunities.

We extend the analysis of these business conditions by asking in our interviews[97] about their importance (defined as the factor that most influences the decision to implement circular concepts) and success (defined as the factor that has been managed most successfully when implementing circular concept) of handling them. (Interviewees were provided a scale of 1 to 10 to rank the level of importance and success rate).

[96] Determining the value of remanufacture in an integrated manufacturing-remanufacturing organization, Mark W. McIntosh and Bert Bras, 1998, pg. 8
[97] Interviews conducted with Philips, Deloitte, PwC, M&S, Ellen MacArthur Foundation, Cradle-to-Cradle Institute, Gap, Nike, B&Q, Cisco, The Coca-Cola Company, Nestle, Renault, Vodafone

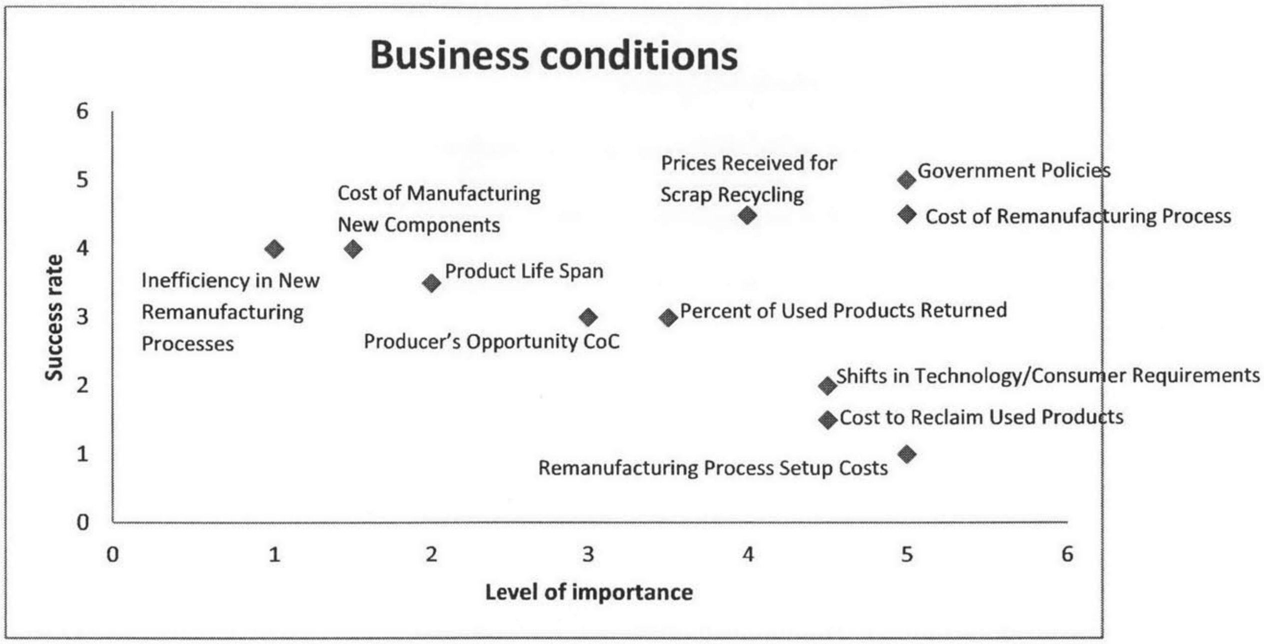


***Fig. 2.10.*** *Success rate and level of importance of business conditions*

Based on the above figure, we see that the most important factors based on our interviews are government policies, cost of remanufacturing process, remanufacturing process setup costs, shifts in technology/consumer requirements and cost to reclaim used products. Out of these, organizations have struggled to manage remanufacturing process setup costs, shifts in technology and consumer requirements, and costs to reclaim used products. On further interrogation, the top reasons sighted were poor financial infrastructure for reverse logistics, underdeveloped market for reclamation, and fast paced changes in competitor strategy and consumer behavior that render design for remanufacturing challenging and rapidly obsolete. We also notice that the claim made by Mark W. McIntosh and Bert Bras (1998) of producer's opportunity cost of capital as one of the most important factor does not hold – organizations have realized the business case for circular supply chains and are willing to implement it with the sufficient knowhow, financial support, technical infrastructure and government incentives.

### 2.3.5 Other decision variables to consider

Besides the above mentioned variables and strategies, certain other factors are worth expanding upon[98]:

#### 2.3.5.a Product or component remanufacture

Closing the loop for components/subassemblies might be a better strategy than that for products. For example[99], train components are commonly remanufactured but interiors and bodies are not. This could be due to the reason that remanufacturing the entire product can have a negative impact on the environment. Older products when remanufactured and put back in use could result in higher energy use due to outdated and inefficient technology. Thus organizations must consider what to remanufacture, reuse, recycle and replace when implementing closed-loop supply chains.

#### 2.3.5.b Product architecture decisions

We have already discussed the role of product durability in creating closed-loop strategies. However, durability only addresses product life cycle due to wear and tear; environmental or chemical degradation; and accident or inappropriate use. Other reasons why products become obsolete as per McIntosh and Bras (1998a,b) include newer technology becoming available and fashion changes (for example, cell phones). Organizations must consider other architecture decisions such as the product's technology stability and relevance in terms of aesthetics and fashion[100], to achieve component reuse.

#### 2.3.5.c Maintenance and repair requirements

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98 Closed-Loop Supply Chains, New Developments to Improve the Sustainability of Business Practices, Edited by Mark E. Ferguson and Gilvan C. Souza, Auerbach Publications 2010, pg. 45-

99 Ibid., pg. 45

100 Closed-Loop Supply Chains, New Developments to Improve the Sustainability of Business Practices, Edited by Mark E. Ferguson and Gilvan C. Souza, Auerbach Publications 2010, pg. 46

Organizations must consider extending the product life by not only adding durability but also designing for effective repair and maintenance. Designers could allow users to maintain the product or have the OEM provide maintenance services. McIntosh and Bras (1998a,b) argue that the latter is preferable as that would allow prescribed maintenance operations, thus keeping the product and its components in check for collection and reuse later. Therefore, organizations must consider strategies to design their product that would require minimum maintenance to more maintenance based on product characteristics and its business model.

### 2.3.5.d Design for reverse logistics

Designers must also consider the reverse logistics for smooth collection and returns. Collections can occur directly from customers through direct mail or handovers to indirectly through several actors such as brokers, third party organizations, and subsidiaries. A design that is easy to use with protective packaging can increase predictability of returns. For example[101], printer cartridges come with returnable boxes, prearranged return address and shipping labels.

### 2.3.5.e Hazardous Material use vs. performance

As a rule of thumb, any "sustainable" product must not contain hazardous materials. However, with the focus solely on creating closed-loop supply chains, certain products contain substances of concern that enhance its performance but can hamper recycling and reuse. For example[102], air-conditioners and refrigeration systems use Freon, a hazardous material. If it is replace by a new refrigerant then performance might degrade. Further, it increases cost of reprocessing due to the requirement of specialized equipment. Also, using metals such as chromium, zinc, lead, etc. will trigger EPA toxic release

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[101] Closed-Loop Supply Chains, New Developments to Improve the Sustainability of Business Practices, Edited by Mark E. Ferguson and Gilvan C. Souza, Auerbach Publications 2010, pg. 49
[102] Ibid., pg. 51

inventory requirements and other regulations[103]. Therefore, designers must consider the use of hazardous material when designing closed-loop supply chains.

### 2.3.5.f Intellectual property use

By excluding third-party remanufacturers from collecting and remanufacturing their product, an OEM might be able to make a better business case for closed-loop supply chains. However, by eliminating competition this would also limit growth in collection and remanufacturing infrastructure, and establishment of more widespread used product markets. Organizations must take into account these factors in their product design's proprietary technology.

We extend the analysis of these variables through our interviews[104] to question their importance (defined as the factor that most influences the decision to implement circular concepts) and success (defined as the factor that has been managed most successfully when implementing circular concept) of handling them. (Interviewees were provided a scale of 1 to 10 to rank the level of importance and success rate).

[103] Ibid., pg. 51
[104] Interviews conducted with Philips, Deloitte, PwC, M&S, Ellen MacArthur Foundation, Cradle-to-Cradle Institute, Gap, Nike, B&Q, Cisco, The Coca-Cola Company, Nestle, Renault, Vodafone

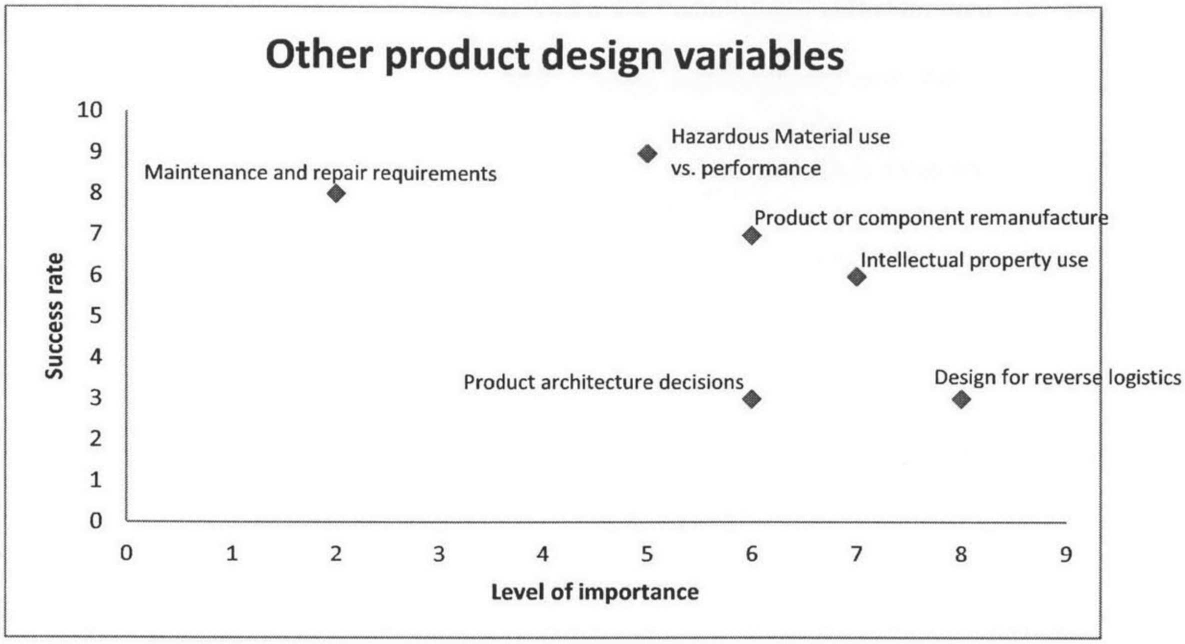



***Fig. 2.11.*** *Success rate and level of importance of other design variables*

We can see from the above figure that design for reverse logistics and product architecture decisions are considered important variables with relatively low success rate.

