RETHINKING THE CIRCULAR ECONOMY FOR PLASTICS

How the transformation to circular value creation can succeed

Results and recommendations
of the VDI Round Table

Green Paper of the VDI Round Table

CONTENT

FOREWORD

The challenges of a circular economy are a strong motivation for engineers to search for new solutions. At the same time, these challenges often deeply interfere with established structures, processes and technologies. Changes are demanding and therefore most likely to be possible in a larger context and with joint strategies agreed by all participants in a value chain.

However, the goal of largely recycling our raw materials also means a paradigm shift in thinking: problems must be defined differently in some cases and approached with completely new solutions.For example, the previous focus on waste recovery is being replaced with a new approach: circular value creation. This means a profound transformation for all players.

At VDI, we have discussed this challenge with all the participating stakeholders in the cycle, taking plastics as an example, and initially concentrating on the overarching and systemic issues. After all, the transformation to a circular economy will only succeed if not only individual technical solutions, but the entire "system" is geared to the production and use of high-quality recyclates from the outset.

This paper is the result of a comprehensive dialogue process over about two years between experts from industry, science, NGOs and politics. The aim was to map the entire plastics cycle from the chemical industry, plastics processors and OEMs, via commerce and consumers, to recycling companies.

The different perspectives of the stakeholders from the various stages of the economic cycle were supplemented by the perspectives of the environmental and consumer organisations and representatives from the government sector. This particularly broad-based approach of the VDI Round Table was the key to a holistic understanding of the challenges of the transformation and to establishing an inclusive approach during the dialogue process.

The members of the VDI Round Table were (in alphabetical order):

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The VDI Office

Dr. Volker Brennecke – Dr. Bita Fesidis – Nadine Freimuth

The paper has been produced in many iterations with all members of the Round Table. The aim was not to produce a consensus version. Although the present "Green Paper" is supported by the participating persons, this does not mean full agreement with every single statement. More important to VDI was the multi-stakeholder perspective and the joint search for shared problem descriptions and solutions. The paper will initially be published as a "Green Paper" to open itself up to discussion. After a commentary phase on this paper, VDI will follow up with a consolidation process to create a "White Paper".

We would like to take this opportunity to thank all the members of the Round Table, as well as all the other discussion partners, for their openness and willingness to engage in discussion. At the beginning of the process, Dr. Peter Orth and Mr. Manfred Rink were particularly responsible for focusing the content, and Dr. Antje Grobe from Dialog Basis for moderating the process. In the further development and preparation of the paper, special thanks are due to Dr. Bita Fesidis and Ms. Nadine Freimuth from the VDI office.

We look forward to your feedback and hope that you find this paper inspiring.

Düsseldorf, December 2021

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EXECUTIVE SUMMARY

In order to build a circular economy, the way in which plastics are handled must be fundamentally changed. Global environmental problems, such as microplastics in the world's oceans and CO_2 emissions from the use of fossil raw materials and thermal recycling, make it clear that the current use of plastics exceeds the planetary boundary. Waste management instruments such as waste sorting and recycling are necessary, but not sufficient for a revolution towards a functioning circular economy. A paradigm shift is required in order to design a system that enables the complete recycling of plastics.

An essential prerequisite for this is a change in thinking in practice: beyond the many ambitious technical innovations, the focus must be on truly closing the cycles. It is crucial to use recycled raw materials (recyclates) and sustainable alternatives as far as possible, not only in individual product areas (e.g. PET bottles), but in the material flows of all polymers. In this way, plastic waste becomes a valuable source of raw materials for new products and, at the same time, a significant contribution to climate neutrality in plastics production could be achieved.

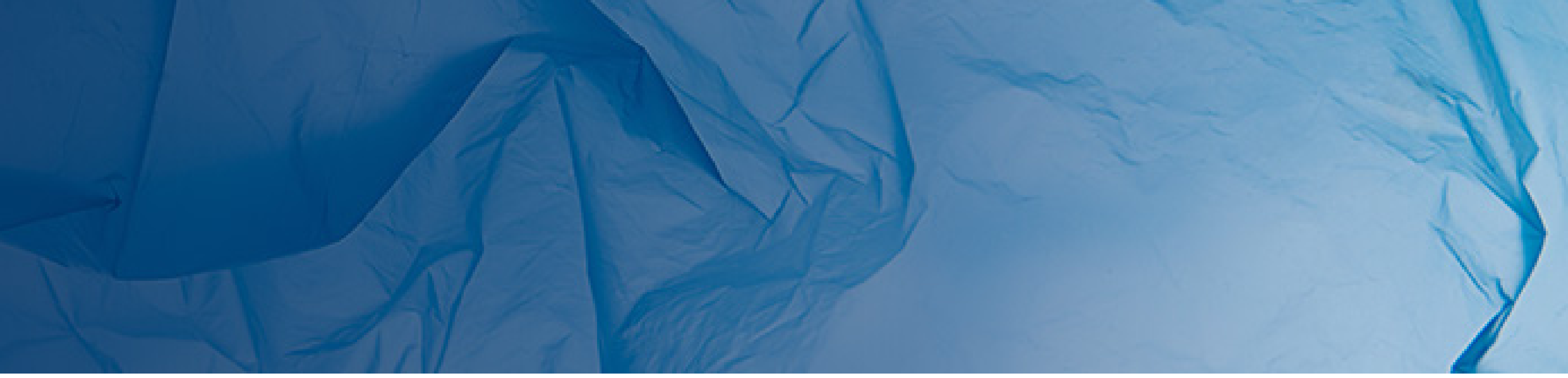
However, this requires a profound transformation of the overall system towards circular value creation. This transformation can only be achieved through joint efforts and cooperation. With this in mind, VDI brought together experts from all sub-sectors of the plastics cycle – the chemical industry, plastics processors, OEMs, commerce, consumers, waste disposal and recycling companies – around one table for the first time with the Round Table format. Representatives from politics, science and NGOs were also included. Only through such a perspective-rich dialogue was and is it possible to formulate holistic solution approaches for the transformation of the entire “system”.

With this systemic perspective, the Green Paper of the VDI Round Table describes, within four fields of action, which technical, economic and ecological opportunities and challenges this change entails. The recycling of plastics through the use of recyclates is always the focus. Recommendations for action for industry and politics are derived from this.

FIELD OF ACTION 1

(Re)organising the plastics industry for a circular economy

The paradigm shift towards circular value creation, the change in business models and the transformation of entire economic sectors require not only clear commitments from all stakeholders in the circular economy, but also a whole new level of cooperation. Instead of focusing exclusively on their own or neighbouring stages of value creation, raw material producers, product designers, commerce, consumers and waste management players will work together to develop optimised solutions. This requires intelligently organised cooperation, also by means of digital support.



FIELD OF ACTION 2

Making closing the loop the task of all stakeholders

This field of action focuses on the challenges faced by the actors at each stage of the cycle and on their potential contribution to closing the loop. It is becoming clear that each individual can and should optimise their own products and processes. With regard to the overall system, however, it is important that optimisations within a stage are carried out in the context of the overall system and in cooperation with other partners in the cycle, so that no contradictory developments and solutions arise. Such an analysis – developed over the course of extensive dialogue – is now available for the first time.

FIELD OF ACTION 3

Create regulatory incentives for a circular plastics economy

In view of the sometimes divergent interests, expectations, and conflicting goals of the various stakeholders, the large number of individual optimisations at each stage of the cycle will not be sufficient to initiate the necessary transformation in the field of plastics. Policymakers are therefore called upon to create a holistic framework that supports and accelerates this transformation through a combination of regulatory requirements and economic incentives. The criteria-based evaluation of various regulatory steering instruments by the VDI Round Table has shown that, due to their different mechanisms of action, an intelligent mix of instruments consisting of use quotas and market-based steering instruments will be necessary.

FIELD OF ACTION 4

Designing products for a circular economy

The shift towards a circular economy requires a holistic design approach in which recyclability is already considered in the product design, and all stages from plastics production to disposal and recycling are taken into account. Accordingly, this approach must also be reflected in norms, standards, education and training, and the political framework. This is because product design will only develop its full effect when recycling has become established as an ecological goal and economic principle among all players in the value chain.

INTRODUCTION

The need to decouple economic growth from raw material consumption

Global consumption of raw materials is increasing, and the trend is rising. Today, the use of natural resources already exceeds the earth's regenerative capacity. The dynamics of global population and economic growth will further exacerbate this problem. At the same time, the concentration of greenhouse gases in the Earth's atmosphere is increasing, as is other environmental pollution on land and in the sea. Many resources extracted from the ecosphere end up in the environment at the end of their lives as untreated, steadily growing quantities of waste. For example, the World Bank estimates that approximately 2 billion tons of waste are produced worldwide each year (see Kaza et al. 2018).

Alongside resource use and climate change, environmental waste is considered one of the most urgent global environmental problems. Challenges like these require new ways of thinking and new approaches to solving them, including in the economy. The prevailing linear economic model, in which consumption and production tend to conform to the short-term mindset of "make, use, dispose", is not compatible with responsible environmental use and does not do justice to other efforts to protect the environment and climate. From both an ecological and an economic point of view, the aim should therefore be to decouple economic growth from the consumption of raw materials and the associated negative environmental impacts, and to reduce resource consumption in absolute terms.

New logic of economic activity: thinking in cycles

In view of the urgency of our global problems, it quickly becomes clear that adapting and optimising the current way of doing business will not be enough to meet these challenges. Instead, a completely different way of doing business is needed. If we are to make responsible use of our limited resources, ecologically sensible recycling must therefore become the new leitmotif of economic and industrial activity. This includes waste reduction and avoidance to conserve resources, e.g., through multiple use of products and materials along the entire value chain.

Fundamental approach to a solution: circular value creation

The concept of the circular economy aims to optimise material and energy cycles and to recycle materials as far as this makes ecological sense. This should not only conserve resources and use them more efficiently, but also reduce greenhouse gas emissions. This requires an increase in the service life of products as well as the use of regenerative energies and the strict closing of the carbon cycle. In concrete terms, this means that materials should be collected after use, processed and fed back into production as raw materials. This means that the term "waste" could soon be a thing of the past, because the raw material for the next life cycle is created precisely when its life would normally be at an end. In order to achieve a functioning circular economy, we need more cooperation, more conscious consumption and new business models that require significantly fewer resources (e.g., remanufacturing or sharing).

Circular value creation does not per se mean a reduction in production or a renunciation of economic growth. Instead, the demand for raw materials is to be covered by increasing circularity (cf. Hiebel et al. 2017). Nevertheless, avoidance is of great importance, not only for ecological but also for economic reasons. This includes the absolute reduction of primary raw material use as well as the significant expansion of secondary raw material use in all sectors. This paper sees avoidance and reuse as central, but concentrates in the following on recycling and the closing of material cycles.

The idea of circular value creation is not new. In some areas, e.g., paper or glass, technical implementation in Germany is already well advanced. However, if we look at other material flows, the path to a circular economy is still long.

Special focus: plastics

Plastics are among the most relevant material flows that need to be fed into a circular value chain. Every year, around 370 million tonnes of plastics are produced worldwide, of which just under 60 million tonnes are produced within the European Union (see PlasticsEurope 2020, p. 16 f.). Of the 29 million tonnes of plastic waste collected in the EU (post-consumer), around two-thirds of the waste was still not recycled in 2018. Instead, around 43% of the waste was recovered for energy and a quarter was disposed of in landfills.

Worldwide, too many products still end up at the end of their life cycle in incineration or randomly strewn in the environment (littering). The increasing prevalence of plastics in the terrestrial and aquatic environment and the dissipation of microplastics into all areas of life have become a global challenge. The fossil raw materials (oil and gas) used in their manufacture are also problematic, as the emissions produced by their combustion pollute the atmosphere and thus have a negative impact on the climate. All this calls for immediate action by the industrial world in dealing with plastics. In order to achieve the goals of greenhouse gas neutrality and complete independence from fossil resources, a transformation of the entire plastics industry is ultimately required.

On the other hand, plastics have become indispensable in many areas of life, and rightly so: be it as food packaging, in the construction sector for profiles and pipes, as materials in the automotive industry or as fibres, paints, resins and adhesives. Plastics are also of vital importance in medical technology (syringes, tubes, gloves, etc.). Sometimes plastic is called the “material of the 21st century” because of its almost infinite variability and functionality. In addition to its versatile material properties, this carbon-based class of materials also boasts high availability and efficient processing methods. Many innovations across all industries are only possible thanks to modern high-performance plastics. It is therefore all the more important not to condemn the use of plastics per se, but to make the paradigm shift from linear to circular, resource-saving value creation wherever their use brings advantages.

Good conditions in Germany

Germany will not be able to solve the global plastics problem alone, because global problems require global solutions. On the other hand, the path to a circular economy is a complex task that requires innovative technical and economic solutions. And it is precisely here that Germany offers good conditions for establishing a model resource-saving circular economy that can provide an impetus for change within the EU and beyond. The German plastics industry is characterised by high quality, reliability and innovative strength and the associated companies in the value chain are among the market leaders worldwide. German waste management, with its differentiated collection and processing structure, is also regarded as an international role model. Last but not least, its pool of engineering skills, a strong research landscape and stable framework conditions create a good basis for pushing the transformation of the entire plastics system in Germany in the direction of circularity.

