Circular economy in the plastics industry – beyond the technological cycle

A white paper by

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Table of content

1 Introduction

Plastic pollution became and continues to be a vast human made environmental disaster. This white paper provides you with a perspective on and navigator for transforming the plastics industry into a more future proof and circular industry basing upon more broad circular economy standard works, that show the possibilities and necessities for implementing a circular business model, incl. e.g. the 7R's (rethink, reduce, re-use, repair, refurbish, recover, recycle).

This white paper starts with an overview on the plastics industry, its pollution and its primary sustainability path of closing the technological cycle. Then the first progress, status and concepts of the technological cycle solutions are highlighted. As a complement, this white paper looks at closing the biological cycle as a further option. It finds that, although a biological cycle sounds counter intuitive for plastics at first, there are relevant fields of application where this should be considered. In its last section, it is found that the transformation towards a more sustainable (circular) economy, including plastics, requires a lot of change management. To highlight this, a framework for assessing the best options for levers (from applications until materials across all phases of the value chain) are introduced by giving examples. On top of that, the positions of the industry, public hand as well as consumers are briefly outlined, underlining that this transformation is vast, needs leadership and prioritization.

In essence, this white paper shall be a contribution for understanding and prioritizing the circular transformation needed regarding plastics.

2 Navigation and overview of the plastics industry

2.1 Overview of the plastics industry and its pollution

The plastics industry is one of the largest industries in the world, producing the 3rd largest volume of built material. "Plastics have become so prevalent because of their range of desirable properties that include their light weight (low density), durability (they don't decompose easily), chemical resistance, relatively low cost, ease of production and processing, safety (they don't break to form physically dangerous fragments), hygiene (they are food safe and protect the products), low gas and liquid permeability (extends shelf life and prevents food wastage) and massive design freedom" (Bucknall, 2020).

"Approximately 80% of the estimated total 6.3 Bt of plastics ever produced have been discarded, representing not only a huge loss of valuable resources, but mismanaged waste is also the origin of an ever-increasing environmental disaster" (Bucknall, 2020). Since the 1950s the plastics production has increased 50-fold and is projected to continue to increase. The plastics industry is, with the exception of some applications, far away from being circular or carbon neutral. The major application (approximately 40% of global production) is packaging. Over 80% of all plastics used, are typically determined for short term single uses. Namely polyethylene, polypropylene (PP), polystyrene (PS and EPS), polyvinyl chloride (PVC) and polyethylene terephthalate (PET). These vast amounts base on fossil resources that took millions of years to build and eventually stay hundreds of years in the environment. (Plastics Europe, 2023; Bucknall, 2020)

In the oceans e.g., we arrived at approximately 70–180 Mt of plastics currently. These estimates indicate that, there is around half a year's current total plastics production in the marine environment. Notably, the thereby estimated socio-economic costs of plastic pollution (0.5-2.5 trillion USD) is exceeding the production costs of new plastics by far. As impressive as this number is, it is only representing a fraction of the socio-economic risks caused by plastic pollution through air, which are unsatisfactorily assessed and estimated to be 500 times higher than of oceanic pollution. Plastic pollution by air typically derives from micro-plastic and particulate matter, e.g. created by usage and production processes of merely uncontrollable, potentially hazardous materials over decades. In addition, the plastic industry has a large greenhouse gas emissions footprint and is contributing to climate change risks. After all, it is clear that we are looking at a typical market failure, at least regarding external environmental costs. (Beaumont et al., 2019, cited in Bucknall 2020; Catarino et al., 2018, cited in Bucknall 2020)

2.2 Circularity of the plastics industry

2.2.1 Circularity of the European plastics industry in a nutshell

In Europe the recycling rate increased to nearly 35%. However, 65% of [plastic waste] were still sent for energy recovery or to landfill." (Plastics Europe, 2023; European Commission, 2022) In essence, we see positive developments, mainly deriving from pushing the technological cycle (mainly mechanical recycling) for first, predestined applications (agriculture, construction and some segments of packaging (e.g. PET)), where recycling systems or incineration infrastructure were already largely setup by public organisations or private public partnerships.