After having discussed and analyzed these variables, we will now attempt to summarize them and build a framework to test the linkages between them in the following Chapter.

# Chapter 3. How can organizations fix the leakage points?

We have now identified several key variables and strategies that surround product design in circular supply chains by bucketing them under Product Life Cycle Analysis, Design Strategies, Product Characteristics, Product Development Strategies, Business Conditions and Other Decisions Variables. To understand their interactions, we summarize them in Figure 3.1. Note that this representation is made only to help construct a demonstration of some of the ways these findings can interact. It is by no means a decision making framework.

For example, an organization decides an appropriate Product Life Cycle Analysis strategy based on several external and internal factors – the key factors are listed under Business Conditions based on our findings. This could be made across the organization or for a selection of products. Let's say the decision is to adopt the hybrid framework with long life products and short life components for a product line. The organization must consider the Product Development Strategies – does it go with a standardized product line to limit number of components and maximize opportunities to reuse, remanufacture and refurbish? How much innovation should be coupled with this product's production so that the organization's product is competitive but not rapidly changing to disallow component resell? If a standardized product line is desired, then what are the Design Strategies must be adopted to assure that variety is not needed. The organization could go for product attachment/trust and durability to enable long-term use and mitigate risk of depletion in value due to fashion changes. It would also want to build the product for swift component disassembly – making these design strategies more important. Other Decision variables it might consider include tight intellectual property with strong reverse logistics to earn maximum revenue from reuse of components as it will be losing out on product sales. This should also translate into Product Characteristics such that the product has a higher number of replaceable components with possibly lower product margins and higher component margins.

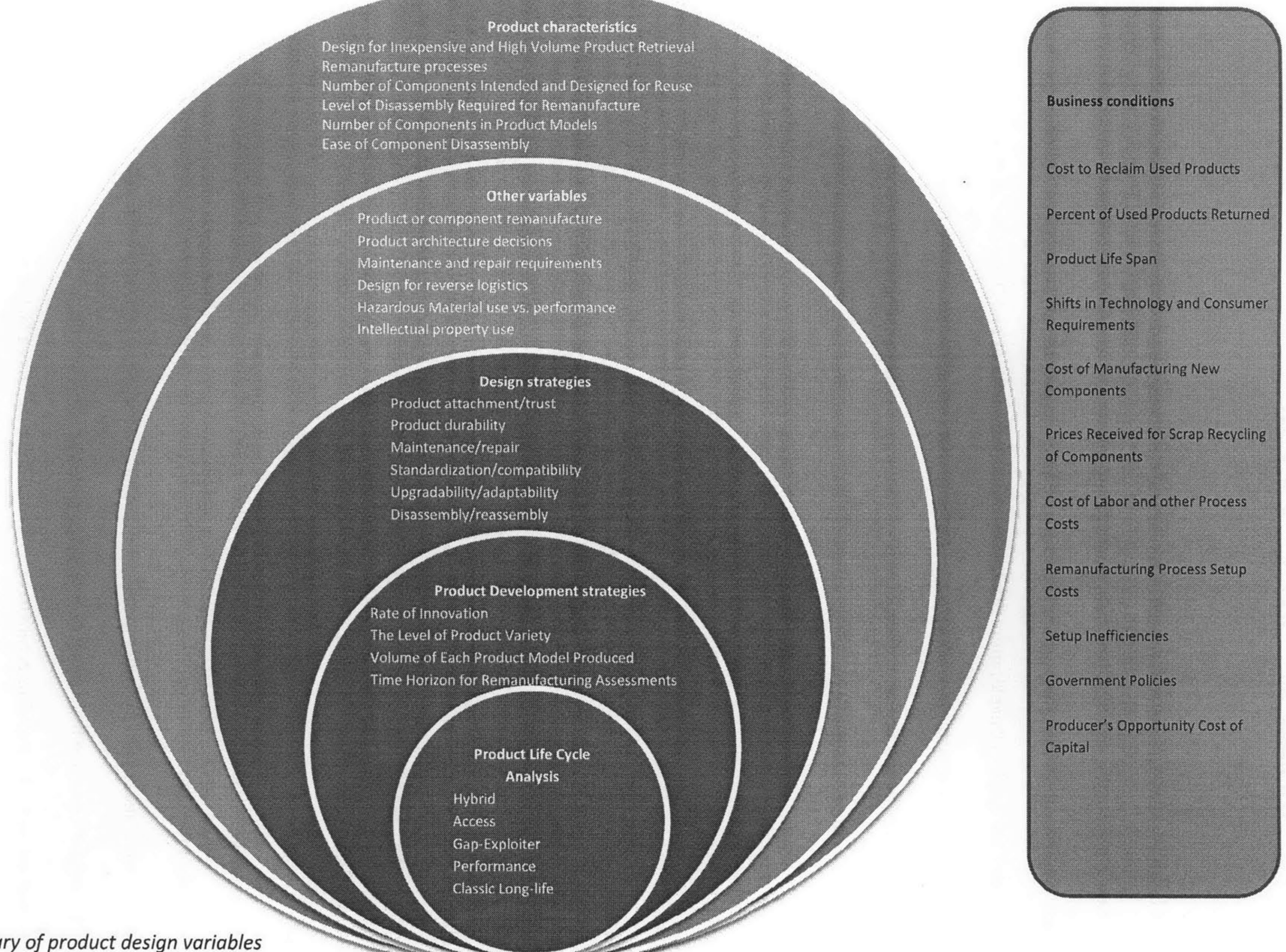


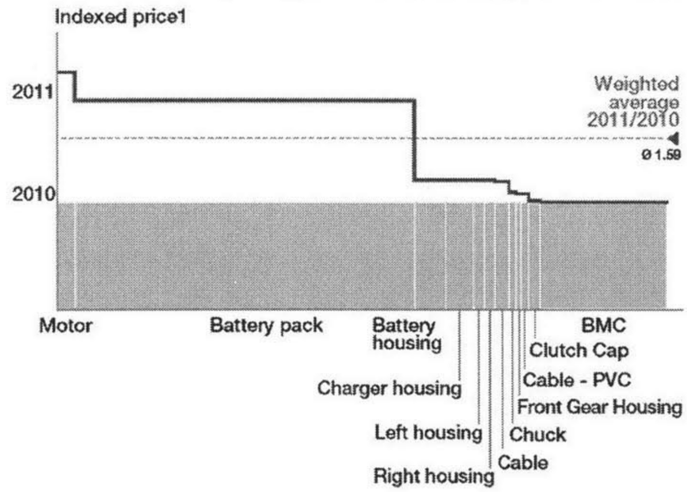

***Figure 3.1*** *Summary of product design variables*

As such, these variables are highly interlinked and must be considered in several stages of the organization's circular supply chain implementation process. The focus of our research is to build the set of variables based on collected data and demonstrate their interaction. To do so, we focus on two product life cycle analysis strategies – Hybrid and Access (as identified earlier in Chapter 2, the two strategies have the highest impact on sustainability based on our interviews) – to test and demonstrate the interaction of the variables and provide conditions for effective product design in circular supply chains based on the two case studies, by using a summary of other researched examples, and through interviews and literature review.

## 3.1 Testing with case studies

Given that the selection of circular supply chain strategies and variables would greatly vary depending on the industry in question, we attempt to analyze the behavior of the strategies an d variables using two test cases within the automobile industry – Renault and Tesla.

The linear model is posing two severe challenges to Renault's and Tesla's growth, and to sustainability. Firstly, with the automotive industry as the highest consumer of lead, studies say that reserves will run out in 2030[105]. This is already creating supply disruptions and business insecurity. Secondly, with rising demand of materials, prices have been volatile (Figure 3.2) and have spiked rapidly, diluting margins.




¹ Prices are indexed to 1 for 2010
² Components shown represent 95% of the material costs
Source: B&Q/Kingfisher 14.4V power drill component price data

***Figure 3.2*** *Price Volatility in the Automotive Industry*

### 3.1.1 Case study 1 – Renault's Hybrid circular supply chain model

#### *3.1.1.1 Background*

Since the early 90's Renault has been active with sustainable development with efforts in corporate social responsibility (diversity, education, etc.), advancements in technology to limit vehicle pollution, social policy (labor health/safety, skill-development, etc.), and transparency through sustainability ratings. However, in 2010 Renault revamped their supply chain strategy to counter the trends posed by the linear model – moving to a tight-loop recycling of materials from vehicles, and remanufacturing and

[105] U.S. Geological Survey (USGS)

re-commerce of the brand itself. Moreover, their strategy involved the Hybrid model with long life vehicles combined with shorter life components that could be disassembled.