What is needed is a “raw materials revolution”. This will involve similarly large technical and structural challenges as in the energy and mobility revolutions in Germany. The goal here is, for example, to keep the emission-relevant fossil carbon and its compounds in circulation in order to end the continual use of new fossil raw materials in the long term. This may never be completely successful for technical and logistical reasons, but every effort must be made and every conceivable process used to approach this goal. This requires a holistic approach and openness to technology in closing the loop while simultaneously considering overall ecological results.

Challenges for a circular plastics economy

A look at various initiatives and political measures reveals that efforts have been made in Germany for several years in the direction of new recycling approaches or specifications and innovations for product and packaging design. However, awareness of the problem has not yet been matched by adequate progress in the recycling of plastics.

The central challenge and task are to establish the incremental progress made so far in all areas of a circular plastics economy and to accelerate it in view of our global problems. The technological possibilities and competences of the German plastics industry are to be used to change the overall system without endangering the profitability and success of the companies in this field.

Despite the good conditions in Germany, there are some fundamental challenges that need to be solved with regard to the transformation:

- **No comparable conditions of competition between recyclates and plastics from fossil raw materials:**

  An important component of the "raw materials revolution" is the substitution of oil-based virgin plastics with recycled materials. Due to the volatile oil price, the costs for virgin materials from fossil raw materials are at times significantly lower than for recycled materials. Added to this is the tax subsidisation of fossil fuels for non-energy use, from which oil-based plastics production also benefits. For a functioning circular economy, however, stable competitiveness of recyclates in terms of price, quality and availability is very important. This paper therefore focuses on the question of how the use of recyclates in the circular economy can be increased.

  At present it is not a level playing field, either on a national or (even less so) on an international scale: there is no competition between virgin material and recycled material under the same starting conditions. Only if raw material prices were also to include externalised, environmentally relevant cost components and the value of the plastic waste or the raw materials contained therein were recognised, could the prices for virgin material and high-quality recyclates also converge.

- **Disparity between supply and demand in the market for recyclates:**

  While recyclate suppliers are temporarily struggling with sales difficulties due to the volatile oil price, plastics processors and product manufacturers complain that their demand for suitable recyclates cannot be met. This contradiction arises because the market often offers mainly recyclates that are suitable for so-called downcycling, i.e., for reuse in applications with lower quality requirements (e.g., for park benches or noise barriers). In contrast, demand often exceeds supply for recyclates of consistently high quality that are suitable for high-value applications. Clearly, supply and demand do not match here.

- **Fragmented value creation in the plastics industry:**

  The German plastics industry is characterised by a wide variety of business models and historically evolved structures. In addition, conflicting expectations among stakeholders sometimes lead to marked fragmentation along the value chain. In addition, there are a few large plastics producers on the one hand and many small and medium-sized processors, waste disposal companies and recyclers on the other. This patchwork of players and responsibilities is difficult to bring together into a strategy that suits everyone and into a positive transformation process. It is already clear that viable circular value creation requires a whole new level of cooperation and coordination across value creation stages that go beyond previous efforts.

- **Technological limits and conflicting goals:**

  Plastics are versatile and offer countless possibilities for variation. However, many of the material properties expected by the market today run counter to the goal of circularity. Composite materials, material mixtures, bonded or cross-linked materials make high-quality recycling more difficult, but pay off in terms of other circularity goals such as high longevity. Although these technological limits can be overcome by changes in product design, further developments in sorting and collection systems or new recycling techniques, they often create ecological and economic conflicts of objectives due to increased energy and raw material consumption and altered product performance.

- **Political regulation so far focused on waste:**

  For a long time, political regulation in Germany was primarily geared towards measures that only started at the end of the life cycle of plastic products and packaging and thus in their waste phase. The focus was on the handling and disposal of waste and less on recovery and recycling to close the loop. In the past, circular economy legislation was de facto primarily waste policy. If the model of a circular economy is to be developed further, political regulatory measures must also have a much stronger impact on this goal than has been the case to date and reward the value of plastic products in the post-use phase as well.

  In view of the international value-added structures, a European regulatory framework will be necessary in order not to endanger the international competitiveness of the German plastics industry. An initial orientation is provided by the EU's Green Deal (e.g., the so-called “plastics strategy” and the circular economy action plan).

- **Increased pressure to act through public communication:**

  Startling images and headlines relating to plastic in the world's oceans and in nature increase the pressure for action on all sides. Quick and decisive action is urgently needed in view of the high and increasing input of plastic waste into the environment. Nevertheless, it is important to resist the temptation to adopt hasty solutions, which are often ineffective or counterproductive with regard to the problem. At this point, a systemic perspective and fact-based measures aimed at transforming the system as a whole are more effective.

Aims of the VDI Round Table

In view of the different interests, structural challenges and complex network of actors, it has quickly become clear that a circular plastics economy requires a rethink by all stakeholders and a clear regulatory framework. The change from today's linear model to a circular plastics economy requires systemic and technical innovations as well as value creation adapted to this. With the Round Table, VDI has conducted a fact-based dialogue with politics, business, science and the general public and discussed together how the systemic change from a linear to a circular economy can succeed in the field of plastics. As an independent technical/scientific association, VDI contributes its expertise in all fields of value creation to the discourse without pursuing its own particular interests.

Against this background, the VDI Round Table has the following objectives:

- The **initiation of a dialogue** bringing together representatives of all stakeholders involved in the cycle.
- The **development of a common understanding of the plastics cycle**: from linear to circular economy.
- The **identification of the framework conditions, potentials and challenges** on the way to the Circular Economy via all the individual cycle stages and actors.
- A **holistic and systemic view of steering instruments that** enables the transformation of the entire system.

The VDI started the dialogue in the form of the Round Table and brought together the stakeholders of the plastics industry involved in the cycle as well as NGOs and scientific organisations to discuss the points listed above. Guests from all topic-related federal ministries and the Federal Environment Agency (UBA) were involved. The results are summarised in this paper with the aim of formulating recommendations for action for policy-makers and industry. The focus is on systemic transformation and therefore neglects many important individual aspects of individual stages of the cycle.

The VDI Round Table has identified **four major priority areas for action**:

FIELD OF ACTION 1 (Re)organising the plastics industry for a circular economy

FIELD OF ACTION 2 Making closing the loop the task of all stakeholders

FIELD OF ACTION 3 Creating regulatory incentives for a circular plastics economy

FIELD OF ACTION 4 Designing products for a circular economy

In the following, the four fields of action are explained and conclusions are drawn for each field of action with regard to the opportunities or challenges of a functioning circular economy. Finally, overarching recommendations for politics and industry are formulated, based on the results of the preceding fields of action.

FIELD OF ACTION 1

(Re)organising the plastics industry for a circular economy

The plastics industry is still primarily organizsed in linear (mostly globally oriented) value chains. Energy, labour and money are invested in order to manufacture plastic products on the basis of petrochemical and thus fossil raw materials. After the product has been used, the resulting product waste is disposed of, usually without recycling the raw and reusable materials.

The circular economy approach

Circular economy, on the other hand, follows a fundamentally different approach: the value of the plastic does not increase linearly, only to be suddenly "terminated" and become waste. It replaces the end-of-life concept with closed cycles and avoids or recycles waste by designing resources, materials, products, systems and business models in a correspondingly holistic manner. In this approach, the recycling of waste is already taken into account during product creation (design for circularity). The aim is to bring plastics into the cycle in such a way that the use of fossil resources is reduced. In the long term, the aim is to achieve complete independence from fossil resources in plastics production. The German chemical industry has set itself the goal of completely recycling the carbon used and being greenhouse gas neutral by 2050 (cf. VCI 2020, p. 2).

However, the path to a circular economy is complex: the transformation of value chains, material flows, product development processes and the recycling of materials deeply affects the currently established organisational structures of the plastics industry. New roles, tasks, interfaces and challenges are emerging, which require new forms of cooperation to overcome. In order for a transformation towards a circular economy to succeed, the existing (linear) value chains must be reorganised and a rethink by all the players involved is necessary.

Cycle diagram

The VDI Round Table has developed a diagram that illustrates the different roles of those involved in the cycle and defines and describes their tasks and responsibilities in it.

The diagram (cf. Figure 1) serves to provide clarity and reduce complexity. Against this background, structures are depicted in a simplified manner. In practice, we are often dealing with highly interconnected, global supply networks across and within all stages. The groups of actors involved can therefore not always be clearly assigned to one stage of the cycle. There are often overlaps, or stages are integrated – for example, raw materials producers are often also plastics producers.

The diagram shown in Figure 1 depicts eight stages of the plastics cycle. These are assigned to the four segments **raw materials, products, market and waste**:

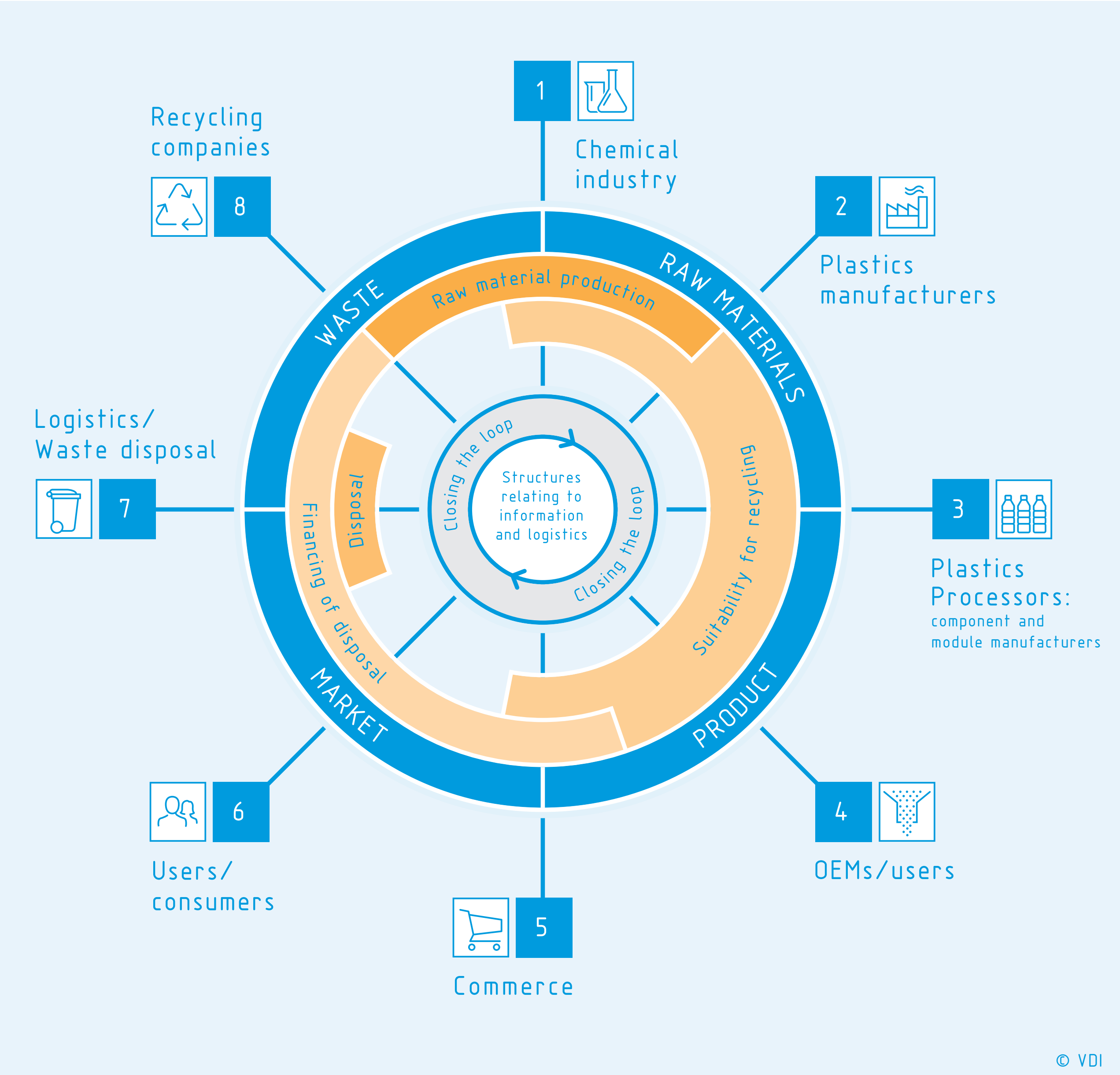
From the raw material producers, i.e., the **chemical industry** 1 and the **plastics producers** 2 the virgin plastic product moves on to the **processors, component and module manufacturers** 3 then to the **OEMs and users** 4, where the product is manufactured and brought to the market via **commerce** 5 and finally to the **consumers** 6.

From the consumers, the plastic product passes as waste via **waste disposal/logistics companies** 7 to the recycling companies 8, who process the plastic waste so that it can be fed back into the cycle as recyclate (PCR: post-consumer recyclate) **(cf. Figure 1)**.

In this paper, the focus is on PCR. As this is still little used in industrial production compared to post-industrial recyclate (PIR), the growth potential is greatest for PCR.