In 2020 8.5% of plastic produced within Europe derived from recycled materials. Yet, it has to be questioned, if that progress (a total recycling quota of 22.8% in agriculture, 16.5% in construction and

6.6% in packaging) can be extrapolated for the remaining product applications and designs or whether they are including large parts of quick-gains, profiting of built infrastructure, and systems including societal habits. For relevant success, we need a systemic change and transition to a circular industry. Without a doubt, some plastics products, that fulfil a function, which renders them as special compounds and difficult to convert in a circular manner, will remain.

Looking at the products with high recycling rates, it becomes clear, that they base on large streams of similar (sorted) materials with local waste collection systems. Furthermore, regulations in the B2B sector have been a key element for high recycling rates of a limited number of plastics. If we take PET as an example, we can look at a high volume of similar goods (chemically, regarding its use and physically), existing infrastructure, technological and commercial feasibility, as well as a well-established labels, societal awareness and commitment. One of the initiatives to transport this success for further (consumer) products are databases, declaring likely contamination, materials and its recycling possibilities. Yet these initiatives will face, among other issues, difficulties with culture and trade secret strategies of various industrial players, who have a vested interest in limited transparency of their supply chains. In essence this conflict may arise mainly regarding material mixtures and processing technologies, but also in usage and maintenance phases. (Bucknall, 2020; European Commission, 2022; Plastics Europe, 2023)

2.2.2 The concept of technological and biological circularity of plastics

2.2.2.1 Closing the technological cycle

The main industrial options for closing the technological cycle of plastics are take-back systems allowing for mechanical or chemical recycling. Those take-back systems, usually base upon a common identification of parts or whole products (e.g. labels, invisible stamps, QR-codes, etc.).

Mechanical recycling means the physical material separation, washing and, if not reused in its original shape, shredding to granules and remolding them to new products. Mechanical recycling is today economical for a few applications, whereas chemical recycling is hardly economical and estimated to remain a minor solution approach, limited to approximately recycling a maximum of 10% of the total plastic products. Today the recycling quotas in principle derive from mechanical recycling coming with strong limitations, especially when looking at hardly separable composites. To address this, the European plastics manufacturers plan to invest 2.6 billion euros in chemical recycling by 2025 and 7.2 billion euros by 2030 respectively. Therefore the chemical recycling production capacity is estimated to increase to 1.2 million tonnes and 3.4 million tonnes respectively. As a consequence, for today's vast amounts of plastic products, which cannot be mechanically recycled, eco-design innovations are needed in order to improve the reusability, reparability, sortability, recyclability and overall sustainability of plastic products. (Plastics Europe, 2023).

"Chemical recycling is the process in which polymers are broken down into either their constituent monomers or other small organic compounds, that can be used as chemical feedstocks for repolymerization to new polymers or exploited in other chemical processes. […] One of the significant benefits for chemical recycling is the prospect of being able to remove additives, contaminants and toxic compounds out of the plastics, and therefore secure their quality and prevent them being sent for landfill or incineration" (Bucknall, 2020). Currently, chemical recycling is hardly industrialized and attracts a lot of effort by public as well as private research and development.

2.2.2.2 Closing the biological cycle

The main requirement for a biological cycle of plastics is their bio-degradability, allowing plastic to reintegrate into the natural environment. Today, the main options for getting closer to close the biological cycle of plastics are the industrial take-back systems, e.g. allowing for bio-gas production and industrial composting and product design supporting this.