For the purpose of this case analysis, we study this cradle-to-cradle initiative to evaluate how Renault has adopted this strategy and how it has impacted sustainability and vice versa. We will see that Renault is effectively contributing to sustainability and competitiveness by controlling three balancing loops; however, there are certain important conditions to be met and limitations to be handled through recommended actions to better achieve this strategy. We will also be able to demonstrate how product design variables are linked in a Hybrid model.

#### *3.1.1.2 Renault's Hybrid model*

Renault has set up remanufacturing facilities that embody the circular economy concepts. Choisy-le-Roi outside Paris is a perfect example of this. In this facility, end-of use components are collected and remanufactured/reconditioned to be used in the production of the same or similar products. It can reuse complex parts such as gearboxes, injectors and turbocompressors. According to the World Economic Forum, Renault has by working with their suppliers and waste management companies, and by actively managing their raw material streams, redesigned their components to incorporate end-of-life expertise, increased the reuse ratio, enabled easier sorting through standardized components[106] and effectively tapped into secondary material streams.

Renault has used Product Development strategies effectively be calibrating each variable according to the competition. The Rate of Innovation is kept at a medium rate (design change timeframe of 8 to 10 years as opposed to approximately industry design change timeframe of 4 to 20 years[107]). This allows Renault to counter obsolescence of parts that can happen due to rapid innovation. However, to stay

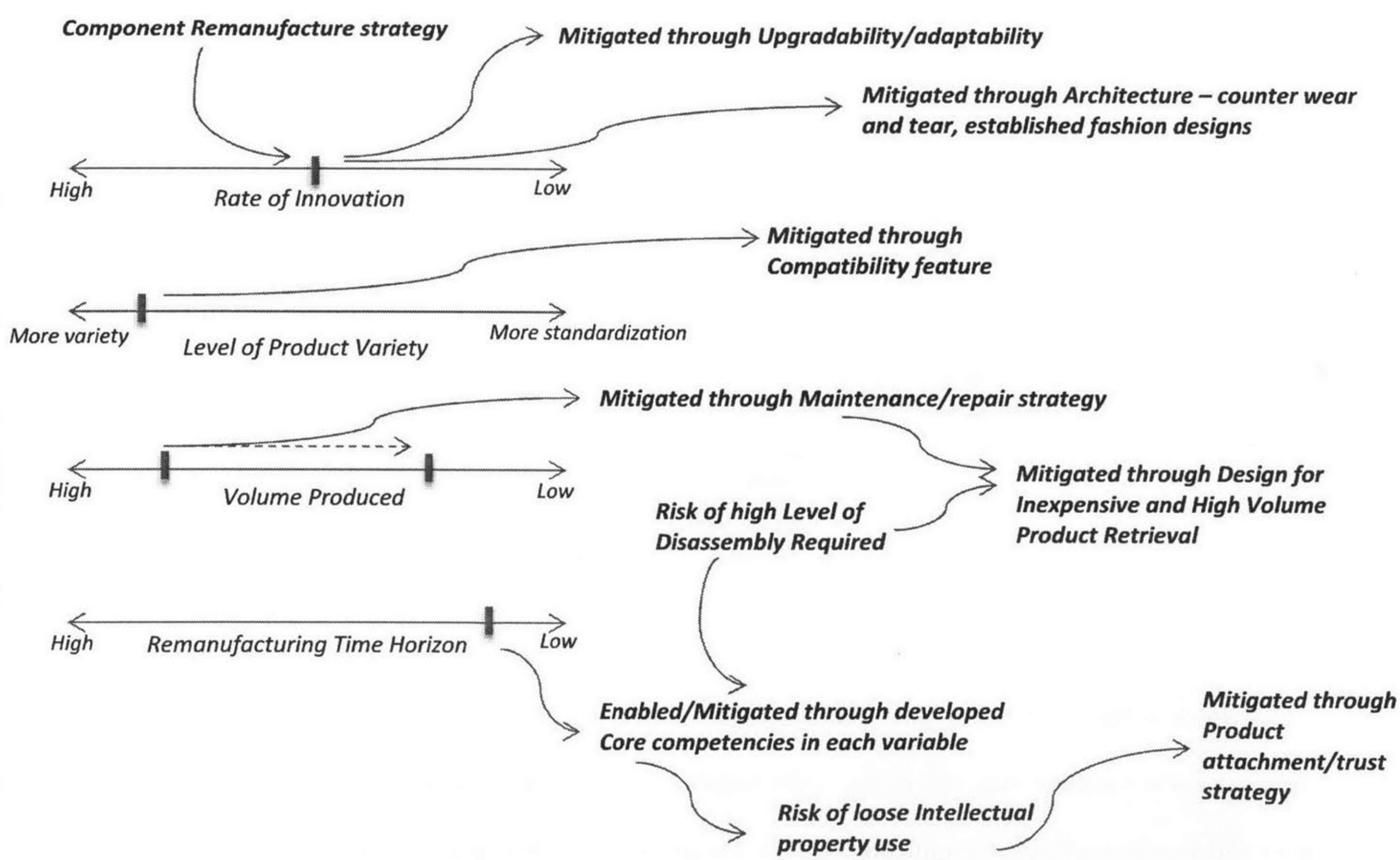
[106] Towards the Circular Economy: Accelerating the scale-up across global supply chains, World Economic Forum, January 2014, pg. 14
[107] Interview with consulting firm B's strategy practice

competitive they stick to a relatively medium innovation rate in the European market and counter obsolescence of parts that are used beyond the design timeframe by adopting the Upgradability/Adaptability Design Strategy where certain parts can be upgraded to a newer version. The Level of Product Variety is kept high due to a highly segmented marketplace[108]. However, to mitigate the difficulty of interchangeability of components, Renault has heavily adopted the Compatibility Design Strategy where parts of one vehicle can be easily used in another vehicle. The Volume of Each Product Model Produced is managed initially by a high level of new components followed with a scale-back in production by estimating component return based on a detailed life-cycle and customer returns analysis. The uncertainty of component end-of-life and returns is a big challenge as identified earlier in Chapter 1. Renault mitigates this risk by incorporating the Maintenance/Repair strategy (free repairs in certain high margin reusable components[109]) where Renault mechanics can track the life of the product during repair visits, and by incorporating Design for Inexpensive and High Volume Product Retrieval Product Characteristic where customer returns of components are free for certain high margin reusable components. The Time Horizon for Remanufacturing Assessments is kept low for rapid monetization of component sales. This is done through a heavy focus on core competency development around remanufacture.

The Product Architecture is designed for durability against wear and tear, and established fashion trends rather than bold forecasted trends to mitigate risk of changes in customer preference[110]. Intellectual Property Use is kept loose to encourage growth in reverse logistics infrastructure and secondary market. Imitation and competition is reduced by using Product Attachment/Trust Design Strategy (for example, including features that allow Internet of Things connectivity, and marketing efforts to highlight

[108] Interview with consulting firm B's strategy practice (Project Manager)
[109] Ibid.
[110] Ibid.

emotional attachment to brand[111]). The Level of Disassembly Required for Remanufacture is high due to industry regulation requirements[112] that increase complexity of disassembly and reassembly. This is mitigated by building core competency in disassembly/reassembly design – Renault claims to be the leader in hiring and training engineers skilled at disassembly/reassembly product design[113]. By using these product design strategies and variables Renault has been able manage the Business Conditions as explained in Chapter 2. Figure 3.3 illustrates the interaction of these strategies and variables. (Here 'high' and 'low' are estimations and demands more analysis and research based on industry averages).




*~~Figure~~ **3.3** Renault's circular supply chain strategy*

[111] Interview with consulting firm A's strategy practice (Project Manager)
[112] Ibid.
[113] Ibid.

The following systems map (adapted from Prof. John Sterman's systems diagram) illustrates the areas where Renault is impacting sustainability:-

1) Reduction in resource consumption through reuse/remanufacture/refurbish (closing the loop)
2) Reduction in resource consumption through extending life of product
3) Reduction in impact through innovation in material disassembly/tracking

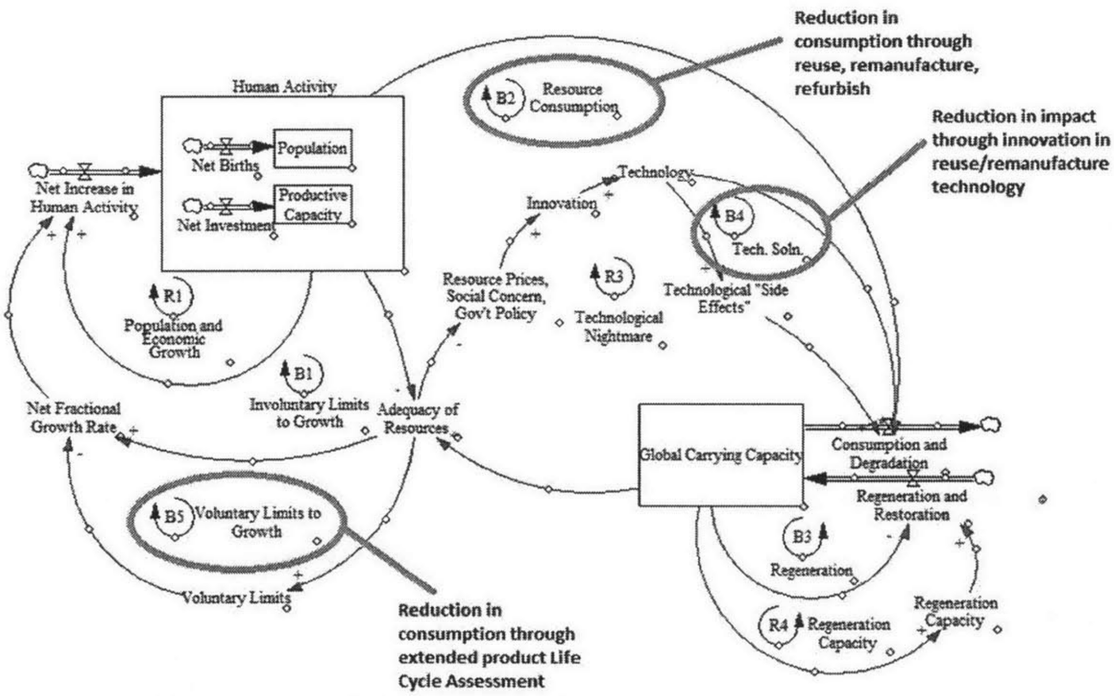



***Figure 3.4*** *Renault's impact on sustainability*

### *3.1.1.3 How does sustainability fit into Renault's strategy?*

In the words of Philippe Klein, Renault's Executive Vice President, "The circular economy now impacts our business in a positive way. The peaks in raw material costs, similar to those experienced in 2004 have had a serious impact on production costs. It is extremely difficult to price this volatility, as it does not represent an immediate functionality for the customer. Therefore, closed- loop recycling is an important lever of risk management for the company. Another example is re-manufacturing of parts:

the profitability of Choisy le Roi is far higher than the average profitability of Renault's industrial sites."[114]