CYCLE DIAGRAM

Figure 1



CORE TASKS of the actors involved in the cycle

Figure 2

1 Chemical industry

Supply of basic chemicals and monomers

2 Plastics producers

Manufacturers of virgin plastics (granules, resin, precursors for polyurethane, etc.)

3 Plastics Processors: component and module manufacturers

Further processing of the plastic granulates into components and packaging (e.g., films, containers), which are delivered to system suppliers or directly to the OEM/user

4 OEMs/user

Product development, manufacturing and marketing

5 Commerce

Provision of the goods for sale. Depending on the industry, commerce can take on a different function and relevance. For example, food retail has a relatively high influence on the manufacturers of packaging materials for food

6 Consumers

Decision-makers, buyers and users of the goods

7 Logistics/Waste disposal

Collection, transport and sorting of plastic waste

8 Recycling companies

Recovery and processing of plastic waste into recyclate with the help of sorting plants and recycling processes

Regardless of the actors, the following activities should be considered as key to a circular economy: the production of recyclates, ensuring suitability for recycling, disposal and closing the loop. The interfaces of the actors that interact during these key activities are manifold:

- When it comes to **suitability for recycling**, the segments of raw materials, products and market are particularly relevant: Due primarily to their diverse combinations and lack of separability, plastics can only be brought into the cycle if the products are conceived, designed and manufactured in such a way that they can be recycled to a high standard. Although product development and design are the responsibility of the manufacturers (OEMs/users), the selection of raw materials already has an influence on a product's suitability for recycling. In order to ensure suitability for recycling, close coordination is therefore required between the actors who manufacture the product and bring it to market, and those who provide or process the necessary raw materials and materials.

- **Closing the loop** affects all four segments. In particular, there are overlaps in the waste, raw material and product segments: when recyclers process plastic waste into recyclates, they themselves become raw material suppliers for processors, component and module manufacturers. Against this background, recyclers become an important partner in the innovation system when it comes to material and product innovations, for example.

- In terms of **disposal**, there are overlaps between the market and waste segments: for example, the quality of plastic waste is also partly dependent on the consumer's knowledge of sorting it and their willingness to sort it. Not all packaging and waste can be separated by consumers. However, there is also no guarantee that products that can be separated well will actually be separated correctly by consumers. In terms of financing, marketing and communication, the commerce sector plays an equally important role in disposal, as well as those who make the necessary materials available or prepare them.

- As a common point of contact from the production of raw materials to the return of the product, **cross-actor information and logistical structures** play a decisive role. Frequently, there is no access to the necessary data, e.g., on materials, design, product specifics, etc.

The interfaces shown result in an increased need for coordination and information between all those involved in the cycle. Up to now, the actors have generally only been in direct (economic) exchange with the upstream and downstream stages.

The result is a plethora of weak points and loopholes. For example, recyclers often do not know the composition of the material of a plastic component, although this is decisive in terms of recycling options. On the one hand, this problem must be addressed structurally, where possible, through standardisation and reduction of the variety of materials. In addition, however, data, e.g., in the form of a digital twin or of the digital product passport proposed by the EU Commission, would also have to be supplied alongside material in order to close this gap. Material and product data are often carriers of company know-how and must be treated with appropriate sensitivity. Procedures for this must be further developed or newly established.

CHALLENGES

A circular economy requires a holistic and systemic approach that does not restrict itself either to the product or production side. In this overall perspective, the plastics cycle already begins with the production of basic materials and thus in chemical production and plastics production, and not just with the OEM or user (see cycle diagram).

The tasks, information requirements and new interfaces associated with this changed perspective necessitate not only the creation of a common awareness of circularity but also a (re)organisation of the plastics industry for the cycle. Although there are numerous NGOs and initiatives that promote circular value creation across all stages of the cycle, no cross-circle cooperation and organisational structures have yet been established at the operational level.

Some product areas are already further advanced in the implementation of circular value creation. Product-specific cycles and special solutions with their own deposit systems have emerged (e.g., PVC window profiles, PET bottles). These solutions, which in themselves are effective, must be integrated into the transformation of the plastics industry as a whole. It must also be taken into account that some players have already set out on that path and are developing new business models. For example, some retail companies are already active in the recycling and disposal business and are thus integrating several circular segments themselves.

There are still hurdles to overcome with regard to the cross-actor transmission of information and data. There is a need for optimisation, for example, in the automation of readable information. Up to now, product manufacturers in particular have been cautious about passing on their product information because of the protection of know-how. There is a lack of standards and regulations on which information should be passed on to which actor and how information should be made available for recycling after the use phase.

In addition, there is a complex waste management landscape with public and private players whose historically grown or politically desired business models make it difficult to organise a plastics cycle.

CONCLUSIONS

In order to orient the plastics industry towards circular value creation, all stakeholders in the circular economy need a common awareness and understanding of the role of circularity. Roles and tasks will change in the course of establishing a circular economy and cooperation will take on even greater importance. Instead of focusing exclusively on their own elements of value creation, raw material producers, product designers, commerce, consumers and waste management players will work together on optimised solutions. This requires intelligently organised cooperation, including with the help of digital support.

Clear commitment as a joint contribution by all actors

All stakeholders can contribute to a circular plastics economy by openly embracing the idea of circular value creation. This commitment must then be reflected in the strategic development and investments of the individual companies, but also in the cooperation and communication and information flow between the various players. New projects and investments should always be examined with a view to a future circular economy and compliance with the Paris climate targets.

Complexity of organisational structures and stakeholder relationships as a hurdle

A major hurdle in the re-(organisation) of the plastics industry for the circular economy is undoubtedly the complexity and diversity of organisational structures and stakeholder relationships. There is a risk that conflicts of interest will arise between the actors due to different interests and that gaps in the cycle will arise or not be closed. However, since cooperation is essential for the implementation of a circular economy, these conflicts of interest must be overcome.

FIELD OF ACTION 2

Making closing the loop the task of all stakeholders

The transformation from linear to circular value creation requires not only a common understanding among all stakeholders, but also a holistic, systemic approach that makes closing the loop the task of all involved. Because although activities and measures undertaken by individual partners in the cycle can and must make a contribution, the plastics cycle will only function successfully if the entire system is aligned to it.

Thinking of closing the loop from the end

With circular value creation, resource efficiency becomes an even more significant economic principle. Closing the loop turns waste into a raw material that has value. This value must be recognised by all stakeholders in the loop in order for supply and demand to develop for a recyclates market.

An important building block for the raw materials revolution, as aimed at in the course of the circular economy, is the substitution of petroleum-based virgin plastics with recyclates. This will only be possible on the necessary large scale if plastic waste recycling is understood as a fixed partner in the cycle and corresponding quantities of plastic waste are recycled into recyclates. The fact that there are currently still gaps in the cycle here is shown by the low proportion of recycled plastics in the total volume of plastics processed: in Germany in 2019, they accounted for only 13.7% of the total volume of plastics processed; the proportion of recyclate from post-consumer waste is only around 7.2% (cf. Conversio 2020, p. 7).

POTENTIAL AND CHALLENGES at each stage in closing the loop

In the following, the potentials and challenges of closing the loop are presented and analysed from the perspective of the respective actors at each of the eight stages. As in the VDI Round Table dialogue process, the discussion throughout the cycle takes place in detail for each individual cycle stage. Only by understanding the logic of action of each individual stage and its actors will it be possible to subsequently identify more clearly the potential for optimising the entire cycle, but also to show its limitations.

The discussion of these limits will show that all the partners in the cycle together – even if they are aware of the necessity and the technical possibilities of circular value creation of plastics – can only change the overall system to a limited extent. For this reason, regulatory instruments are presented and discussed in Field of Action 3, which are intended to better exploit the potentials of all eight stages of the cycle and help overcome their limitations.

POTENTIAL for closing the loop

The chemical industry has a key position for circular value creation as the starting and end point for closing the loop. Frequently, the two value creation stages of chemicals (provision of basic chemicals/monomers) and plastics production are vertically integrated.

The potential of the chemical industry stems from its (possible) decision option to dispense with the raw materials oil and gas and instead use both high-quality recycled and renewable raw materials to produce plastics. It is also up to the chemical industry to define and develop the demand in terms of quality and quantity that can push recyclers, and ultimately the overall system, to invest heavily in reprocessing into recyclates. The pull effect on the upstream stages would be significant, but so would the push effect on the downstream stages, in which recyclates could be made available in sufficient quantity and quality and would have to be called off.

Further potential of the chemical industry lies in the development of technologies for the processing of plastic waste, which up to now cannot be recycled or can only be recycled with a loss of quality. This includes chemical recycling processes (e.g., solvolysis, pyrolysis, gasification), which enable the chemical degradation of used plastics into pyrolysis oils or monomers that can be reused as raw materials for new plastics or other chemical products. The potential of chemical recycling processes are currently under intensive and sometimes controversial discussion (see “Challenges”). In future, chemical recycling could play a role above all where mechanical recycling reaches its limits despite far-reaching design for circularity (cf. Field of Action 4). A significant opportunity lies in the fact that composite materials, as well as contaminated and polluted mixed waste and non-meltable plastics, which cannot be recycled to a high standard using mechanical recycling (or at least not without an unreasonable amount of effort), can sometimes still be recycled to a high standard by chemical means. The use of chemical recycling may also make sense in the future in product areas where high safety requirements demand a particularly high quality of recycled raw materials. For other areas such as lightweight packaging, the combination of mechanical and chemical recycling processes could be an ecologically and economically sensible alternative in the future (cf. Stapf 2020). With such a process, the mechanical plastics that are easy to separate would be identified in the sorting process using sensors and processed into recyclate; the residues that cannot be mechanically recycled could be further processed into new material by means of chemical recycling.

The chemical industry has communicated its intention to invest specifically in chemical recycling plants in Europe. The European plastics association Plastics Europe recently announced a planned increase in the industry's investment in innovative recycling processes from €2.6 billion in 2025 to €7.2 billion in 2030. Nevertheless, further research and development work is necessary for the development of chemical recycling processes and especially for the combination of mechanical and chemical recycling. Study results to date illustrate the potential of chemical recycling processes, but also reveal the technological, ecological and economic challenges that still need to be solved. This also applies to carbon capture and utilization (CCU) processes, which are also under development. CCU aims to capture carbon dioxide emitted from combustion and make it economically usable. In order to use emitted CO_2, it must first be captured by so-called capture technologies either from gas emitted via combustion or even simply filtered out of the atmosphere. For this purpose, independent life cycle assessments (LCA) should be carried out in pilot plants on an industrial scale, and the environmental balance of the various technologies should be determined. Only if chemical recycling also proves to be advantageous from an ecological point of view and in comparison with existing technologies should it be further developed. Therefore, new projects and investments should always be examined with regard to a future circular economy and compliance with the Paris climate targets (cf. also Field of Action 1).

CHALLENGES in closing the loop

The chemical industry not only has great leverage for successful transformation, but also faces major technical, economic and environmental challenges.

The use of high-quality recycled raw materials produced by mechanical means is currently only possible to a limited extent due to the mostly inadequate quality, which is partly due to the diversity of inputs into recycling systems (cf. chapter on disposal and recycling). One challenge is procuring recyclate at competitive prices. Due to the volatile price of crude oil, recyclates are often not competitive with virgin materials. Fluctuating crude oil prices also make planning difficult. Challenges are also associated with necessary adjustments to process technologies and production processes that increase process efficiency. A further challenge is to establish the mass balance approaches required for many recycling processes in regulatory terms and on the market. Some certification systems already exist for this purpose (ISCC+, RedCert). Independent, certified mass balance approaches are necessary in order to transparently determine the proportion of defossilised materials in the end product if, for example, fossil and recycled raw materials (such as recyclates) are used simultaneously in large-scale plants. Mass balance approaches would also be relevant for the combination of mechanical and chemical recycling processes outlined above.

Another key hurdle to moving away from fossil fuels relates to investment costs: huge investments have already been made in production facilities that have been built or are under construction. The asset investment of the chemical industry over the last 20 years is estimated at more than USD 2.7 trillion globally (vgl. Ellen MacArthur Foundation 2019, p. 8). The plants are designed and optimised to process crude oil (naphtha)-based precursors, but can also process chemical feedstocks (e.g., pyrolysis oil) produced on the basis of plastic waste. Some companies collaborate so that their production plants are interconnected and interdependent. Adapting the existing infrastructure for the processing of high-quality recycled raw materials involves considerable costs and risks. Efforts are therefore being made in the chemical industry to produce alternative naphtha that can be used in existing production plants.

The technological developments mentioned above (chemical recycling, combination of mechanical and chemical recycling, CCU) have not yet reached market maturity. One challenge today is still that the processes have a high energy consumption and the use of renewable energies is expensive, so that they are not currently economically viable. There are fears that merely the announcement of the possible alternative (chemical recycling) could have a negative impact on the further development of mechanical recycling, which is currently advantageous from an ecological point of view – e.g., by reducing investments, or that the importance of product design (design for recycling) could be neglected (rebound effect). In order to actually advance the circular economy in the field of plastics, the various recycling processes should not be viewed in competition with each other. Instead, it is important to use reliable methods to determine which material flow through which recycling option (mechanical, chemical, or combined) makes the best ecological, economic and qualitative contribution to climate neutrality and the circular economy. Artificial intelligence approaches can also provide support here.