Bio-degradability means, that the product breaks down, within an environmental friendly timeframe, into natural substances like water, carbon dioxide and biomass, without leaving behind harmful residues. Therefore, bio-degradable plastics make sense, where they likely end up in the environment. This is especially important for product applications that interact by design with nature (e.g. material abrasion or loss) and therefore contribute to micro-plastic or other plastic residues. Other reasons for bio-degradable plastics are to de-risk landfills and to power bio-gas powerplants. After all, the necessity for bio-degradability is driven by the local environment, situation and infrastructure at the point of use and end-of life.
Switching from conventional to bio-degradable products usually comes with application specific trade-offs for maintenance, material and product design. Yet, this is one of the most sought after area of product innovation and pricing power for more sustainable plastic solutions. (Bieringer, 2022)

Bio-degradability is especially relevant for products, that cause micro-plastics. Here the 10 most micro-plastic emitting applications are listed according to the Fraunhofer Institute (Bertling, Bertling, & Hamann, 2018, S. 10 f.):

1. Tires (abrasion)
2. Waste management and recycling processes (loss)
3. Bitumen (abrasion)
4. Lost granules (loss)
5. Outdoor sports (loss & abrasion)
6. Construction sites (abrasion)
7. Shoe soles (abrasion)
8. Packaging (loss)
9. Road marking (abrasion)
10. Textiles (abrasion)

Bio-degradability does today not imply biobased material. Biobased materials are renewable, biological growing resources. Using biobased, instead of fossil resources, does not make the material circular or more bio-degradable per se. Nevertheless, basing plastics on biological resources may contribute to lowering the ecological footprint and achieving to close the biological cycle. Here, one of the most critical points is the origin of these bio-resources, especially if they are competing with feedstock or leading to detrimental social or environmental effects, like hunger, water depletion or deforestation. For instance, this would be the case with sugar cane monocultures replacing tropical rainforest.
Ideally, biobased materials base on regenerative, not with feedstock competing, biological sources. Following a value cascade of resource use being; food first, feed second, material (e.g. plastics) third and finally energy production (e.g. bio-gas). For example, this is the case for food side streams, like peals and shells, that grow naturally as a necessary side product, but are not of nutritional value for humans or cattle.
Looking for the future-proof plastic industry, a shift from fossil based to renewable, (bio-)based resources is demanded. This means, that within the next decades, most plastics should be biobased and some, where their applications allow it, are going to be bio-degradable as well and are thereby closing the biological cycle.

2.3 Circular way forward for plastics

2.3.1 Circular options for business and policy leaders

For business leaders, after having defined a circular strategy for the overall business model, the following application score card, focussing on plastic parts, may help expert teams (e.g. with lean management, product design & material experts) to double down on the right plastic application phases first:

Circular plastics transformation scorecard (Source: Groupe Schweizer (2023) inspired by King & Locock (2022))

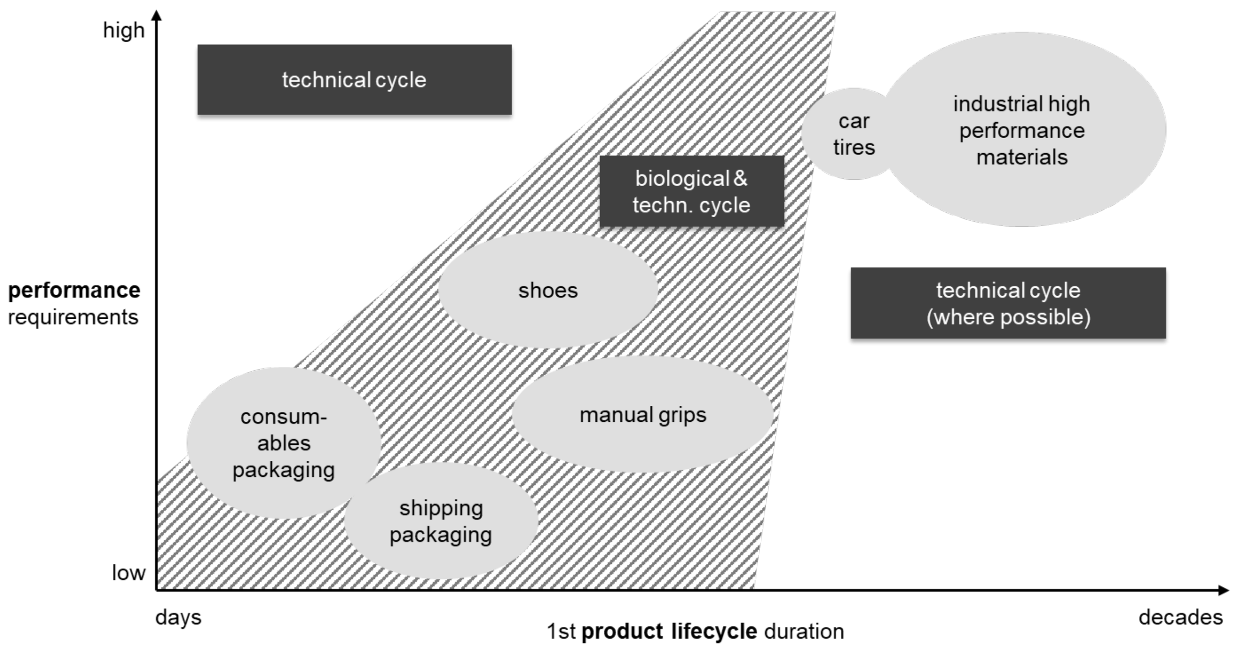
Transformation Tactics / Application	1 avoid plastic	...	5 usage (e.g. abrasion)	...	13 leakage / loss
Small kids toy	4		3		5
Car tire	1		5		2
Door handle	5		1		1