Renault claims that to manage the risks associated with high volatile prices and resource limitations, reducing business disruption risk. By remanufacturing parts they have significantly reduced costs and end-user prices, giving themselves a cost advantage. We also see them as a first-mover in breaking the linear lock-in to move towards the circular model that the industry will eventually have to move to some degree due to the increasing resource exhaustion and geographic distribution, thus giving them the power to define the new business model and regulations around it. By enabling a service model they are also creating a differentiation (example, pioneered electric batteries leases and Renault vehicles are branded with the $eco^2$ mark saying that they are designed so that 95% of their mass can be recovered at end-of-life to be reused or recycled). Moreover, by creating joint ventures with suppliers and waste management companies, they have created a superior material flow control for robust material management, thus enabling higher product quality as they know the material composition from the start.

### *3.1.1.4 Evaluation of Renault's strategy*

#### *3.1.1.4.a On competitiveness*

Collecting and reusing parts allows Renault to sell the remanufactured parts 30-50% cheaper with the same quality control tests and product guarantee[115]. Further, Renault is able to replenish parts that would otherwise be out of stock due to product discontinuation, allowing a revenue stream from customers of older products, creating loyalty with clients. The remanufacturing operation generates new revenue of US$ 270 million annually. While more labor is required for remanufacturing than making new parts, there is still a net profit because no capital expenses are required for machinery, and no

[114] Ibid., interview, pg. 14
[115] Ellen MacArthur Foundation book: circular economy thinkers set out views, The Guardian, Oliver Balch

cutting and machining of the products, resulting in no waste and a better materials yield[116]. Its supplier service model for cutting fluid has resulted in a cost ownership reduction of 20% and gives the supplier a differentiated solution[117].

### *3.1.1.4.b On sustainability*

Through a comprehensive life cycle assessment and circular model, Renault is decreasing resource consumption by reduced new car and parts sales. A move towards the service model enables it to introduce the shared service concept, reducing idle capacity and total number of cars. This not only reduces emissions but also decreases waste. Renault's remanufacturing facility is run partly through renewable energy, which again results resource savings. Moreover, this initiative and technology innovation does not displace labor force – it creates new jobs locally as to be viable the facility has to be set up within the market in which the vehicles are used (example – shipping the engines abroad would negate savings)[118]. The following results of this initiative were published by Renault[119]: 80% less energy, 88% less water, 92% less chemical products, 70% less waster production, 43% carcasses re-usable, 48% recycled, 9% valorised, 0% landfill.

### *3.1.1.5 Conditions for Renault's circular strategy*

1. Cost of repair/remanufacture is less than purchase price of new product

2. Quality of remanufactured product is acceptable to consumer

3. Communication of credible information about product and process to stakeholders

4. Defense against imitation (although through adoption, better collaboration and material standardization is achieved, further enabling disassembly and reverse logistic capabilities)

5. Ease of returns for customers

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[116] Towards the Circular Economy: Accelerating the scale-up across global supply chains, World Economic Forum, January 2014, pg. 14
[117] Ibid. , pg.14
[118] Ellen MacArthur Foundation book: circular economy thinkers set out views, The Guardian, Oliver Balch
[119] www.renault.com

6. Supplier collaboration for material standardization and specification

#### *3.1.1.6 Recommended actions to better achieve this strategy*

Creating a successful circular strategy to build competitive advantages and support sustainability is challenging due to the various leakage points such as geographical dispersion of materials and products, materials complexity and proliferation and the lock-in trap[120]. Following are recommended actions to enable this strategy (demanding more thorough analysis, which is out of scope of this thesis):

1. Technological innovation and scientific research in better material separation and recovery
2. Better material standardization
3. Improve interchangeability of components
4. Set up of global reverse networks for products and components
5. Streamline pure material flows and create efficient secondary markets
6. Establish the concept in scale to better understand arbitrage opportunities
7. Educate consumers on recycling and returns
8. Promote service-over-ownership model through consumer awareness to mainstream the sharing economy
9. Enhance collaboration and knowledge sharing with stakeholders
10. Systemic change through better leadership and advocacy
11. Work on building capabilities and not only improvements – avoid the capability trap[121]

Ultimately, Renault's strategy aims to achieve increased market share with same or even reduced total consumption – decoupling growth and resource exhaustion. With innovations such as 3D printing of

[120] Towards the Circular Economy: Accelerating the scale-up across global supply chains, World Economic Forum, January 2014, pg. 37
[121] Stumbling towards Sustainability: Why organizational learning and radical innovation are necessary to build a more sustainable world—but not sufficient, John Sterman, pg. 9

parts and bio-based regenerative materials[122], we can certainly see a future for Renault in this business strategy for sustainability and for circular economies (particularly the Hybrid model) in mainstream management practice.

### 3.1.2 Case study 2 – Tesla's Access circular supply chain model

#### *3.1.2.1 Background*

Tesla was founded as early as 2003 by visionary entrepreneur Elon Musk whose mission is to solve environmental, social and economic challenges. Its strategy is to disrupt and question the fossil fuel dominant automobile sector altogether by heavily spending in research and development for electric vehicles together with the required infrastructure. With a driving range of 200 miles and recharge time of only 20 minutes, their capital expenses in research and development seems to pay off as early adopters of electric vehicles have shown considerable interest. Moreover, Tesla has adopted the Access model where electric batteries are leased instead of sold with the car. Returned batteries are refurbished or disassembled and recycled.

For the purpose of this case analysis, we study the Access based cradle-to-cradle initiative to evaluate how Tesla has adopted this strategy and how it has impacted sustainability and vice versa. We will see that Tesla is effectively contributing to sustainability and competitiveness by controlling three balancing loops; however, there are certain important conditions to be met and limitations to be handled through recommended actions to better achieve this strategy. We will also be able to demonstrate how product design variables are linked in an Access model.

[122] Towards the Circular Economy: Accelerating the scale-up across global supply chains, World Economic Forum, January 2014, pg. 46

### *3.1.2.2 Tesla's Access model*

Tesla's Access model enables their customers to lease batteries rather than purchase it. By using this Component Strategy, Tesla is able to reuse the battery and/or materials that the battery is made of. Rate of Innovation is high for Tesla as it is looking to disrupt the market. However, this increases the risk of batteries becoming obsolete as a new vehicle design is produced. This risk is mitigated through a battery and chassis design that is adaptable[123]. This allows Tesla to use batteries from an older vehicle on a newer vehicle without degrading performance. Tesla also aims to have the most durable batteries such that component life is long and several cycles of reuse can be implemented. Further, Tesla works hard on Product Attachment/Trust strategy by creating brand loyalty and differentiation. This forces customers of even older generation vehicles to go without replacing their vehicle for a longer time.

Tesla has a standardized product range (Level of Product Variety strategy) which again balances the high rate of innovation – newer design cars are built on the concept of older cars[124]. The Volume Produced strategy is handled by keeping production of vehicles and batteries low. This enables more use of remanufactured/refurbished batteries. However, the loss of revenue from reduced volume is compensated by high margin product strategy. This high price point is still favorable for customers due to the use of High performance strategy (Hazardous Material use vs. performance) – Tesla claims to use the minimum hazardous material and yet produce the best performance in terms of distance covered by a single battery recharge and general overall electric vehicle handling[125]. This is only enabled due to the intense focus on Tesla's research and development practice and core competency development in electric battery technology.

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[123] Interview with consulting firm B's strategy team (Project Manager)
[124] Ibid.
[125] Ibid.

The Remanufacturing Time Horizon is kept low[126] through the Product characteristic – ease of component disassembly. Tesla builds its batteries in a way that the integral parts can be disassembled relatively quickly. This is enabled by the fact that Tesla puts its focus on Design for Reverse Logistics. Finally, by keeping a tight intellectual property right, it mitigates the risk of the benefit of ease of disassembly taken by third-party manufacturers, thus keeping a stronghold on their market share of electric battery reuse/remanufacture/refurbish/recycle sales. (Here 'high' and 'low' are estimations and demands more analysis and research based on industry averages).