CONCLUSIONS Possibilities and limitations

The leverage of the chemical industry to close the loop is considerable, but due to the volatile crude oil price, the international competitive situation, the investments made so far and the complex production and supply situation, at this point in time a transformation driven solely by the industry seems hardly feasible at within the necessary timeframewithout suitable political framework conditions.

Approaches to solving this problem lie in increasing cooperation and joint project investments, which, in addition to chemical recycling, also focus on design for recycling and mechanical recycling technologies.

CHEMICAL INDUSTRY

Table 1

Closing the loop from the perspective of the chemical industry

POTENTIAL CONTRIBUTION	CHALLENGES	CONCLUSIONS
■ Covering the demand for raw materials by using recycled materials Taking sustainability into account: ■ Exploiting the potential of chemical recycling ■ Tapping the potential of CO_2 utilisation (e.g., through carbon capture and utilisation, CCU) ■ Tapping the potential of renewable raw materials (bioeconomy)	■ Development and procurement of recycled and renewable raw materials ■ Modification of existing processes and production ■ Complexity of composite production ■ Traceability and documentation of the raw materials used ■ Availability of low-cost renewable energy ■ Investments in assets already built or under construction ■ Global competitiveness (costs, quality, ability to deliver) ■ Adaptation of existing business models to the circular economy	■ Key position: starting and end point of closing the loop ■ Scientific/technical basis exists for closing the loop ■ But: high risk (for pioneers), high financial expenditure – lack of planning security ■ Cross-cycle collaboration as an approach for solutions

PLASTICS PRODUCERS

POTENTIAL for closing the loop

Similarly to the chemical industry, plastics producers can be regarded as the starting and end point for closing the loop. They are the ones who can make a significant contribution to ensuring that high-quality recycled raw materials increasingly find their way into the cycle, e.g., by further processing high-quality recycled raw materials. To this end, plastics producers must adapt their process and product development. With regard to the necessary properties of plastics, which differ depending on their intended use, plastics producers are required to develop the necessary property profiles, e.g., by compounding and skilfully mixing mechanically produced recyclates, chemical recyclates and virgin materials. They can also play a key role in building up knowledge for various processes and thus exert a significant influence on ecologically sound solutions overall.

CHALLENGES in closing the loop

Plastics producers face economic, technical and regulatory challenges. The challenge described for the chemical industry, namely that alternative raw materials such as mechanically produced recyclates are not available in sufficient quantities, of the necessary quality and at competitive prices, affects plastics producers to the same extent. In terms of quality, the lack of consistency in quality makes it difficult to further process and use recyclates from mechanical recycling. The quality of today's recyclates is significantly influenced by the purity of the starting materials. A high degree of purity of the starting materials is a prerequisite for plastics producers in order to be able to continue supplying the required material variants to customers. There is often a conflict between product requirements and recyclate quality. However, a constantly high recyclate quality as well as sufficient supply quantities are currently not in existence. Against this background, a high degree of recipe flexibility is also necessary in order to be able to map the different raw material flows entering the plants.

With regard to design, the standardisation of materials and their composition is often discussed in order to achieve higher recycling rates. As a rule, however, the focus is more on the processing and use properties of the plastics and less on high-quality recyclability or a material design that allows the material to be used over several cycles. Nevertheless, design for circularity has to start with the plastic producer and the materials used.

CONCLUSIONS Possibilities and limitations

Similarly to the chemical industry, the potential of plastics producers to contribute to closing the loop is considerable. However, the dependence on available, high-quality recyclates from mechanical processes is a significant inhibiting factor today. There is a lack of reliable and comprehensive quality standards and norms for recyclates, e.g., procedures to verify the source from which recyclates originate.

Since the success of plastics is based on the mutual adaptation of the material properties of the respective plastic and the design of the application (e.g., OEMs in cars), this interface must be activated as a driver of plastic innovation for the circular economy. In this respect, the exchange of information on material properties, design, requirements for recyclates and their characteristics between plastics producers, processors and the OEMs/users in relation to design for circularity definitely requires improvement.

A functioning circular economy requires a product design that is consistently geared towards recyclability, starting with the plastics producer, as well as comprehensive quality standards for the resulting recyclates, without which plastics producers cannot meet the product and quality requirements of their customers.

Product safety directives and authorisations should be reviewed and developed to facilitate the commercialisation of new materials (e.g., the REACH Regulation).

PLASTICS PRODUCERS

Table 2

Closing the loop from the perspective of plastics producers

POTENTIAL CONTRIBUTION	CHALLENGES	CONCLUSIONS
■ Provision of alternative plastics that are capable of being recycled (e.g., recyclates or plastics with recycled content, plastics made from renewable raw materials) ■ Ensuring the quality and development of the necessary property profiles of the alternative plastics, through optimised process and product development	■ Availability of recyclates ■ Cost of recyclates ■ Lack of quality consistency of recycled materials ■ Mass balancing: traceability and documentation of the raw materials used ■ Recipe flexibility ■ Approval/registration of new products from alternative raw materials (REACH) Product requirements of OEMs/users	■ Key position: starting and end point of closing the loop Activate interface between plastics producers, processors and the OEMs/users as a driver of innovations for the circular economy ■ Product safety guidelines/approval procedures for new materials to be examined and further developed ■ Assurance needed of the availability of recycled materials and quality consistency

PLASTICS PROCESSORS

POTENTIAL for closing the loop

Plastics processors – which are often small and medium-sized enterprises (SMEs) – are "sandwiched" between the large plastics producers and the original equipment manufacturers (OEMs). They use various processes (injection moulding, extrusion, blow moulding, thermoforming, etc.) to shape plastic granulates and process them into components and packaging (e.g., films, containers), which they supply to system suppliers or directly to the OEM/user.

Plastics processors have various options for keeping the plastic in circulation:

1) The processor uses virgin material (based on fossil raw materials) with recycled content, for which it needs a specification or a certificate from the supplier (plastics producer) and possibly also the approval of the customer.

2) The processor, in agreement with the customer, uses only recycled material, either:
   a. Recycled material from the market (a specification is required, or it should be of the same standard as virgin material), or
   b. Recyclate that it collects, prepares and compounds itself.

Depending on the business model, customer requirements and the availability of recyclates, their quality and price, the plastics processor may use either or both options.

The use of recyclates on a large scale (Option 2) would contribute significantly to the creation of a circular economy. Plastics processing companies have an important role to play here, as they create the necessary conditions for the use of recyclates by ensuring the technical suitability and processability of the recyclates and by identifying product applications (taking quality requirements into account) in a customer-oriented manner. Together with their customers, plastics processors can create demand stability for producers and recyclers.

It should not be forgotten that, in addition to the widespread use of recyclates, saving and avoiding plastics are also important levers. This means that the total volume of plastics must be reduced within the framework of a circular economy.

CHALLENGES in closing the loop

Due to their sandwiched position, plastics processors are particularly caught between quality, availability and costs as well as regulatory conditions and standards. Plastics processors must supply products that meet the quality requirements of the customers (OEMs and users). These generally have little willingness to compromise when it comes to product quality; as a minimum, consistent quality is required (vs. products made from fossil raw materials). Processors are therefore faced with the challenge of creating an unchanged product with a different material input (recyclate). Under certain circumstances, this means increased effort in the processing procedures (e.g., addition of additives) and a tendency towards reduced process efficiency. In addition, there are higher purchase prices for the recyclate. However, higher costs are not borne by customers (a price premium is seldom accepted), unless legal requirements make this mandatory for all market participants (e.g., PET, EU Single-Use Plastics Directive).

The task of designing for circularity continues with the processor, who helps to conceive and implement the design of the components/modules. Here, too, the focus is often on processing and usage properties as key drivers of product performance, rather than on design for circularity. The proportion of material composites is still very high and would have to be significantly reduced. Another challenge for processors is that they must learn to work with recycled materials in a reliable manner. A 1:1 substitution of virgin material is currently not possible in most cases, as recyclates are not only technically different in their material properties, but also not always the same, i.e., fluctuating with regard to the materials.

With regard to the roles of the actors in the cycle, the plastics processor must be able to cope fully with its position between recycler/raw material manufacturer and customer (OEM and user).The processor must meet the quality requirements of its customers and translate them or identify sustainable (innovative) solution options together with the recyclers. This requires the development of recyclate know-how on the part of the processor as well as an understanding of the recyclers' work processes and requirements. Uncertainty about the availability of recyclates makes it difficult for processors to plan with certainty.

CONCLUSIONS Possibilities and limitations

Plastics processors play a decisive role at the interface between the recycler and plastics producer and product development at the OEM and user. They can influence the product design and the use of recyclates. However, they are limited in their scope of action by the lack of availability of recyclates (and poor planning ability) as well as cost and quality problems. One option is to identify niche markets with lower quality requirements. However, this is not sufficient to transform the entire system.

PLASTICS PROCESSORS

Table 3

Closing the loop from the perspective of plastics producers

POTENTIAL CONTRIBUTION

- Design for circularity (at component/module level)
- Ensuring the technical suitability and processability of alternative plastics
- Identifying product applications where recyclate can be used
- Formulating quality requirements for recyclates
- Demanding stability for producers and recyclers

CHALLENGES

- Quality requirements of OEMs and users with little willingness to compromise
- Regulation and standards (including EFSA)
- Costs for recyclate and process adjustments
- Design for circularity (component/module level)
- Sandwiched between recycler and customer: dealing with uncertainty about the availability of recyclates
- Recycling know-how: especially at the interface with the recycler

CONCLUSIONS

- Restrictions on the recycler with regard to availability, quality and costs
- Regulations and standards are to be examined/developed further
- Opportunities in the market must be identified (often niches)

OEMs/USERS

POTENTIAL for closing the loop

In their role of designing and offering products for specific end-user markets, OEMs and users have a key position in the circular economy. It is up to them to absorb demand from the market and also to shape (or even generate) it. The decision on the use of certain materials is made by the OEM/user during product development. With a circular product design, the OEM/user can not only increase the demand for recyclates in the long term, but also the amount of product waste that is suitable for high-quality recycling. Sustainability is increasingly becoming a competitive factor for OEMs/users. Against this background, new business models are emerging, e.g., subscription or sharing models, which are also leading to a rethink among consumers.

OEMs/users also play an important role in the plastics cycle in terms of data and information.With responsibility for product development and design, OEMs/users have the knowledge of what properties and quality the materials used require. For some products, sometimes hundreds of plastic parts made of different, mostly thermoplastic materials are used. Passing on this information – in the sense of product life cycle management – is of crucial importance both for the upstream stages with regard to the raw materials required for new developments and for the downstream disposal and recycling of plastic waste. At the same time, however, the protection of confidential, non-public information and know-how is also important.

CHALLENGES in closing the loop

Product responsibility goes hand in hand with responsibility for product quality and safety, as well as the obligation to reduce waste and dispose of it in an environmentally friendly manner. For OEMs/users, the constant availability of high-quality recyclates is therefore of great importance. Currently, the market for recyclates cannot always meet these requirements, and willingness to accept compromises in quality tends to be low. In many sectors, there are also standards or legal regulations on the use, processing and quality of products, which may differ even within the EU. In some cases, these regulations hinder the use of recyclates and would have to be reviewed and adapted accordingly (e.g., for packaging used for food or cosmetics).

Cost and competitive pressures are a key challenge for OEMs/users who need to justify higher product costs to consumers. This requires new pricing strategies and new business models. In addition, when using recyclates, there are increased costs for approval processes and testing for materials. This in turn has an impact on product design: until the uncertainties regarding the price and availability of recyclates have been resolved, OEMs/users will also remain hesitant to develop new, more sustainable product designs.

CONCLUSIONS Possibilities and limitations

In a circular economy, the product must be designed from the perspective of circular value creation. The course for the circular economy is already set here. This requires a rethink on the part of OEMs/users with regard to product design (cf. also Field of Action 4) as well as an evaluation of options along the entire product life cycle (e.g., in the form of life cycle assessment (LCA) and life cycle costing (LCC)). At the same time, it must be ensured across all stages of the value chain that quality and safety requirements can continue to be met through the use of high-quality recyclates. In terms of quality, no compromises are possible from the OEM/user perspective. Consistent availability of high-quality recyclates is a prerequisite for long-term product planning (quantity planning), which provides recyclers and producers with the security they require in order to accept them.

With regard to the traceability of product data, the recycled content and its origin, a digital solution for certified material information is necessary, in which all relevant data from product data sheets, certificates, etc. are stored and central access is made possible for those involved in the cycle. The prerequisite for this is not only a review of technical and legal issues, but also the willingness of the companies to share the data.

If circular value creation is consistently considered right from the product conception stage, this will not only secure demand for recyclates, but will also open up the possibility for German companies to assume a pioneering position in international competition.