(Relevance: 1=very low; 5 = very high)

The above scorecard may look at the 13 phases of the value chain defined by King & Locock (2022). It shall allow a simple first identification and prioritization of the most relevant phases, in order to deep dive and subsequently define levers to transform (plastic) products more circular. The phases defined are:

1 avoid need, 2 feedstock/material selection, 3 product design, 4 manufacturing & remanufacturing, 5 consumption/use, 6 reuse, 7 repair, 8 collection, 9 sorting, 10 mechanical recycling, 11 advanced recycling, 12 waste to energy, 13 leakage/loss.

For industry leaders and policy makers, a first schematic navigator on the likely circular implementation options (technical or biological cycle) can be found below:



Regardless of the necessity to assess the right levers on a more detailed level for eventually transforming a product more circular, this graph illustrates a high-level indication. In its schematic version, it shows selected product category examples, according to the application specific

requirements of their designated function and lifecycle. This tool shall be a navigator and is neither precise nor complete.
The material selection, e.g. whether a bio-degradable or biobased plastic makes sense, depends on the individual product-market setting. Whenever bio-degradable materials are used, there is a logical conflict with longevity and some performance criteria.
In essence, choosing the right circular transformation option depends on the product and material design derived by application requirements (and regulatory requirements). Requirements may be durability, flexibility, heat resistance, UV resistance, environment at usage, environment at end of life, duration of use and an abundance more.

The example of a cucumber plastic packaging:
What are the most straight forward circular transformation options?

- Avoid packaging and risk the product quality and thereby avoidable waste
- Create reusable containers
- Create recyclable packaging
- Switch to biobased packaging with less impact on greenhouse gas emissions
- Switch to bio-degradable plastics (or other materials) for packaging that have a higher likelihood on landing in the environment (e.g. picknick sizes)
- Switch to home compostable packaging
- Incinerate and generate heat with the general waste collection
- Prioritize other product applications, if changes on other materials have higher net benefits

One might think of the best option to be switching to biobased and bio-degradable plastic as long as the industry and consumer cannot manage to utilize the produce within fewer days after harvest. However, a change in the supply chain and consumer behaviour might render the additional conservation through plastic unnecessary. Obviously, this possibility may also vary according to local availability, seasonality and societies' demand for produce that is not seasonally and locally available.
Here, we want to leave the answer to the above question at hand open. It serves as a demonstration for how important the local, systemic and individual assessment of different value chain phases are, in order to find the ideal approach – even for such a common form of plastic. Therefore, the ideal solution might vary per local situation or distribution channel and isn't necessarily the same for products of the same category (e.g. tomatoes vs. cucumbers).