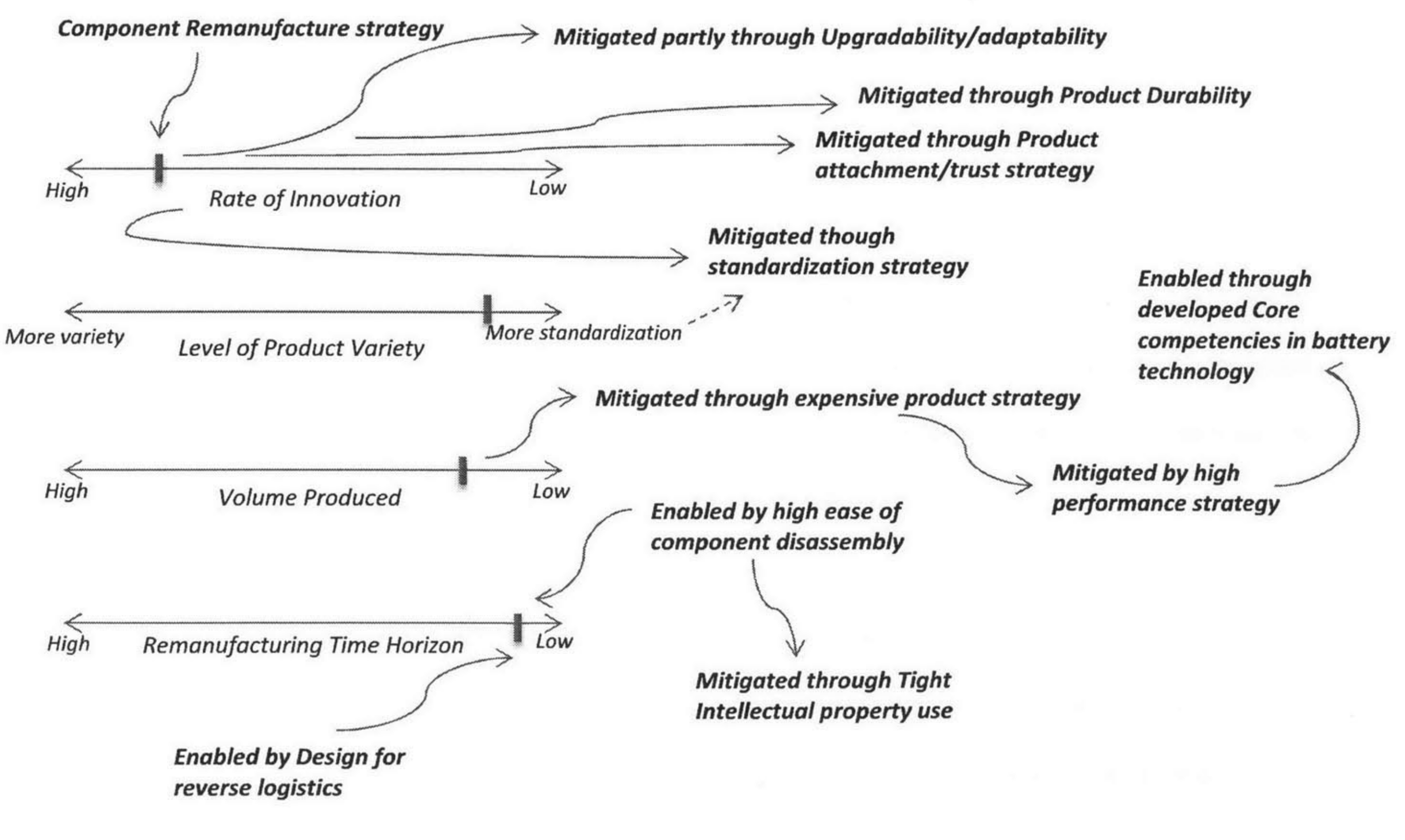


***Figure 3.5*** *Tesla's circular supply chain strategy*

126 Interview with consulting firm B's strategy team (Project Manager)

The following systems map (adapted from Prof. John Sterman's systems diagram) illustrates the areas where Tesla is impacting sustainability:-

1) Reduction in resource consumption through reuse/remanufacture/refurbish of leased batteries (shared use service model)as an alternative energy use
2) Reduction in impact through innovation in electric vehicle and battery technology

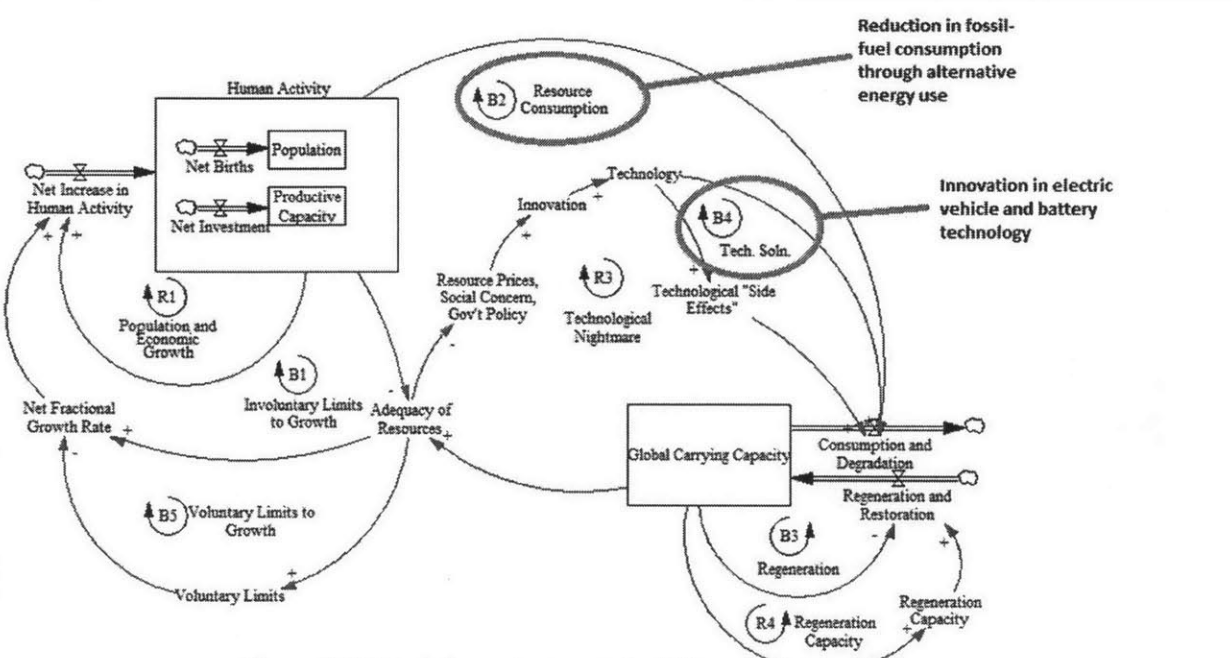


***Figure 3.6*** *Telsa's impact on sustainability*

### *3.1.2.3 Evaluation of Tesla's strategy*

#### *3.1.2.3.a On competitiveness*

Tesla is developing core competency in electric vehicles and batteries, thus segmenting the market. It also sells cars directly to customers changing the paradigm American model of car dealers, creating a brand differentiation. Tesla recognizes that a shift towards sustainable transportation adoption involves systemic change and hence has pitched their brand to be that leader in making that transition. For example, they have stepped out of the pack by offering 'Supercharge' stations for free. By installing 70+ such stations across the US they allow customers to drive from coast-to-coast. According to their reports, their European stations have provided energy to drive for 11 million kilometers, replacing 1.13 million liters of gasoline or 2.67 tons of CO2[127].

Further, their 'Gigafactory' saves cost of batteries and allows them to be the knowledge leader in electric vehicle and battery innovation. Based on their reports, after years of losses, Tesla has shown profits in 2013 with its stocks increasing in value by 14%, showing that their strategy is paying off. This seems to be a classic high CAPEX, worse-now-better-later strategy. With this they have established strong stakeholder relationships and have been able to influence electric vehicle regulations. Moreover, incentives from the state of California of $219 million in 2013 coupled with an innovative emission credit selling strategy have enabled them to turn profitable – a Zero Emission Vehicle regulation is a requirement that places large auto makers to make and sell zero emission vehicles. The California Air Resources Board requires automakers to show a certain credits per year. Tesla sells credits to its competitors, making additional revenue and adding cost buckets for its competitors to level the playing field as comparable electric cars still carry a higher price tag than gasoline or diesel vehicles[128].

#### *3.1.2.3.b On sustainability*

Tesla's primary focus with sustainability is to create and market sustainable transportation vehicles in the form of electric cars to reduce impact of carbon emissions, and to use the Access model to reuse resources. It has invested heavily in advancing innovation in the technology including lithium-ion battery packs which can store large amounts of energy in a small space, allowing flexibility in car designs and mitigating conflicts with space, safety and performance. This technology claims to eliminate usage of

[127] "Tesla Expands Supercharger Network in Europe, Press Releases, Tesla Motors", 2014
[128] Tesla's secret to success? Selling emissions credits, Marketplace Sustainability, David Weinberg, May 8, 2013, http://www.marketplace.org/topics/sustainability/teslas-secret-success-selling-emissions-credits

fossil fuels for passenger vehicles which represent approximately 60% of total $CO_2$ emissions from transportation in the US[129]. Additionally, Tesla has succeeded in influencing emission regulations – the state of California has created a target of reducing 38 million metric tons of $CO_2$ by 2020[130].

A rebound effect can be created by refurbishing batteries using fossil fuel based energy, essentially shifting the impact on environment from one problem to another. To counter this, Tesla partners with energy companies, such as SolarCity, to use solar and wind power in some charging station[131]. In 2014 Tesla announced the construction of a 'Gigafactory' to manufacturer, charge and deploy battery packs, using solar and wind energy sources, to be in full capacity by 2020[132]. This plant will recover battery cells and recycle and reuse them[133], allowing reduction of $CO_2$ emissions of 500,000 cars per year and reduce cost of electric batteries by at least 30%[134].