OEMs/USERS

Table 4

Closing the loop from the OEM/user perspective

POTENTIAL CONTRIBUTION	CHALLENGES	CONCLUSIONS
■ Conceiving, developing and establishing circular products on the market (design for circularity) ■ Formulating quality requirements ■ Demanding transparency in the supply chain ■ New business models for the circular economy (e.g., sharing economy) ■ Creating acceptance among customers through transparent communication	■ Cost and competitive pressure to use recyclates compared to oil-based virgin plastics ■ Product responsibility leads to high quality requirements. ■ Constant availability (ability to deliver) not always ensured ■ Access to material information on the proportion of recycled content ■ Laws and standards make the use of recycled materials more difficult.	■ Key function through product development and buyer power ■ Long-term product planning (quantity planning) ■ No compromise on the quality of products possible ■ Digital solution for approval of materials necessary (e.g. IMDS International Material Data System) ■ Positioning of German companies in global competition; opportunity for pioneering position

COMMERCE

POTENTIAL for closing the loop

As a direct interface to the end consumer (B2C), commercial companies have a great deal of buyer power vis-à-vis product manufacturers, especially if the product is distributed by the manufacturer exclusively via indirect channels (B2B). Consumers are also significantly influenced in their purchasing decisions by commercial companies, whether through the range of products on offer, the marketing or the information available on the product. The use of plastic packaging in the retail trade, which is addressed by the German Packaging Act (VerpackG), is certainly of particular importance here. At around 3.22 million tonnes, packaging accounts for the largest share of total plastics consumption in Germany, followed by the construction sector with 2.92 million tonnes, the automotive sector (1.11 million tonnes) and electronics applications (0.94 million tonnes) (cf. Conversio 2020, p. 10).

With a view to closing the loop, commercial companies can exert pressure on manufacturers as a kind of "gatekeeper" in terms of cycle-compatible product and packaging design. In addition, commercial companies in the private label sector have a direct influence on manufacturing and thus also on product design. Commercial companies can also develop further potential with regard to the distribution and redistribution of plastic products, for example by establishing additional return and deposit systems, refilling stations or solutions for tracing and returning plastic components.

The retail sector in particular has already recognised that sustainability and the circular economy are not only important for a company's image, but also enable new business models. For example, some large retail chains are investing in their own disposal and recycling structures in order to cover all stages of the cycle themselves for their own brands.

CHALLENGES in closing the loop

By developing its own solutions, commerce is doing important pioneering work. However, more comprehensive solutions are needed to drive the overall system towards the circular economy.

And even if ecological aspects are becoming more important in the purchase decision, the price is ultimately the deciding factor. As a result, some products are declared to be recyclable and sustainable when they are not. Such actions, also known as "greenwashing", impede the change towards circular value creation and should therefore be monitored and prohibited. Commercial companies must be able to communicate reliable product information transparently. Advertising and competent consumer advice play a major role here. Commercial companies and product manufacturers also use labels and seals to try to provide information not only about the product itself, but also about disposal. However, there is often a lack of comparable criteria in the "label jungle".

CONCLUSIONS Possibilities and limitations

As the interface between consumers and product manufacturers, commerce occupies an important position in terms of product demand and setting new standards. Developments in the area of acquisition and participation (integration of the value-added stage of disposal and reprocessing) illustrate not only the financial strength of commercial companies, but also the first approaches to realigning business models. Commerce as a whole must not only become aware of its significant role in the cycle, but also live up to this responsibility. What is needed is transparent, comprehensible communication to consumers and a clear positioning of commerce (role model function) with regard to the circular economy, also considering other players along the supply chain.

COMMERCE

Table 5

Closing the loop from a trade perspective

POTENTIAL CONTRIBUTION	CHALLENGES	CONCLUSIONS
■ Promoting recycling capability and use of recycled materials in own brands ■ Including circular products in the product range, marketing at the point of sale ■ Providing infrastructure where appropriate (e.g., sorting and collection points), space for re-use models (e.g., refilling stations), tracing solutions ■ Transparent communication to the consumer	■ Adaptation of procurement processes and conditions at the point of sale (e.g., warehousing, alternative packaging concepts) ■ From isolated solutions and niche products to comprehensive solutions in relation to the overall system ■ Quality requirements regarding transport, storage, shelf life of products ■ Transparent, honest communication vs. greenwashing ■ Consumer advice (qualified staff, communication on the web, etc.) ■ Transparent pricing policy; if necessary, additional costs for suppliers of more sustainable products	■ Key function at the interface to consumers, to the market as well as to logistics and disposal; the power of demand and distribution ■ Setting of new standards possible, e.g., shaping of consumption patterns/shopping behaviour ■ Clearer positioning of the retail sector on the subject of consumer advice (employees, marketing)

CONSUMERS

POTENTIAL for closing the loop

The behaviour of millions of consumers can significantly promote or hinder the circular economy. On the one hand, this concerns product manufacture and design, which consumers can influence through their purchasing and consumption decisions. On the other hand, it also concerns the recycling of products in their post-use phase, the quality of which is also influenced by the consumer's waste reduction, separation and provision.

Sustainability aspects are becoming increasingly important for consumers. This development must be used to sensitise consumers to daily consumption patterns and purchasing decisions and to mobilise them in favour of the circular economy. If consumers are aware of their role in the circular economy and know how to act accordingly, then they can make an active contribution to closing the loop.

CHALLENGES in closing the loop

In fact, however, self-image and consumer reality often do not match.According to their own statements, consumers are indeed sensitised to environmental and sustainability issues (cf. Bovensiepen et al. 2018, p. 21 ff.), but their purchasing decisions are still primarily determined by the price factor. As long as products made from recycled material are more expensive than products made from virgin material, this can be an obstacle in their purchasing decisions.

Furthermore, information deficits also prevent consumers from increasingly opting for recyclable products. Even if consumers have developed a high level of awareness of the problem, they lack comprehensible, comparable, easily accessible and also credible information. This is where retailers and product manufacturers are called upon to educate consumers with suitable advertising and reliable information. The introduction of a digital product passport could also help. This should contain information on the proportion of recycled material in the total material input, the recycling capability of the product and the correct recycling route.

Handling plastic waste is also a challenge for the consumer. Be it due to a lack of willingness, ignorance or difficult-to-separate materials among the product waste, mistakes often happen during separation and disposal, which affect the subsequent sorting, processing and recycling. In order for consumers to recognise the value of the materials used, including in the after-use phase, the continuous provision of information and education is also necessary here. In doing so, it is important to maintain a balance between providing the necessary detailed knowledge and overtaxing the consumer.

CONCLUSIONS Possibilities and limitations

Without consumers, the transformation of the plastics industry towards circular value creation will not succeed, especially in view of the societal change that will accompany it.

Consumers must therefore be regarded as relevant actors within the value chain who need information from pre-production to consumption and disposal of the product in order to be able to evaluate and consider the consequences of their purchasing decisions. Access to such reliable and easy-to-understand information must be made mandatory and monitored, because consumers can only be empowered for the circular economy through education that is appropriate for the target group.

CONSUMERS

Table 6

Closing the loop from the consumer's perspective

POTENTIAL CONTRIBUTION	CHALLENGES	CONCLUSIONS
■ Purchasing decisions: choosing products made from recycled material; avoiding packaging that is not absolutely necessary; willingness to try out new reuse models ■ Disposal decisions: - waste reduction - waste separation - waste provision	■ Information retrieval ■ Sense of responsibility ■ Purchasing decisions ■ Cost awareness ■ Excessive demands for evaluation (labelling, certificates, etc.) ■ Formation of opinion through public discourse	■ More awareness needed of waste's potential as a raw material ■ Continue to raise awareness of responsible product use (reparability, upgrading, etc.) ■ Empower the consumer to make the right sustainable product decisions

LOGISTICS/WASTE DISPOSAL

POTENTIAL for closing the loop

Without logistics and waste disposal, the plastics cycle cannot be implemented, because this sector collects, transports and sorts the plastic waste which, after recycling and processing, is to be reintroduced into the cycle as recyclates. Germany has a well-organised waste management industry with a differentiated collection structure, which is regarded internationally as a role model in many areas. The German waste management sector is characterised by two competing pillars: the municipal enterprises or legally independent companies of the towns and districts, and the private waste disposal companies. The dual systems are a special feature of German waste management. They organise the collection, sorting and recycling of used sales packaging throughout Germany and are responsible for ensuring that the recycling quotas prescribed by law under the Packaging Act are achieved. The dual systems are financed by licence fees paid by manufacturers and retailers on sales packaging in accordance with the polluter-pays principle.

In the area of waste disposal, the greatest potential lies in the optimisation of collection and sorting systems, e.g., by enabling technical innovations to achieve greater volumes, lower levels of contamination and improved grade purity of plastic waste. For example, the use of artificial intelligence or machine learning can improve the sorting of waste streams. Waste management can make a further contribution by educating consumers to enable them to separate waste correctly.

CHALLENGES in closing the loop

Although the German waste system is considered an international model in many areas, the system is primarily designed to ensure reliable disposal and not for circular value creation. In addition, the German waste management system is largely in the hands of public waste disposal companies, which also operate waste incineration plants in parallel. Although recycling rates in Germany are comparatively high, only a small proportion is used for the manufacture of new products.The potential is much greater, but competition between the dual systems is primarily determined by price and not by the most ecologically sensible solution. According to the amendment of the Packaging Act, product manufacturers and commercial companies are obliged to participate in a dual system with their packaging quantities and to report their data both to the selected dual system and to the newly created Central Packaging Register Office. This is intended to enable electronic data reconciliation and thus monitoring.

In some areas, industry solutions have been established on their own initiative or due to legal obligations, e.g., in the electrical industry as a result of the German Electrical and Electronic Equipment Act (ElektroG). Here, too, costs are the decisive factor. Companies generally look for the most cost-effective way to dispose of waste. There is a lack of incentives to comply with more than the specified quota.

CONCLUSIONS Possibilities and limitations

Both logistics and disposal are indispensable for the recycling of plastics. There is great potential for both areas, especially with regard to technical innovations (sorting facilities, collection systems, information transfer). At the same time, however, there is a lack of incentives to make circular value creation a priority. The numerous regulations, such as the Packaging Act (VerpackG) or the Closed Substance Cycle Waste Management Act (KrWG), focus on waste streams, not on circular value creation.

A functioning plastics cycle requires closer feedback between logistics, waste disposal and recycling companies and the manufacturing industry. To this end, the waste and disposal system, including logistics, must be more strongly geared to closed-loop recycling and must also hold its own in competition with new market participants (see Commerce).

LOGISTICS/WASTE DISPOSAL

Table 7

Closing the loop from the perspective of waste management and logistics

POTENTIAL CONTRIBUTION	CHALLENGES	CONCLUSIONS
■ Optimisation of the collection and sorting systems: allowing large volumes, low degree of contamination, higher grade purity ■ Ensuring the flow of information in the cycle (logistics as a point of contact throughout the cycle) ■ New business opportunities and models for logistics providers (e.g., individual solutions in small-volume logistics such as end-of-life products and spare parts supply)	■ Fee/cost structures ■ Competing waste management – private/public (price and quality competition) ■ Conflicts of objectives of public disposal companies in recycling ■ Dual systems – confusion and complexity make monitoring difficult	■ Important position as interface in the entire cycle ■ More opportunities than currently perceived ■ Create incentives to make circularity a priority ■ Stronger feedback needed from logistics, waste management and recycling companies to the manufacturing industry

RECYCLING COMPANIES

POTENTIAL for closing the loop

Plastics recyclers are of great importance for circular value creation, because they recycle and prepare plastic waste, and are thus responsible for the current supply of recyclates in the required quality and quantity.

In the cycle, they thus become raw material suppliers themselves, and normally supply the plastics processor directly with recyclates. Circular value creation means, among other things, that more recyclates must be used throughout the plastics industry. This opens up the opportunity for recyclers to produce significantly more recyclates and increase their sales. If the appropriate incentives are put in place, the business with recyclates therefore has great ecological, but also economic potential.

In order to be able to substitute virgin plastics, recyclates of equal quality are needed. Investments in the further development of sorting plants, mechanical recycling processes and technologies can contribute to improving recyclate quality and consistency. In addition, the new and further development of technologies in the field of mechanical and chemical recycling offers innovation potential. Until now, the chemical industry and plastics production have barely been involved in the business with recyclates, as recyclers usually supply directly to processors. Today, however, many plastics producers have their own subsidiaries that carry out recycling. Increasingly, collaborations will create value when recyclers and companies in the chemical industry jointly process recycled goods into new raw materials for high-quality applications.

CHALLENGES in closing the loop

The volatility of oil prices shows the limits of a business model with recyclates that is in direct competition with virgin material. Due to the volatile prices for virgin material, at least in some areas it is difficult to create a stable sales market. There is a lack of investment security to expand production and reduce the price of recycled material, e.g., through economies of scale. In other areas (e.g., PET and PP), recyclate prices have already decoupled from the prices of virgin material due to high demand – e.g., as a result of legal requirements – and there is a relatively stable market.

In addition, there are still a number of challenges that affect recycling itself and have a major influence on the quality of the recyclates.The unsuitability for recycling of many products made of plastics (often mixed with other materials), insufficient data on the composition of the material and high procurement prices make recycling difficult. Also the input quantities, the degree of contamination and the grade purity cannot be influenced by the operators of the recycling plants (interface between consumers and industrial users). The low capital resources of many of these often medium-sized companies also inhibit technology development and investment, although these are absolutely necessary to increase recyclate quality. It is therefore questionable whether recyclers would even be able to serve the market for high-quality recyclate applications to an increasing extent without cooperation with the chemical industry and plastics producers. Therefore, closing the gap between waste disposal companies, processors and recyclers as suppliers of recyclates on the one hand and plastics producers on the other hand is one of the greatest challenges, but at the same time also an opportunity when it comes to the transformation towards a circular economy.