On top of that, it has to be mentioned that there are other ways to look at plastic waste as a resource. E.g. as a source of energy (e.g. heat or bio-gas) for necessary energy intensive processes or nutrition (a variant of bio-degradability, applicable for very locally controllable end-of-life) for the environment. We take incineration here as a part of the technological cycle. Out for the pragmatic reason of energy demand for the next decades that will not be fossil free. Nevertheless, one should be aware, that incineration is theoretically not part of a circular economy, where materials should be kept in the cycle as an ingredient for new products.

2.3.2 Leading individual behaviour for business, public and private actors

The transformation poses a chance for innovative companies, research communities and economies. Yet it comes with risks, especially associated whit the encompassing systemic change. As a major example, product development needs to include various parties of the supply chain in order to factor in the best application specific options for circularity. This can include foreseeing what the second life of a product can be across many different locations and situations. Moreover, this transformation

does not only include new supply. It encompasses adaptions of existing designs as well as physical products already in the market or even lost in the environment. Therefore, the challenge encompasses value chain phases such as product and material development, reengineering, sorting and take-back systems as well as waste collection. The required multi-stakeholder approach can be overwhelming for most actors, especially for organisations, which are used to functional management, one-off sales and design freezes instead of physical product updating processes.
Here, industrial goods come generally with an advantage, as they are within structured and documented environments and often including product updates, compared to consumer goods being destined to be one-off sales to individuals in individual circumstances. Therefore circular quick-wins are likely to be found in re-cycling of production, product and waste of industrial or commercial products and sites.
Looking at the vast challenge, the industry opts for an incremental approach regarding product design and material innovation. Innovation cycles become shorter and risk management for plastics will be adapted reflecting the necessary transformation. Or in other words: The material development and selection cannot be based upon a decade long design freeze or broadband solutions, like it was often the case for many non-high-performance applications in the past. (Bieringer, 2022; Plastics Europe, 2023)

Of course, politics, regulations and public organisations have an important role to play as well. They can set and enforce standards, set incentives and build infrastructure, e.g. for recycling or bio-gas power production. Legislation together with public organisations or private public partnerships can be a powerful setup, when demanding e.g. circular product design (e.g. right to repair for some durable goods) and at the same time foster infrastructure, education and incentives, e.g. for the value chain phases after initial use. Anyway, the force of regulators and the public sector will be necessary to fight externalities like health and environmental issues deriving from micro-plastics, the carbon footprint and political risks deriving from the dependence on fossil resources. (Bucknall, 2020; European Commission, 2022)

On the other side, a proactive public sector might be an excuse for the private sector. The private sector might be tempted to free-ride on the public efforts in building infrastructure, bearing most of the cost and taking the accountability for delays of the transformation of the plastic industry. In essence the private sector may retreat to incremental changes to the status quo, being rather a laggard than an accelerator of change and awaiting public funds for structural change, infrastructure as well as research. Therefore one could assume a slower and less radical transformation as long as the externalities are not accrued to the industry and its customers.
Whereas corporate customers demand more sustainable solutions reflecting their sustainability targets, the consumer behaviour and their accustomed mindset is rather strengthening the status quo. Among other factors, marketing, pricing and the willingness to pay respectively matters. "Plastic" is often associated to being cheap, albeit plastic composites are some of the highest performing and efficient materials. So, on the aspect of value perception, the general public and industry experts may differentiate considerably. Notably, the high-end composites valued by end-customers, are usually branded or named avoiding the word "plastic". After all, this different value perceptions primarily derive from the low cost base of fossil resources, the abundance of plastics as well as the highly efficient and effective material properties allowing to design, compose and form plastics on demand.