#### *3.1.2.4 Conditions for Tesla's circular strategy*

1. Preference of consumers for sustainable vehicles
2. Communication of credible information about product and process to stakeholders
3. Defense against imitation

#### *3.1.2.5 Recommended actions to better achieve this strategy*

Following are recommended actions to enable this strategy (demanding more thorough analysis that is out of scope of the current thesis):

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[129] "Car Emissions and Global Warming | Union of Concerned Scientists," accessed March 4, 2014, http://www.ucsusa.org/clean_vehicles/why-clean-cars/global-warming/
[130] California Environmental Protection Agency, Air Resources Board, Assembly Bill 32, http://www.arb.ca.gov/cc/ab32/ab32.htm
[131] Tesla unveils free, solar-powered charging for Model S Owners, Sustainable Brands, October 1, 2012, Bart King, http://www.sustainablebrands.com/news_and_views/articles/tesla-unveils-free-solar-powered-charging-model-s-owners
[132] Ibid.
[133] "Tesla's Closed Loop Battery Recycling Program | Blog | Tesla Motors," accessed March 1, 2014, http://www.teslamotors.com/blog/teslas-closed-loop-battery-recycling-program
[134] Ibid.

1. Promote service model through consumer awareness to mainstream the sharing economy
2. Increase early adoption rate through incentives, complementary services, partnerships, etc.
3. Control imitation from Renault's and other electric cars through increased brand differentiation
4. Establish the concept in scale to better understand arbitrage opportunities

### 3.1.2 Summary of other cases

We used more case studies (Appendix A) to analyze the variables and strategies of product design that each company has at some point implemented. All companies (N=18) that used the hybrid model successfully (defined as at least top 3 KPIs achieved), also identified the following variables as most important (also, note that this is consistent with Renault's hybrid model):

**Product Development Strategies –** Medium to Low rate of innovation and low time horizon considered for remanufacturing.

**Design Strategies** – Upgradability/adaptability, standardization or compatibility.

**Other Decision Variables –** Product architecture to counter wear and tear, large focus on design for reverse logistics

**Product Characteristics** – Design for Inexpensive and High Volume Product Retrieval

Similarly, all companies that used the access model successfully (defined as at least top 3 KPIs achieved), also identified the following variables as most important (also, note that this is consistent with Tesla's access model):

**Product Development Strategies –** Low to Medium rate of innovation and low time horizon considered for remanufacturing.

**Design Strategies –** Product durability, Disassembly/reassembly

**Other Decision Variables** – Design for reverse logistics, High performance design

**Product Characteristics –** Ease of component disassembly

While there might not be a direct causal relationship between the implementation of these variables and the success of the Hybrid and Access model in these cases, it is still worth noting the commonalities to demonstrate how product design can counter challenges of circular supply chain as mentioned in Chapter 1, and to provide a basis for further research work.

## 3.2 Criteria for product design to be an enabler for circular supply chains

We have now discussed the emergence, need and challenges of circular supply chains (Chapter 1). We then identified strategies and variables around product design that can act as enablers to implement circular supply chain concepts (Chapter 2). Also, we were able to demonstrate linkages between these variables and strategies to show how companies deriving competitive advantages through circular supply chain models (Chapter 3).

Following these steps, we now identify five criteria to allow product design to be an enabler for circular supply chains.

### 3.2.1 Government Support

Government will need to provide impetus to the adoption of circular supply chains through support for innovation, setting conditions for investment, encouraging business-to-business and business-to-university linkages[135], and incentives. The largest effect will be in reducing the cost of transitioning away from the lock-in with linear models. Some ways in which the government can intervene are:

[135] A Global Redesign? Shaping the Circular Economy, briefing paper, Felix Preston, Energy, Environment and Resource Governance, March 2012, pg. 17

| | |
|---|---|
| Fiscal measures | Pricing in the externalities associated with resources and encouragement of minimal resource use, waste and pollution.<br>Incentives for owners to put materials back into circulation – e.g. land-value taxes, value-extracted taxes and 'recovery rewards'.[a]<br>Removal of distorting subsidies on resources, energy and land. |
| End-of-life regulations | These are already applied in countries including the EU, Japan and South Korea, especially for consumer electronics, electrical equipment and vehicles. The focus should be on rates of remanufacturing and reuse.[b]<br>Just as important will be the removal of any unnecessary regulatory obstacles to the use of 'waste', remanufacturing and new business models.[c] |
| 'Top runner' standards | Used in Japan since the 1970s and now proposed for China, the 'top runner' policy sets minimum average energy performance standards for different product categories that tighten over time, encouraging innovation by manufacturers and removing inefficient goods from the market. For a CE, this approach could be broadened across other resources and adapted to ensure that the reuse and remanufacturing of products are incentivized. |
| Public procurement | Obligations on public-sector agencies and government departments to purchase resource-efficient and cradle-to-cradle products. In many countries this is a powerful lever for creating markets for more sustainable goods and encouraging innovation. |
| Public support for innovation | Policy is crucial in setting the framework to encourage private-sector investments in innovation, for example in new materials or supply-chain resource tracking. |
| Addressing legal frameworks | Review of the legal implications of company-to-company cooperation – e.g. anti-trust frameworks and data protection and security. |

a A reward scheme was proposed by the Green Alliance. See Hislop, H. and Hill, J. (2011), *Reinventing the Wheel: A Circular Economy for Resource Security* (Green Alliance).

b Examples include the EU's Waste Electrical and Electronic Equipment Directive and End-of-Life Vehicles Directive, Japan's Home Appliance Recycling Law and End-of-Life Vehicles Recycling Law, and South Korea's 2007 Act for Resource Recycling of Electrical and Electronic Equipment and Vehicles.

c According to the European Commission (2011), 'a major policy issue is the need for legal clarity for defining when reprocessed waste can be reclassified as a product': 'Communication: Tackling the Challenges in Commodity Markets and on Raw Materials'.

*(Source: A Global Redesign? Shaping the Circular Economy, briefing paper, Felix Preston, Energy, Environment and Resource Governance, March 2012)*

### 3.2.2 Information sharing

Even though there are several success stories of circular supply chains, smaller businesses need guidance in recovery, reuse and remanufacture[136]. With explanation of benefits of circular concepts and encouragement of dialogue between companies to share their learning curves, there is scope of mitigating the lock-in problem. Only when the entire value chain – suppliers, manufacturers, wholesalers, retailers, customers, recycle companies, certification authorities and government agencies act together will we find greater incentive for companies to make that transition away from linear

[136] A Global Redesign? Shaping the Circular Economy, briefing paper, Felix Preston, Energy, Environment and Resource Governance, March 2012, pg. 16

supply chains. Cross-sectoral hubs and networks are of much need where multiple sectors can talk to each other as almost every circular supply chain involves multiple sectors. This would allow designers to use Integrated Design Process concepts and enable them to be more confident of their design strategies.

### 3.2.3 Standardization

Currently, there are no so-called 'best practices' to design for implementing circular supply chains. According to my interviews, most designers use a trial and error method to get it right. Systems thinking has allowed them to push boundaries of design to incorporate holistic solutions for the entire value chain. However, the cost of conducting such an analysis has deterred many companies from moving forward with implementing circular supply chains even if they can find a business case for it. Standardization of circular standards, technology use and metrics of performance measurement can reduce bottlenecks and encourage economies of scale[137]. Further formation of industry-level standards bodies can bring laggards and accelerate diffusion[138]. Felix Preston (2012) builds this concept – entrants will supply intellectual property for mutual use available for all members within agreed boundaries. They will pay royalties into a common pool[139]. This will allow more minimizing the cost of switching to circular supply chains, enabling a network effect.

### 3.2.4 Certification system

Cradle to Cradle Products Innovation Institute has already built a framework for C2C certification and several companies have adopted it. A stable certification program will allow designers to follow guidelines and customers to recognize products that are more sustainable. This awareness will in turn

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[137] A Global Redesign? Shaping the Circular Economy, briefing paper, Felix Preston, Energy, Environment and Resource Governance, March 2012, pg. 17

[138] Lee, B. et al. (2009), Who Owns Our Low Carbon Technology? (London: Chatham House), pg. 61

[139] A Global Redesign? Shaping the Circular Economy, briefing paper, Felix Preston, Energy, Environment and Resource Governance, March 2012, pg. 17

encourage companies to build a business case for circular concepts. Further research in this area regarding the typology of voluntary programs and certification systems based on Matthew Potoski and Aseem Prakash's work on Voluntary Programs, A Club Theory Perspective, 2009; and on Benjamin Cashore, Graeme Auld and Deanna Newson's work on Governing Through Markets, 2004, will allow us build a construct for an efficient circular supply chain certification system. We look forward to more research in this area.

### 3.2.5 Credible measurement mechanisms

Current performance metrics and benchmarks capture incremental resource efficiency improvements. For large-scale adoption of circular supply chains, companies need metrics that can capture transformative actions such as waste reduction through design and environment impact minimization through sustainable material use. This coupled with a process for collaboration to agree with common metrics across companies and countries is highly important for large-scale adoption for common measurement mechanisms[140].

[140] Pintér, L. (2006), International Experience in Establishing Indicators for the Circular Economy and Considerations for China: Report for the Environment and Social Development Sector Unit, East Asia and Pacific Region (Washington, DC: World Bank), www.iisd.org/pdf/2006/measure_circular_economy_china.pdf

## Conclusion

In this research we were able to analyze the impact of circular supply chains on organization's strategy and operations. We started by providing a background of the linear supply chain model and then setting the context for the emergence of industrial ecology and circular supply chains. We also illustrated the impact of circular supply chains and the need to make the transition, along with its limitations. Following that, we identified the key variables, strategies and business conditions that surround product design for circular supply chains.

We then tested these variables and strategies using two case studies and several live examples to demonstrate the linkages that exist between them in the case of two product life cycle models. Thos helped us to draw out some of the most important linkages as considered and implemented by various organizations. We used our analysis to recommend five key criteria for effective product design to enable circular supply chains. Even though they provide a good grounding to counter the challenges of circular supply chains based on our interviews, case studies, and literature review, further research would be required to determine the potential path towards implementing each of them.