CONCLUSIONS Possibilities and limitations

The relationship, division of roles and distribution of tasks between waste disposal and recycling companies on the one hand and the chemical industry and plastics producers on the other is one of the key issues for circular value creation in the plastics industry with regard to the use of high-quality recycled raw materials.

As long as the prices for virgin and recycled plastics are so volatile, the demand for recyclates will not increase to the decisive and necessary extent for economic reasons.

In order to be able to increasingly substitute fossil raw materials, the quality and quantity of the recyclates currently obtained and used must be increased. For the recycling itself, it is therefore important to make recyclates more attractive with a quality campaign and thus increase the value of plastic waste.

RECYCLING COMPANIES

Table 8

Closing the loop from a recovery/recycling perspective

POTENTIAL CONTRIBUTION	CHALLENGES	CONCLUSIONS
■ Increasing input quantities and grade purity ■ Production and supply of recyclates in increasing quantities and qualities	■ Volatility of oil prices (prices of virgin plastics) ■ Many plastic wastes cannot be recycled to a high standard ■ High quality requirements for recyclates currently difficult to meet ■ Insufficient data on the composition of the material ■ Fragmentation of the industry; players often have low financial resources	■ Key role for the circular economy as a new raw material supplier ■ Acceptance of the recycler as a partner in the cycle by the other actors in the cycle is necessary ■ Value of waste must be increased, and demand secured ■ Cross-actor information structures necessary

CONCLUSIONS Challenges for the entire cycle

All stakeholders can and must make their individual contribution to enable the closing of plastics cycles. At the same time, all stakeholders have to overcome challenges. Some potentials and challenges are specific to a particular cycle stage, while others affect the entire cycle:

- **Information and data flow within the cycle:**

  Necessary information is missing at many points in the cycle, e.g., on the properties of the materials, products and, above all, recyclates. This information must be made available to all stakeholders throughout the entire plastics value chain. In particular, the traceability and documentation of the raw materials used must be ensured. Similar to virgin materials, (digital) data sheets are needed, which can be used to assess the quality of recyclates. Quality standards for recyclates could promote customer acceptance and help to increase the use of recyclates. This requires technical information and quality requirements to be set by processors and manufacturers. Recyclers and plastics producers would then in turn have to provide proof of the quality of the recyclates.

- **Adaptation of technical rules and specifications:**

  An important instrument for coordinating the eight stages of the cycle is technical regulation. Through standardisation, the flow of information and data can be optimally adapted to the different requirements of the participants and their interfaces. A standardisation roadmap is currently being drawn up by DIN, DKE and VDI. In this roadmap, it has been agreed that both “plastics” and “packaging” are to be considered as a single topic. The recycling of plastics is now increasingly being considered in technical regulation at both national and international level.For example, the Guideline Committee VDI 4095 deals with the evaluation of plastics in the circular economy. At CEN level, the Working Group CEN/TC 249/WG 11 “Plastics recycling” is working, among other things, on the characterisation of recyclates. At ISO level the Sub Committee ISO/TC 61/SC 14 “Plastics – Environmental aspects” is working on standardisation activities in the field of environmental and sustainability aspects of plastics, including recycling. ISO/TC 323 “Circular economy” is concerned with standardisation in the field of implementation of the circular economy.

In addition, existing specifications and regulations on product safety as well as approval procedures for new materials currently make the use of recycled raw materials more difficult. For example, polyethylene terephthalate (PET) is currently the only recyclate approved by the European Food Safety Authority (EFSA) for food packaging.

- **Establish infrastructure for take-back systems:**

  Efficient take-back must be organised and established throughout the entire plastics cycle. For this purpose, new take-back systems must be established and all parties involved in the cycle must be involved in the processes. This is key to ensuring suitable recyclate qualities.

- **Further training and qualification of employees:**

  With the establishment of a circular economy, the requirements and the necessary know-how of employees are also changing. Further training and qualification measures will play a role across all levels.

- **Product design:**

  Product design, which is primarily conceived by manufacturers, also plays an overriding and significant role in closing the loop (cf. Field of Action 4). However, it cannot currently develop its full potential due to a lack of quality, the availability of recyclable raw materials and the price of recyclates.

Despite numerous activities and voluntary commitments by various players at all stages of the cycle, which demonstrate the will to change in the direction of a circular economy, it is still not possible to implement comprehensive recycling of plastics and their raw materials. Although many individual examples show the fundamental possibility of using, for example, 100% recycled materials for plastic packaging and also recycling them, these examples are only possible because recycled materials are available for this packaging and, at least initially, it may be possible to justify a higher price for the products on the market if there is a unique selling point.

If a significantly larger proportion of the market were to use recyclates, there would no longer be any unique selling proposition to differentiate the product. Also, in the event of a demand pull, a sufficient supply of recyclates would have to be ensured.

The limitations of the business model of producing recycled materials in competition with virgin materials is one of the main obstacles for all players. This finding, confirmed in the VDI dialogue process, leads to the discussion and evaluation of steering instruments for the market as a whole, which are intended to compensate for these deficits (cf. Field of Action 3).

FIELD OF ACTION 3

Creating regulatory incentives for a circular plastics economy

The goal of complete independence from crude oil in plastics production by 2050 requires a huge transformation of an entire industry and, at the same time, of the use and disposal of plastics in almost all areas of life. Although this transformation process requires a wealth of technologically sophisticated innovations at the most diverse levels – whether in chemical composition (compounding) and product performance, innovative design in the substitution of other materials, innovative sorting technology with polymer-specific analysis methods, new business models or innovative methods of mechanical and chemical recycling – the "Gordian knot of recycling" cannot be cut by these means alone. Without regulatory framework conditions that enable competition between virgin plastics from crude oil and high-quality recyclates (a level playing field), this goal will not be achievable.

The need for regulatory incentives

Until recyclates of the appropriate quality are competitive with fossil-based virgin materials, demand will not increase to any significant extent. And the lower the quantities of recyclates produced, the higher the price for the recyclates. Circular business models that promote recycled raw materials or even avoid waste are therefore rarely economically competitive with those of primary raw material producers at present.

Established instruments of waste and recycling management are not capable of achieving the desired effects alone. Nor does simply addressing OEMs/users create either the required quantities or the sales for recyclates. Without question, plastic recyclates have already established themselves in some sub-markets, but they only account for a small proportion of the total quantities of plastics produced. A gradual increase in the proportion of recyclates can be observed, but not at the speed that would be required from an ecological point of view.

On the market, there is neither the supply of required high-quality recyclates by recyclers nor the demand for recyclates by OEMs/users – mainly due to the upstream stages of plastics production and the oil price relevant for this – as existing recyclates hardly ever meet their high quality requirements so far. The required quality, the price of high-quality recyclates and the lack of availability mean that supply and demand do not match. Such a typical "chicken-and-egg" problem can also be seen in many other economic sectors. For example, in electric mobility with hydrogen (fuel cells): due to a lack of end users, there is a lack of incentives for the expansion of a hydrogen infrastructure, which in turn is the prerequisite for new demand by end users.

Market forces alone will therefore not be sufficient to trigger the necessary transformation in the field of plastics. In view of the individual potentials and challenges, different interests and expectations of the individual stages of the cycle, it is clear – as outlined in Field of Action 2 – that mechanisms are needed to stimulate and optimise the overall system.

In the debate on the circular plastics economy, both the technical and the political debate – especially at EU level – are considering, on the one hand, the instrument of minimum use quotas for recyclates and, on the other hand, market-based instruments for pricing (cf., e.g., AGVU [German working group on packaging and environment] 2021, UBA 2019a, acatech 2020, CEAP 2020).

STEERING INSTRUMENTS

This paper discusses steering instruments to promote the increased use of post-consumer recyclates (PCR). Steering instruments should be considered in a European context, as EU-wide regulation is required. National solutions within the EU restrict the free movement of goods and are not expedient. Nevertheless, Germany can and should take on the role of thinking ahead, testing/piloting concepts and driving them forward within European policy. From this perspective, the opportunities and challenges of steering instruments were elaborated from the perspective of the various actors in the cycle as well as with a view to the overall system.

The following three steering instruments are considered in this paper:

STEERING INSTRUMENT 1 Product-specific recyclate input rate

This model obliges distributors of certain products to use a legally defined minimum quantity of recyclates. The model discussed here concerns a minimum proportion of post-consumer recycled plastic (PCR) to be specified. Such an approach is taken, for example, with the EU Single-Use Plastics Directive (Directive 2019/904), which requires a minimum recycled content of 25% for PET beverage bottles from 2025, increasing to 30% for all single-use plastic beverage bottles from 2030. The implementation of such a minimum quota can vary and be set, for example, as an average value for the industry, as an average value for the individual distributor or as a commitment for each individual product (cf. AGVU 2021). In this way, a pull effect can be triggered, as a demand guarantee for recyclate suppliers is created. This in turn generates investment security in the waste management and recycling industry.

The product-specific recycling quota is to be set in such a way as to be fundamentally open to technology with regard to the recycling processes (mechanical or chemical recycling). Depending on the application, the sustainability of the solution would have to be evaluated on the basis of certain criteria.

STEERING INSTRUMENT 2 Material- or polymer-specific substitution rate

This model starts with the material, i.e., the production of plastics, irrespective of the product. With a material- or polymer-specific substitution quota, plastics producers are obliged to generate a certain minimum proportion of their plastics sold on the market from non-fossil raw materials such as recyclates. Such regulation aims to reduce price-related competitive disadvantages of recyclates. The aim is to ensure that the downstream value chains are supplied with sufficient and qualitatively appropriate (in line with demand) quantities of plastics with recycled content (push effect). New products could then gradually be substituted to the greatest possible extent. At the same time, this quota stimulates investments in the recycling business both in the waste management and recycling industry as well as in the chemical industry and plastics producers. Due to the increasing demand for high-quality circular raw materials, the upstream value chains from OEMs/users through to commerce and recycling companies will focus on the high-quality recyclability of their products (pull effect).

The implementation of the polymer-specific substitution quota can vary, e.g., substitution quotas could be implemented for plastic materials in general, or it could relate to individual polymer types (e.g., PE, PP, PET, PS). However, there are no product-specific specifications; the market would itself regulate which product applications the recyclates are used for, in order to meet the specifications.

The polymer-specific substitution quota is to be set with regard to the recycling processes (mechanical or chemical recycling) comparable to the product-specific recyclate use quota and it should be open to technology. It would have to be assessed on a case-by-case basis to what extent the technological implementation is sustainable.

STEERING INSTRUMENT 3 Market-based steering instruments

There are many ways in which market-based steering instruments can be designed. Basically, this type of steering aims to give an advantage to activities that aim to close the loop, as well as to the use of recyclates in the market. Market-based instruments generally start with prices and follow the logic that making certain resources more expensive reduces the use of these resources. Conversely, making resources financially more advantageous would increase their use.

Examples of this are incentive taxes, such as the CO_2 tax or the inclusion of the plastics and recycling industry in emissions trading, financial incentives for products with recycled content, or additional taxation or pricing of individual products without recycled content. The following section outlines various market-based steering instruments that are currently under discussion in the technical and political debate.

Criteria for the discussion of steering instruments

Proposals for state market intervention require an intensive discussion of the advantages and disadvantages for different actors as well as their effectiveness in achieving the objectives. A useful method for fact-based discourse lies in the formulation and discussion of criteria for evaluation. Such an approach of working with criteria that can be defined objectively and reviewed in later phases has proven its worth in many initially controversial debates.

The portfolio of assessment criteria was developed in order to enable a well-founded, targeted discourse between different perspectives and interests on the one hand, and to be able to more precisely identify the opportunities and challenges of the respective instruments on the other.

At the same time, however, this portfolio of assessment criteria is also intended to be useful for the public and political debate when these instruments are discussed further and the advantages and disadvantages are weighed up against each other. With this proposal, VDI would like to support the fact-based discourse in order to increase transparency and ultimately establish the broadest possible consensus among all stakeholders in the cycle.