As a consequence of vested interests, the technological cycle is pushed by the industry as well as the public hand, resulting in less radical need for change with costs primarily covered by the public hand. This keeps price levels and socio-economic systems rather stable, respectively bound to fossil resource prices.
However, this does not align with societal trends to stop the decoupling of value streams from natural resources and their scarcity as well as the willingness to reduce the dependency of fossil

resources. In general, the (re-)coupling to our natural boundaries is more intuitively understood by people, when looking at a biological cycle instead of a technological one. The technological approach usually rendered material origin and destiny anonymous and did not lead to a large shift in consumer awareness and behaviour, like overconsumption. Adding to that, it may lead to an industry, which acts as if it’s seemingly unlimited in the amount of materials produced and cycled.
After all, building-up recycling schemes for a majority of plastics needs a lot of time and resources. Hence, it might be a critical success factor to be able to replace current plastics (e.g. granules) with more sustainable alternatives, while integrating into the existing infrastructure and value chain processes. This is how time, capital, power and knowhow barriers for change can be kept as small as possible. Yet, incremental changes may only solve the pollution problem partially and might waste a lot of time, when being accompanied with a defocussing of alternative solutions for traditional plastics.

In addition to environmental risks, health risks seem to be most pressing. In a complex environment, the regulator needs to be carefully selecting the incentives set. Besides duties, regulations and taxes, norms, like e.g. EN 13432 for bio-degradability, need to be very well tailored. Because those norms guide demand, development and supply. Thus, if they were crafted unsatisfactorily, they will lead to an undue market behaviour. In casu, EN 12432 is opt for a precision or revision, as it is merely defining degradability until particle sizes above 2mm of diameter. Regarding size, the norm and research is unsatisfactory on the topic, if smaller parts (<2mm) can be considered an advantage for all major risk dimensions and mitigation options, or how the ideal target for given materials and environments look like.

3 Summary

Plastic pollution has become a major environmental, social and economic problem. In order to address the challenge, mitigation and solution definitions need to look at the whole value chain and there is no one-size-fits-it-all solution.

The transition to a circular economy, i.e. a circular plastics industry, is one of the major and most promising global efforts besides demand avoidance. Yet, looking high-level at phases or major functions in the value chain is not enough. Levers for a more sustainable plastics industry are found on a more detailed level. Among others, resource origin, applications, market behaviour, legislation, production technology and product design need to be considered. (Bucknall, 2020; United Nations Environment Assembly of the United Nations Environment Programme, 2022)

Circular economy transition in plastics needs deep dives to understand the material applications in the different stages of the value chain. This means an understanding of the materials in their interaction with their environment and usage per phase, especially, but not limited, of the use and possible 2nd use phases. Only on an application and material specific level, the best option for closing the technical and/or biological cycle can be found. Whereas an application means the treatment of materials within and across the different phases of the value chain. As a consequence, product design e.g. needs to consider the products materials, production, use phase (incl. its interaction with the environment), maintenance (e.g. necessary lubrication of sealings or repairability) and end-of-use situation.

Clearly, this transformation towards a future proof (circular) economy needs multi-stakeholder management and systemic change. This requires bold leadership in the private as well as public sector. Supporting that, clear and multi-stakeholder aligned strategic priority, goals and a lot of effort, encompassing the global and local value chain, are needed (likely at least per product category, if not product). While the cultural and operational risks, path dependencies and backlashes have to be balanced with an ambitious vision, clear mission and implementation plans. Therefore, first optimizations need to be made attractive and visible for companies and teams performing them (e.g. by regulation and corporate incentives). Most likely, the B2B sector will show the quickest progress, as it has more sustainability reporting needs, structured setup and closer stakeholder alignment. This will guide the way out of broadband plastic solutions, which come with dependency on fossil fuels, environmental and health risks. After all, the need for change regarding plastics cannot be ignored when looking for a future proof socio-economic system.

Considering the broad change and the vast investments necessary, a strong socio-political and economical will needs to be established, e.g. preventing littering and unnecessary fossil fuel based plastics, establishing and enforcing international standards preventing and reversing the global race-to-the-bottom (competitive advantages through exploiting lowest regulatory standards) as well as fostering local collection, recycling and reuse schemes. (Bucknall, 2020; Ellen MacArthur Foundation, 2021; European Commission, 2022; Plastics Europe, 2023)

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