Although implementation of circular supply chains for business competitiveness and sustainability is challenging, this paper has shown that there has been significant movement towards it. We hope that this research along with the publications used for our findings provides a good basis for further movement within the field of circular supply chains for sustainability.

## Appendix A

Following is a summary of other companies that have implemented circular supply chain concepts (and have also certified themselves using the cradle-to-cradle certification by Cradle to Cradle Products Innovation Institute)[141]:

| Company | Product description | Material Health | Material Reutilization | Energy | Water | Social Fairness | Product |
|---|---|---|---|---|---|---|---|
| Accoya | acetylated wood | | Product contains only natural, compostable elements; produced from rapidly renewable softwoods; wood is sourced from sustainably managed forests; 100% biodegradable | | | | More dimensionally stable than any other wood, enabling less replacement and maintenance while retaining strength, increasing hardness, increasing thermal insulation properties, and enhancing carbon sequestration. |

[141] Source: Compiled from Cradle to Cradle Products Innovation Institute

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| AGC Glass Europe | Float glass, soft coatings, main range of decorative glass | | Products contain an average of 30% recycled glass, reducing use of non-renewable resources by 1.15 million tons per year; since 2012, AGC has "been focusing on the possibilities for recovery and recycling of windows from building renovation projects as a source of raw materials."; AGC "also actively seek[s] alternative routes for glass waste that we cannot recycle in [their] own products." | Recycled content reduces $CO_2$ emissions by around 300,000 tons | | | |
| Alcoa | Aluminum bottle, primary aluminum, lithographic sheet, wheel products, can sheets, etc. | | 75% of the primary aluminum produced since 1888 is still in use today. | | | | |
| Royal Auping | Essential Bed, mattresses, meshbases | | The Essential bed contains more than 50% reused or recyclable materials; | | | | 2012: Most reliable bed brand in the Netherlands |
| Aveda | Seven beauty products and their packaging | | | 100% wind power | | Aveda's annual Earth Month campaign has raised more than $31 million to support environmental | |

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| | | | | | | project since 1999, including a community water system in a region near their supplier's farms |
| Be Green | Packaging Materials | Produced from annually renewable tree-free plant fibers | Fully compostable, general waste is reused | | Water is recycled | |
| Bella-Dura | Textile | Manufacturing process produces no harmful industrial water or byproducts | Only textile on the market (synthetic or natural) that begins as a by-product of post-industrial waste and end as a 100% recyclable material; over 90% of ancillary production waste is recycled, including 100% of cardboard and loom selvage waste | Being 100% solution dyed substantially conserves on energy consumption during manufacture | Being 100% solution dyed substantially conserves water consumption during manufacture | |
| Constructio n Specialties | Building Care (5? Certified products) | First PVC-free product (Acrovyn 3000) in 2004, since then has modified its formula to contain no persistent bioaccumulative toxins, no bisphenol A, and no halogenated fire-retardants. | C/S recycles up to 75% of its facilities' total solid waste, also allows customers to recycle C/S products, launched the first building products recycling locator | C/S has reforested 17 unused acres in an effort to improve carbon sequestration. | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| Cosentino | Upcycled Countertops | | Composed of 75% post-industrial and post-consumer recycled raw materials, keeping nearly 30,000 tons of new material from having to be mined | | | | |
| DA.AI | Gray Eco Blanket | | Each is made from 63 recycled soft drink PET bottles, 100% post-consumer recycled polyester yarn; 31.56 million bottles diverted from waste streams | Recycled feedstock for each blanket reduces 4 kg $CO_2$ emissions and 1023 milliliters of oil. | Recycled feedstock for each blanket reduces need for 170 liters of water; added color chips during spinning (instead of traditional piece-dyed processes) significantly reduces water consumption | | |
| Decade Products | Plastic pallet | Contains no harmful chemicals or additives in the process | Made from 100% post-industrial recycled materials; 100% recyclable with buy-back incentive that provides an incentive toward the purchase of a new pallet. | | | Support various program such as Welfare to Career, Anti-Racism Awareness, and Re-Entry Employment Resource Centers. | Pallets designed to last over 10 years; |

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| Designtex | Textile Climatex Upholstery | Natural fibers wool and ramie, only the 38 chemicals and dyes Michael Braungart deemed safe for humans and the environment | | | Water flowing out of the factory for this process is cleaner than the inflowing water. | |
| Desso | Flooring | Up to 97% of the total materials in EcoBase backing are positively defined. | Company launched a TakeBackTM program for recycling into new carpet products or other recycling initiatives by revolutionary separation technique Refinity® which separates yarn and other fibers from the backing. The yarn is purified and returned to the yarn manufacturer for new yarn production. | | | AirMaster carpet is eight times more effective than hard floors at retaining the fine dust particles that can cause damage to human health; 90% of Desso's carpet tiles in the commercial business division were certified as of 2012. |
| DOW | Insulation | Starting in 2009, STYROFOAM Brand insulation production converted to zero ozone-depleting, no-VOC foaming agent, phased out hydrochlorofluurocarbon 142b; Invented falme retardant that is a non-PBT | | Innovations in the foaming agent used in production of STYROFOAM™ Brand insulation has cut U.S. process greenhouse gas emissions | | 2012 Thomson Reuters Top 100 Global Innovators list |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | (persistent, bioaccumulative, toxic) substance. | | in half; DOW has committed to limiting GHG emissions to the level that DOW experienced in 2006 while still growing the company. | | | |
| ECOVER | Professional Cleaning Products | The most dangerous particles were found in the packaging, leading to the transition from colored to transparent caps. They intend to investigate the label ink in the future. | Most products are composed of 95%-99% renewable ingredients; Packaging from Plantastic Polyethylene is 100% renewable, reusable and recyclable. | Already uses 100% renewable energy, and are now looking into biogas. | | All suppliers are screened for social fairness and encouraged to innovate as well. Additionally they are involved in many local community building activities. | |
| emco Bau | Entrance mat | | Fully recyclable components from the yarn to the aluminum profile, leaving no residues behind; at the end of its life, the mat can be returned to emco Bau's Lingen-based company for separation into components | | | | First fully recyclable entrance mat in Europe |

| | | | | |
|---|---|---|---|---|
| gDiapers | disposable diaper inserts | Diapers contain no polypropylene or polyethylene; disposable inserts are 75% cellulose -based | Wet disposable inserts will break down in home composts in 3 months; gDiapers operates with a nearly 100% recycle rate. | gDiapers' commitment to Cradle-to-Cradle brought their disposable insert manufacturer to switch to 100% renewable energy |
| Gessner AG | Climatex upholstery fabrics | | Developed a decomposable textile hybrid that joins different recyclable fiber systems in the fabric using a textile lock. | |
| gugler* | Printing products | gugler* has selected components and developed inks to be completely recyclable | Sludge from de-inking is completely safe for the biological cycle; C2C products are completely compostable and if burnt, ash can be used as compost as well. | |

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|---|---|---|---|---|---|
| O'right | Hair care -Goji Berry Volumizing Shampoo | "Tree in a Bottle" made of 100% biodegradable material with embedded acacia seeds; eco-cartons are made of 80% recycled paper | Manufacturing plant reutilizes rainwater for irrigation and reclaims water from the purification process for daily cleaning uses, restroom water and a landscaping waterfall. | Supports ORBIS Int'l for saving sight of children with vision problems; Assoc. of Pingtung Indigenous Culture and education to rebuild a joyful learning environment for children in typhoon-stricken regions; Eden Social Welfare Foundation to help developmental delayed children catch up to their age; ELIV International Service Assoc. to create a green. sustainable orphanage to help Cambodian | 100% Made in Taiwan |

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|---|---|---|---|
| | | | children grow up healthy |
| HermanMiller | Office Products | 92% reduction in the total operational footprint (solid and hazardous waste, energy, water, and air) from baseline of 1994, even amid significant growth | |

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|---|---|---|---|---|---|---|---|
| IceStone | Countertops | Design to eliminate problematic pigments from the product recipe took about three months and create similar hue; ingredients are 100% recycled glass, portland cement, and non-toxic pigments; | | | A water recycling system has been added to the facility, saving several million gallons of fresh water per year. | Employees collectively own 10% of the company, women represent 60% of the top positions at the company | |
| Interwand | Modular Wall Systems | Interwand has phased out PVC, a problematic mineral wool and a powdercoating; | Company is working optimizing the wall system as a service product with a take back system | Implementation of solar energy has begun at a subsidiary in Germany, with intent to include it at factories in the Netherlands as well; they are also considering wind power | | | |
| Jules Clarysse NV | Towel | FairTrade, GOTS-certified Bio-cotton | | Residue heat from the generator heats the production facilities; | All waste-water is treated in a water purification installation | | |
| KE Fibertec | Fabric Ventilation Ducts | | | | | | "Since getting our product certified it has |

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|---|---|---|---|---|---|---|---|
| | | | | | | | been recognized by the architecture community as a superior product." |
| Las Vegas Rock | Meta-quartzite stone | Geological make-up of the stone requires no chemicals or fillers; 100% of byproducts are repurposed, even the finite materials; | 100% of the Las Vegas Rock by-product is repurposed | Quary operates on at least partial solar energy | All onsite water is reused and recycled | Uses company *Natural Resources* to transplant any native vegetation on ground to be excavated; also contribute to a fund for post-use transformation of the quarry. | the only C2C certified silver natural stone in the world |
| The Lighting Quotient | Architectural Luminaires | Uses a non-PVC wire specifically developed to be flexible enough for their application; phased out softer aluminum alloys for those with no lead content; | Product comes with details on the take-back process as well as disassembly instructions and links to local recycling centers. | Upgrading of central heating system in 2010 has reduced natural gas consumption by up to 40% (20% in winter); replacing facility lights with C2C LED lights reduced | Facility improvements led to water reductions of 11% (46 thousand gallons of water) in just one year (2009-2010) | | Product achieves up to 82% energy savings over traditional light sources. |