Four different types of criteria, each with two to three sub-criteria, were distinguished for the discussion of **steering instruments** for the transformation of the plastics industry as a whole towards the circular economy:

MATERIAL-SPECIFIC AND TECHNICAL CRITERIA

- **Suitability for recycling:**
  Does the steering instrument lead to incentives for all actors in the value chain to improve suitability for recycling within product development, production, distribution, use and disposal?
  (cf. Field of Action 1 and 4)

- **Recyclate properties:**
  Does the steering instrument lead to an increase in the quality and availability of recyclates in the overall market (e.g., through innovations)?
  (cf. Field of Action 2)

- **Recycling technologies:**
  Does the steering instrument lead to the effective use of all recycling options for plastic waste (mechanical, chemical recycling, etc.) in terms of the supply of recyclates in the market?
  (cf. Field of Action 2)

ECOLOGICAL CRITERIA

- **Environmental consumption and pollution:**
  Does the steering instrument lead to a significant reduction in the consumption or linear use of environmental resources (e.g., raw materials, soil, water, air) with regard to the overall plastics market? Does it lead to a reduction in losses from the cycle through downcycling and waste incineration and avoid inputs of waste into the environment? Does it lead to a reduction in environmental impact (e.g., avoidance of pollutants)?
  (cf. introduction)

- **Defossilisation:**
  Does the steering instrument lead to a massive reduction in the use of fossil raw materials or render their use unnecessary by 2050? Does it contribute to climate neutrality through closed-loop recycling?
  (cf. introduction and Field of Action 2)

ECONOMIC CRITERIA

- **Recyclate markets:**
  Does the steering instrument lead to the creation and expansion of recyclate markets by creating supply and demand?
  (cf. introduction)

- **Market mechanisms:**
  Does the steering instrument lead to the establishment of the advantages of market mechanisms (competition, price, demand, etc.) in circular value creation and to their use in balance with the regulatory framework?
  (cf. Field of Action 1 and 2)

- **Competitiveness:**
  Does the steering instrument ensure or strengthen the competitiveness of (German) companies both in the European internal market and internationally?
  Is the speed of adjustment of markets and companies taken into account in order to avoid economic damage?
  (cf. introduction and Field of Action 2)

REGULATORY CRITERIA

- **System optimisation:**
  Does the steering instrument lead to the entire system of the plastics cycle being optimised with regard to the recycling of plastics, and not to many individual policy interventions producing a "patchwork" effect?
  (cf. Field of Action 1 and 2)

- **Enforceability:**
  Is the steering instrument suitable for efficiently enabling the review of government requirements and thus avoiding enforcement deficits?

- **Reliability:**
  Is the steering instrument suitable for communicating a reliable long-term adaptation strategy to all actors, thus making investment and personal initiative possible in the first place?
  (cf. Field of Action 2)

Summary: Criteria for the evaluation of steering instruments for closed-loop recycling

Ecological criteria

- **Environmental consumption and impact:**
  Does the steering instrument lead to...
  - A significant reduction in consumption or linear use of environmental resources (e.g., raw materials, ground, water, air) with regard to the overall plastics market?
  - A reduction in recycling losses through downcycling and waste incineration and avoidance of inputs of waste into the environment?
  - A reduction in environmental impact? (e.g., avoidance of pollutants)
- **Decarbonisation:**
  Does the steering instrument lead to a massive reduction in the use of fossil raw materials (oil) or render their use unnecessary by 2050? Does it contribute to climate neutrality through closed-loop recycling?

Material-specific and technical criteria

- **Suitability for recycling:**
  Does the steering instrument lead to incentives for all actors in the value chain to improve suitability for recycling in product development, production, distribution, use and disposal?
- **Recyclate properties:**
  Does the steering instrument lead to an increase in the quality and availability of recyclates in the overall market?
- **Recycling technologies:**
  Does the steering instrument lead to the effective use of all recycling options for plastic waste (mechanical, chemical recycling, etc.) in terms of the overall market for recyclates?

Economic criteria

- **Recyclate markets:**
  Does the steering instrument lead to the creation and expansion of recyclate markets by creating supply and demand?
- **Market mechanisms:**
  Does the steering instrument lead to the establishment of the advantages of market mechanisms (competition, etc.) in circular value creation and to their use in balance with the regulatory framework?
- **Competitiveness:**
  Does the steering instrument ensure or strengthen the competitiveness of (German) companies both in the European internal market and internationally? Is the speed of adjustment of markets and companies taken into account in order to avoid economic damage?

Regulatory criteria

- **System optimisation:**
  Does the steering instrument lead to the entire system of the plastics cycle being optimised with regard to the recycling of plastics? (Avoidance of a "patchwork" effect, local optima)
- **Enforceability:**
  Is the steering instrument suitable for efficiently enabling the review of governmental requirements and to avoid their circumvention, as well as avoiding overburdening the administration and the companies?
- **Reliability:**
  Is the steering instrument suitable for communicating a reliable long-term adaptation strategy to all actors, thus making investment and personal initiative possible in the first place?

The criteria presented were then applied to evaluate the product- and polymer-specific recyclate use rate. The results are summarised here in the form of opportunities and challenges for the two steering instruments.

STEERING INSTRUMENT 1 Product-specific recyclate use rates

MATERIAL-SPECIFIC AND TECHNICAL CRITERIA

Technically, a specification in the form of a product-specific recyclate use quota for suitability for recycling and the use of recyclates at product level initially makes sense, as it offers the OEM/user firm information on their product and the respective market must align itself with this specification. This would certainly also have advantages for distribution, use and disposal. All in all, all players in the industry would be motivated to design, produce and market products that are suitable for recycling and to align the infrastructure for collecting, sorting and processing product waste accordingly. Clearly defined recyclate markets would emerge for specific materials, with closed product cycles where appropriate, as in the case of PET drinks bottles.

A product-specific use rate would lead to recyclates with clearly defined properties. Standardisation of the plastics used and the product design would also be able to provide direction for other markets and applications. Another critical aspect is possible restrictions in the product design of OEMs/users, because the higher the quality and safety requirements of a product, the more difficult it is to formulate a quota. Many technical requirements would first have to be clarified through standardisation and other specifications.

ECOLOGICAL CRITERIA

By means of product-specific use quotas of recyclates, avoidance of fossil primary raw materials can be stimulated in a sector- and product-related manner. The ecological effect to be achieved can be very precisely adjusted to the product area. In addition, it is possible to respond to very specific ecological requirements. In implementation, care should be taken to avoid diversion effects. This is because the quota requirement could lead to recyclates merely being diverted from existing applications to those with quotas. This would make neither ecological nor economic sense if, for example, further processing steps were then necessary. In order to counteract this effect, there would have to be several quotas in different product or application areas, which would have to be coordinated with each other as far as possible. Closed product cycles would be desirable, in which the plastic is made available again for the same application.

Public discussions, e.g., about the pollution of the oceans with microplastics (marine litter), simultaneously show the advantages and disadvantages of the product-related perspective: although the ecological impact of certain products comes to the attention of the public and political regulation, it also often follows a public debate that forces the regulation of certain product groups, while others of possibly higher ecological relevance are left out. Against this background, an independent body would have to weigh up which product groups are selected according to which criteria.

The product-specific recyclate use quota can quickly achieve initial ecological effects, but does not guarantee that the use of recyclates will also be effectively increased in the overall market. However, the desired conservation of resources depends on whether this type of quota could achieve significant effects. The central objective of defossilisation – moving away from petroleum – depends on the amount of plastic that can be captured by such quotas in the overall market. In this respect, ecological assessment criteria must be applied not only to the individual product, but to the market as a whole.

ECONOMIC CRITERIA

The most important criterion for this quota model from a macroeconomic perspective is whether it leads to the emergence of recyclate markets. Only if sufficient quantities and quality of recyclates are available on the market will OEMs/users be in a position to meet the quotas.

In closed product cycles, investments in recycling technologies would be initiated by the clearly defined demand and the associated planning certainty. At the same time, a demand guarantee with investment security for recyclers would arise in these defined markets. Due to the product specifics, the cycles would be manageable and less complex, which would facilitate rapid implementation.

However, the diversion effects described above must be taken into account, in that recyclates could be diverted from previously existing product cycles or applications into those with a product-specific use rate. In addition, especially for the OEMs/users who are responsible, at least initially, greater effort would need to go into development and also procurement, which can have a cost-increasing effect. Initially, there would be a high risk of sharply rising prices for recyclates in the required qualities until the supply could be secured in sufficient quantities and qualities (ramp-up phase). Similarly, this can currently be observed in the R-PET market, where due to the EU Single-Use Plastics Directive (Directive 2019/904) and the voluntary commitments of large corporations, demand for recycled PET from bottled goods has risen sharply, but availability is limited.The question of the level of the quota is critical to success; if the quota is too high, there is a danger of quality risks and even a threat to product safety and the supply of raw materials. A quota that is too low, however, would not create any incentive effect.

Since the speed at which companies adapt to the quota requirement will vary depending on the market and product area, problems of competitive equality can also be expected for this type of quota. In summary, it is necessary to assess whether the use of a product-specific quota as a regulatory instrument can effectively increase the use of recyclates in the plastics market. The most important criterion for evaluating this type of quota across the board is ultimately the effective increase in recyclate use in relation to the total volume of plastics sold in the market. This is because considerable adjustment measures would be required by individual companies in their product areas, but the ecological effect could be limited across products, with a view to the plastics market as a whole. The effect ultimately depends on how many product cycles can be closed, how quickly and with what effect (depending on the level of the quota).

REGULATORY CRITERIA

The implementation of a product-specific recyclate input quota would tie in with the EU's Circular Economy Action Plan (CEAP). The CEAP pursues various measures to promote a circular economy at EU level and has been adapted or expanded several times since 2015. The most recent adaptation in March 2020 initiated the examination of regulatory measures for the introduction of statutory minimum use quotas for recycled materials (cf. CEAP 2020).

Only a transparent, traceable and effectively state-controlled quota will fulfil its purpose. Thus, regulatory criteria are of particular importance for the evaluation of this quota due to the large number of product-specific specifications. However, the sheer number of tens of thousands of products made of or containing plastic makes meaningful and affordable monitoring by authorities difficult. At the same time, the ecological effects depend not only on the quota level but also on the amount of plastic that can be covered by such quotas. In addition to monitoring, there is a further regulatory problem: each quota means an intervention in the product markets, as well as in the economic situation of companies, and would require an elaborate justification in each individual case, which – as is also shown by the German Federal Immission Control Act (Bundes-Immissionsschutzgesetz – BImSchG) – could lead to greater regulatory density.

The reliability of the quota system is an essential criterion for any economically active player to invest in technical innovations or profound changes in product design.

Summary of the opportunities and challenges of product-specific recycplate use rates

MATERIAL-SPECIFIC / TECHNICAL

OPPORTUNITIES

- Concrete orientation for OEMs/users and the entire industry; promotes the ability to plan.
- Promotes the need for recyclates that are very clearly defined in terms of materials
- High motivation for circular product design, production and marketing in the relevant industry (design for circularity)
- Application-related optimisation of suitability for recycling and the closed-loop recycling process

CHALLENGES / NEED FOR ACTION

- Depending on the product, adaptations and restrictions to the product design may apply
- Recyclate grades and supply are currently not designed for a wide range of plastic products.
- Need for technical specification

ÖKOLOGISCH

OPPORTUNITIES

- Fast and verifiable solution for individual products/product groups
- Small cycles make it possible to react quickly to changing/differentiating ecological product requirements.

CHALLENGES / NEED FOR ACTION

- Environmental impacts of the instrument must be assessed per product.
- Contribution to defossilisation depends on the number and type of product cycles.
- Possible diversion effects: if recyclates are diverted from existing applications to those with quotas (no ecological and economic added value)

WIRTSCHAFTLICH

OPPORTUNITIES

- Creation of defined recyclate markets with demand guarantee and investment security for waste management and recyclers
- Manageable cycles, low complexity with low entry barrier; quick implementation possible
- High adjustment speed of the quota specification depending on market and product area

CHALLENGES / NEED FOR ACTION

- Development and procurement costs unclear, may have a cost-increasing effect
- Finding the right balance: depending on the level of the quota, there may be risks related to quality, product safety, raw material supply, price increase

REGULATIV

OPPORTUNITIES

- Implementation of the EU Circular Economy Action Plan

CHALLENGES / NEED FOR ACTION

- Diversity of product groups – regulatory burden and complexity
- Enforcement of the regulation practically impossible in view of the large number of products and pro-cessors to be inspected; thus no fair conditions of competition either.
- No EU-wide monitoring/supervision/clearing system at present.
- Need to establish a system (see recyclate use quotas for PET bottles).

MATERIAL-SPECIFIC AND TECHNICAL CRITERIA

The polymer-specific substitution quota starts with the plastics producer. It obliges them to generate a certain minimum proportion of the plastics sold on the market from non-fossil raw materials such as recycled materials. First of all, such a substitution quota aims at reducing any price-related competitive disadvantages of recycled materials. In order to have sufficient and qualitatively appropriate quantities of plastics with recycled content available on the market, all plastics producers would be equally obliged to offer a certain quota of recyclates or a certain level of recycled content in their plastics.

In order to be able to survive on the market with such a quota, plastics producers would have to invest in recycling technologies and also in the development of alternative plastics. If necessary, the development of virgin materials made from a combination of fossil and non-fossil raw materials (conversion products) would also be promoted. The proportion of recycled raw materials must be determined and guaranteed by means of an appropriate mass balance approach. The customer could obtain the relevant information on this via the product specification. The properties of the raw materials to be procured by the plastics producer are crucial for this approach. It would be expected that the emerging demand for this material would trigger an investment and quality offensive on the part of the recyclers. The development time required for this would have to be taken into account by keeping quotas low initially. The decisive factor for the effect of this quota model would be a farsightedly planned and defined increase in recyclates. This would provide long-term orientation for investment decisions and technology development not only for the chemical industry and plastics producers, but also for all players in the plastics cycle.

Openness to new technologies for the recycling of plastic waste would also be a key prerequisite for the success of this approach. All available processes are needed to meet quality and quantity requirements. Mechanical as well as chemical recycling must be further developed at full speed in order to ensure this, even with increasing quotas.