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| | | | | energy consumption by 4.6kW. | |
| MechoSystems | PVC-free Shadecloths | EcoVeil uses PO (thermoplastic olefin) extrusion over a polyolefin core yarn (replacing the polyester core yarn), replacing the PVC-coated polyester yarn; | Chemical optimization has led to opportunity for disassembly and return to industrial waste streams, and MechoSystems has committed to reuse or recycle all products sent back to the factory at the end of their lifecycle | | |
| Mermet | Fabrics | Greenscreen Revive is made of 100% PVC-free polyester; Cortina and Siena are both 100% polyester, PVC-free fabrics. | Each yard of Greenscreen Revive uses 11 post-consumer bottles; Cortina and Siena lines are both completely recyclable; approx. 90% of post-production materials are now recycled; Pepreve ® fibers are made from 100% recycled materials; Recycling program facilitates collection and repurposing of manufacturing scraps and post-consumer shades. | In comparison to virgin polyester, Repreve fibers reduce energy consumption by over 6% and GHG emissions by over 34%; manufacturing partners for Greenscreen Revive use 75% of thermal energy from methane gas | In comparison to virgin polyester, Repreve fibers reduce water consumption by nearly 50%. |

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| | | | | from a nearby landfill, the equivalent of 1 million gallons of oil. | | |
| Method | Cleaning Products | Products are optimized to biodegrade | Bottles contain 100% post-consumer recycled content; designed with plastic resins most widely accepted by curbside recycling programs; in 2012, Method launched bottles made from a blend of recovered ocean plastic and post-consumer recycled plastic | Purchase renewable energy credits; carbon reductions through incentives to suppliers that implement energy and water conservation strategies, leading to new projects like water recycling and solar powered forklifts | Several facilities use practical processes to eliminate effluent; one facility uses reverse osmosis water production to remove any chemicals in the water intake; biodegradable products minimize impacts to water treatment systems and water bodies; | Mission-explicit commitment to social impact as well as three community volunteering days each year. |

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| Micro-Pak LTD. | Mold-prevention stickers | Material testing revealed the opportunity to replace certain pigments, and testing is underway. | Completely recyclable at the end of its life | Because the product is 5-10 times lighter than typical silica gel packets, use-phase energy savings would be significant if applied to the shipping industry. | | | Sticker is 5-10 times lighter than a corresponding silica gel packet; |
| Minlan | Yarn | Non-toxic polypropelene base | Polypropelene is very easy to recycle; all production remnants are used to produce gloves, socks, and recycled apparel and accessories | Polypropelene is the lowest energy option due to a decrease in temperature during the whole process; process recovered heat and water reduces carbon emission | Polypropelene allows for no water pollution due to the solution dying process that colors during the extrusion process | | |

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| Mosa | Ceramic tiles | Designed for the technocycle, but safe for the biocycle; mainly containing clay and sand; | Wall tiles contain 22 or 25 percent of pre-consumer recycled materials; floor tiles contain 21% or 45% | 2007, Mosa switched entirely to hydropower generated electricity; hydropower and continuous improvements have resulted in 48% reduction of $CO_2$ emissions per tonne finished product in the past 10 years. | Closing of a cooling water cycle in the wall tile factory resulted in a 60% reduction of required ground water; aim is to vaporize or reuse all process water by 2020. | Working environment is one of the best in the European ceramic tile industry | Nearly 90% of all raw materials are sourced from controlled quarries in Holland, Germany and France, all within a 500 km radius from Maastricht |
| Playworld Systems | Playgrounds | 99.99% PVC-free, substituted with an automated, fluidized bed coating process using polyethylene powder; The company has eliminated neoprene from its belt bridges and identified a safer polyethylene coating for high-traffic parts. | Over 95% of product's materials are recyclable; | More than 20% of their corporate property is maintained as a natural area. | | Employee recycle from home program has helped divert more than 8 tons of materials from landfills since July 2012. | |

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| Puma | Apparel, footwear and accessories | research has led to pigment and dyestuff positive lists, including formulations which adhere to C2C regulations and which Puma is sharing with the textiles industry through the Zero Discharge of Hazardous Chemicals project | Partnership with I:CO for Bring Back bins for recycling; | | | | |
| Rendemint | Furniture | No toxins, no formaldehyde; extremely low off-gassing; the finish is approved for direct contact with food; the product is edible if your teeth can handle it; | All materials are agro-waste from rubber and coconut plantations; plantation wood comes from trees that are commercially unprofitable; runs a Pre-Returnable Procurement program which is a contract between manufacturers and end users where consumers agree to give back and suppliers are legally obliged to take back and reuse the products | The entire collection is carbon positive (produced without any fossil fuels); production facility runs on 100% geothermal energy | The process involves no water; | | |
| Replenish | Cleaning Products | 99% plant-derived, non-toxic, readily biodegradableand pH-neutral | | | | | Top pick of Good Housekeeping and Martha Stewart living; |
| REWORK | Apparel | 100% cotton dyed/treated with only approved | Natural dyes and treatments allow the cotton to be directly | | | | |

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| | | chemicals; | recycled into new yarn or composted | | | | |
| SABIC | Resin | | transforms PET into PBT (polybutylene terephthalate) containings 60% recycled content while performing nearly equivalent to virgin PBT | By displacing raw materials needed to manufacture raw PBT, VALOX iQ reduces energy by 61% and carbon footprint by 49%. | | | VALOX iQ has won awards form the Society of Automotive Engineers (2006), Society of Plastics Engineers (2007), Dutch Responsible Care Award (2009), China Plastics Technology Green Material Innovation Award (2012), and was named PLASTPOL' s Best Material Ingenuity (2012). |
| Sapa | Light Pole | Weight reduction of product by up to 20%. | Product contains minimum 95% recycled aluminum; a take-back system has been set up with partners to close the aluminum loop, when delivering new poles, Sapa retrieves the old poles in its entirety for complete return to the technical cycle; | Use 100% green energy in the final manufacturin g stage and uses 100% renewable energy via certificates. | | | |
| Schott | Glass | | | 20% of purchased | 90% of water demand is | | |

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| | | | | energy is renewable; | grey water |
| Shaw | Flooring | | Product is fully recyclable and Shaw pledges to collect and recycle this line for no additional cost; Post-consumer carpet recycling efforts encompass all types of carpet, reclaiming 100 million pounds of carpet | | |
| Steelcase | Office Products | | Loop 2 Loop is the first upholstery material to be produced from a closed loop system that recycles textile waste back into original-quality fiber and yarn. | | |
| Steinbeis | Paper | | 100% recovered raw materials, | Production achieves up to 72% savings in energy; production usage of 100% thermal energy and 50% electrical energy reduces carbon emissions up to 62%. | Production achieves up to 83% reduction in water usage |
| Synbra | Plastics-Foam | World's first poly-lactic acid-based | After use, the material can either be remolded to a | The bio-based product emits | |

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| | | product; continuing to improve and research substitutes for pigments | new product or be completely biodegraded | 70% less CO2 during production. | | |
| Tagawa Sangyo | Surfaces | Some finishes contain up to 50% (by weight) of fine aggregate made from reprocessed eggshells, which contain 95-97% calcium carbonate crystals; materials are all natural, including a natural binder, crushed limestone, plant fiber, soybean oil, seaweed extracts and Diatomaceous Earth (a material for humidity and VOC control). | | Non-baked Limix tiles use 90% less energy in production compared to normal baked ceramic tiles. | | Provide work opportunities to physically disabled people for their final manual assembly of Ecopo. |
| Tarkett | Flooring | First flooring company committed to offer products with VOC emission levels 2 to 20 times lower than the most stringent IAQ certification requirements. | The product is 100% recyclable and contains recycled materials, Internal volume of waste decreased 20%; their vinyl flooring contains recycled materials and is 100% recyclable; Post-Installation and post-consumer collection and recycling circuits are available in France, Sweeden, and the U.S; They also have a | 5% energy reduction from implementati on of biomass-based energy. | KPIs set during 2010-2012 required 5% annual water use reduction, but actual water consumption reduction was 24% from closed-loop water circuits set up in half | |

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| | | | recycling/collection/reuse system for artificial turf fields. | | of their production sites. | |
| Troldtekt | Acoustic Panels | PEFC-certified source wood, | Acoustic panel waste is composted, and the panels themselves can be composted after use. | 95% of the energy used to heat the factory's production area comes from combustion of production wood waste; the company buys certificates to cover 100% of the company's electrical consumption in 2013. | The Danish factory operates with no release of wastewater. | Troldtekt asks all suppliers to sign their Code of Conduct for following internationally recognized standards; The company also sponsors the Danish Association for the Hard of Hearing; |
| Van Houtum | Hygienic Paper, Soap and Dispensers | All-natural and biodegradable ingredients; the production method is completely free of harmful chemicals | Recovered paper can be used as a raw material; | | | |

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| Van Swaay | Sustainable Wood | Optimization of glue has resulted in decrease in required volume; | After use, healthy parts of the product can be used to create a new product. | | The company uses as much rain water or rain water drainage as possible before using drinking water in production; | | Intelligent design allows for 80% of the wooden retaining wall to be sustainable European Hardwood and the remaining 20%, the portion that actually experiences the most degradation, is a durable tropical hardwood. |
| Victor | Polyester Textiles | Industry's first antimony-free polyester, designed to be free of organohalogens and PBTs | Completely reusable in the technical cycle | 91% hydroelectric power | | | |
| Voigt & Schweitzer | Corrosion Protection Layers | Certified process and product | Planet ZINQ designed to enhance product sustainability through continuous recycling and material reutilization | Planet ZINQ designed to enhance product sustainability through ensuring resource and energy efficiency | | | |

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