As the value of waste increases, the pressure on and motivation of participants in the cycle to design, produce and market their respective products in a recyclable way and to invest in the necessary infrastructure is likely to increase. This will have a positive impact on waste recovery, the quality and quantity of their products and recyclates. In this respect, it can be assumed that this steering instrument would lead to incentives for all actors in the value chain to improve products' suitability for recycling and increase levels of recycling. If these incentives are not sufficient for the downstream stages, further steering instruments should be considered in the relevant stage of the cycle, such as requirements for design for circularity. Better traceability of the plastics used would also be important for implementation, to clarify in which products the processed plastics are used.

As this is a considerable intervention in the previous production of plastics, it is necessary to develop standards and norms with regard to the quality requirements for different types of polymers.

ECOLOGICAL CRITERIA

The quota model of gradually increasing polymer-specific substitution could be an important contribution to climate policy with regard to the goal of complete defossilisation of the chemical and plastics-producing industry to be achieved by 2050. The recycling of plastics in the mix of different recovery technologies can also lead to a reduction in environmental pollution – by reducing the input of solid plastic waste into the environment (landfilling) as well as its release as CO_2 into the atmosphere.

The savings potential of climate-damaging greenhouse gas emissions through the use of high-quality recycled plastics compared to the use of virgin granulate from crude oil varies, especially depending on the energy input.

It may already be over 50% today (cf. Fraunhofer UMSICHT 2020 on behalf of the ALBA Group). The higher the quota and the lower the electricity consumption, or the higher the share of renewable energies, the greater the savings potential would be.

However, in order to be able to make a reliable statement about the actual potential for improvement, a transparent, clear and comparable method for calculating the CO_2 balance for the recycled raw materials is required. This can vary considerably depending on the recycling process or even the combination of different processes. From an ecological perspective, the greatest leverage effect would be expected from this kind of quota, assuming it was set at an appropriate level. However, this would have to be examined in more detail in scientific studies and further dialogues between the relevant actors.

ECONOMIC CRITERIA

A polymer-specific substitution quotawould be a strong intervention in the market, but at the same time it would create market-based incentives to make the use of plastic recyclates attractive throughout the life cycle in the overall system. By gradually increasing the quota for plastic production, the plastic would also retain a value in the post-consumer phase, as plastic waste is of high economic importance for the waste and recycling industry.

The demand for recyclates stimulated by the substitution quota would – in terms of the cycle diagram – both induce development and investment in the collection, sorting and processing of plastic waste in the respective upstream stage and facilitate the implementation of a design for circularity in the downstream stages (OEMs/users) (e.g., due to the increased availability of recyclates, which needs to be ensured). From the point of view of plastics producers, such a quota would thus stimulate both the supply of recyclates for the downstream stages of the cycle and the demand for recyclates in the direction of the upstream stages (waste management). A polymer-specific quota for plastics producers would therefore have considerable leverage effects in both directions of the cycle. The “chicken-and-egg” problem described above could thus be eliminated. A long-term, slowly and reliably increasing quota development would also ensure planning security for the respective players.

At the same time, this quota model would have a significant impact on companies: the plastics producing industry would be motivated to invest in the development, purchase or their own production of mechanically and chemically produced recyclates. In the long term, a minimum input quota established at a certain level would lead to a relative shortage of virgin plastics on the market. This would make recyclates more competitive compared to virgin material. There would then be a financial incentive to use recyclates. Economies of scale would also lead to recyclates becoming cheaper.

A gradual increase in the substitution quota in a regional market can nevertheless temporarily lead to considerable competitive disadvantages compared with other – “quota-free” – economic areas. The plastics industry, and in particular the plastics-producing industry, is internationally positioned, meaning that the consequences for plant utilisation and the individual economic consequences are highly relevant. Similarly to the energy industry, the development of a transformation strategy and an associated roadmap is also required here in order to bring together the requirements of the market as a whole with entrepreneurial business models in a meaningful way. This can and must be done at the level of the European Union and with regulatory frameworks set by it in order to create fair, competitive conditions in a sufficiently large and significant market.

Enforceability in the global market is a major challenge: EU border adjustment mechanisms would be necessary for imports. Competitive disadvantages vis-à-vis other “quota-free” economic areas would be relatively easy to prevent in the case of granulate imports by means of suitable WTO-compliant border adjustment mechanisms; the much greater challenge lies in the import of finished products (e.g., cars). In the case of imports of those plastic products that have a lower recycled content than the average among EU products, WTO-compatible compensation rules would then have to be found if the recyclate costs were higher than those for virgin material on the world market.

To ensure security of supply in the start-up phase, the quota would have to be set relatively low at the beginning and gradually increased.

REGULATORY CRITERIA

Limiting a regulatory measure to a few players with large market shares is highly attractive from the regulator's perspective. Communication, traceability and monitoring are easier to achieve for a few large players with established compliance systems. For the regulator, addressing a few legal entities is comparatively easy; addressing a large number of products, some of which are highly complex, and their corresponding markets and supply chains would no longer be necessary.

A major intervention in the market – as would be the case with polymer-specific substitution – increases the legislator's steering options for a few players. However, such a quota system can only be implemented meaningfully on a European scale; it needs the large European internal market. A voluntary commitment by companies operating in Germany or a pilot scheme in Germany should be examined in order to be able to place the instrument at European level.

Ultimately, the reliability and predictability of the future strategy is crucial for the transformation process of the plastics industry. Similarly to other transformation processes, such as in the energy industry, political will and flexibility in implementation are required. This balance would be achieved in Germany to a large extent, due to the favourable positioning of all actors.

OPPORTUNITIES AND CHALLENGES

Table 10

Summary of the opportunities and challenges of polymer-specific recyclate use rates

	OPPORTUNITIES	CHALLENGES / NEED FOR ACTION
MATERIAL-SPECIFIC / TECHNICAL	■ Approach at plastics producer with chemical and technical expertise stimulates investment ■ Promotes investment and quality campaign on the part of recyclers and producers ■ High motivation for circular product design, production and marketing throughout the plastics industry due to shortage of fossil virgin material	■ Standardisation of quality requirements for different polymer types necessary ■ Traceability of the polymers used in the direction of the OEM/user
ECOLOGICAL	■ Significant savings of resources and emissions possible – potential for great leverage ■ Recirculation of molecules and materials opens up flexibility to find ecologically effective cycles	■ Environmental impacts must be calculated and assessed on a case-by-case basis.

ECONOMICAL — OPPORTUNITIES	CHALLENGES / NEED FOR ACTION
■ Incentives to make the use of plastic recyclates attractive throughout the life cycle in the overall system. ■ Stimulates the supply of recyclates for the down-stream stages of the cycle and the demand for recyclates towards the upstream stages ■ Motivation of the plastics producing industry: purchase of recyclates or volume certificates as well as investment in their own production of mechanically and above all chemically produced recyclates ■ Long-term planning security, with long-term quota setting ■ Recyclers generate additional income by selling volume certificates to producers; investments in larger plants possible ■ Possible relativisation of the current competitive imbalances between recycled and virgin material	■ Enforceability in the global market difficult, EU border adjustment mechanisms for imports necessary ■ Preventing competitive disadvantages vis-à-vis other "quota-free" economic areas by means of appropriate WTO-compliant border adjustment mechanisms. ■ Ensuring security of supply during the start-up phase

REGULATORY — OPPORTUNITIES	CHALLENGES / NEED FOR ACTION
■ Limitation to a few players with large market shares and high leverage effect ■ Monitoring simpler compared to the product-specific quota	■ Need to engage with large international companies on intervention in business decisions ■ Regulation at EU level necessary ■ EU border adjustment schemes may be necessary ■ German-EU-global implementation (WTO) to be pursued

STEERING INSTRUMENT 3 Market-based (price-based) steering instruments

Economic incentives are also a possible steering instrument to promote the transformation to a circular economy and to increase the use of recyclates. The design options are just as diverse as the direction of their effects. In this paper, therefore, only a few aspects of market-based instruments will be mentioned by way of example. These are measures that are either frequently or currently under discussion, such as CO_2 pricing, the introduction of an earmarked fund or financially improving the position of products with recycled content.

In principle, these steering instruments aim to better position recycled plastics on the market compared to virgin materials based on fossil raw materials.

Carbon pricing

Carbon pricing (or carbon tax) is a policy instrument that is already used in Germany in areas such as transport and buildings/heating to make CO_2 emissions more expensive and thus achieve a reduction in CO_2 emissions. The fossil raw material is priced regardless of whether it is used as an input for industrial production (as in the case of plastics) or as a fuel for energy production. A financial incentive is provided for the entire value chain to make products and processes more resource-efficient and energy-efficient (and thus lower producers of CO_2).

In the case of carbon pricing, plastics produced on the basis of recyclates would receive an advantage, provided they are not excessively energy-intensive in production. This would be a clear driver to invest in recycling and to minimise the use of fossil raw materials. In turn, the revenue generated by carbon pricing on the part of the state would be used for the purpose of supporting circularity (e.g., through funding initiatives).

In order to be effective, carbon prices would have to be high enough that companies that implement the principles of circular economy and efficient energy management well actually have a financial competitive advantage. Another prerequisite for the success of this control approach is that there are fair competitive conditions. This includes that all suppliers are covered indiscriminately, the target market must be sufficiently large (at least the European internal market) and the intended industrial transformation must take place in a sufficiently large time window. Carbon pricing should also be compatible with the European Emissions Trading Scheme (EU ETS), which is being continuously extended to other sectors.

Earmarked fund

In order to increase the effectiveness of the incentives for recycling capability and the use of recycled materials on the part of the distributors, the effectiveness of Section 21 of the Packaging Act (VerpackG) is currently being examined in a research project of the Federal Environment Agency, and the adaptation or further development of this regulation is being considered. One idea is to set up an earmarked fund into which distributors of plastic products would be obliged to pay and receive refunds if they put highly recycling-capable packaging or packaging with recycled content on the market.

The idea of this approach could also be transferred beyond the area of packaging in order to motivate distributors to use more recyclates and to consistently implement a design for circularity. The obligated parties would pay lump-sum contributions into a fund. Following the assessment period, they would have to declare the fulfilment of certain criteria with appropriate evidence in order to receive a distribution from the fund. Central to this is the question of what criteria would be used for reimbursement. Recycling capability and recycled content would be essential criteria for the objective of recycling. In addition, reusability should also be taken into account (resource conservation and waste avoidance – also objectives of the Circular Economy).

When designing this steering option, it would be important to ensure that it is actually applied in a way that is appropriate to the polluter so that the desired steering effect is achieved. Although the focus of this paper is on plastics, all materials should be affected, partly in order to avoid substituting plastics with ecologically more disadvantageous materials.

Other economic incentive options

There are a variety of steering instruments that aim to promote a circular economy by means of economic incentives and that specifically promote the use of recycled materials by providing direct or indirect financial benefits for products with a recycled content. These include, for example, **a reduction in VAT for products containing recycled material**. In terms of implementation, however, the question arises as to whether a reduction within a product group depending on individual criteria is (currently) legally possible. It would also have to be borne in mind that the recyclate content alone does not determine the environmental friendliness of a product. In terms of the effectiveness of the measure, only a limited increase in demand would be expected unless the availability and consistent quality of recyclates could be improved at the same time.

Investments are therefore necessary in this area. Funds could come from tax revenues if, for example, **a tax on single-use plastics or on virgin plastics** were levied and used for a specific purpose. In this way, a tax on single-use plastics or on virgin plastics could have a steering effect towards the use of recyclates and lead to a considerable inflow of funds. If this is used in a targeted manner, e.g., in the scale-up of transformative recycling technologies or in recycling infrastructure, the transition to recycling plastics could be accelerated. The effectiveness of the incentive depends, among other things, on the level of taxation. The cost of using recycled plastics would have to be lower and the availability of suitable recyclate grades would have to be ensured. Implementation at EU level presents a challenge.Different taxation in different EU member states would potentially restrict the free movement of goods. EU-wide coordination of such measures would require that the EU has competence for taxation policy (which is currently not the case).

Another way to encourage the increased use of recyclates is to reflect the **environmental costs of plastics production**, which is based on fossil raw materials. For example, the fossil raw material input for the production of plastics is currently exempt from **energy tax**. Taking this into account could lead to a levelling of the playing field between fossil-based virgin plastics and recycled materials. With regard to production, further measures could also be taken that start with the **construction or further development of production facilities**.
For example, projects for new production facilities should be examined with a view to creating a more extensive circular economy and compliance with the Paris climate targets and either discontinued or specifically promoted, as necessary.

CONCLUSIONS of the evaluation of the steering instruments

The discussion points presented above on the opportunities and challenges of the steering instruments make it clear that each instrument has its advantages and disadvantages.

Product-specific recyclate use quotas offer the potential to introduce "small", product-related cycles relatively quickly and thus increase the need for material-specific, clearly defined recyclates. Ecological signals can be sent and innovations stimulated in the respective product segments. Those segments in which industry can ensure that recyclates can be made available on the market in sufficient quantity and quality are suitable for this. The level of the quota should be gradually increased and should initially take account of the fact that the potential use of current recyclate qualities is limited.

Against the background of the regulatory challenges (criterion of system optimisation), however, product-specific recyclate use quotas for the transformation of the overall system into a circular plastics economy also has its limits. A large number of product groups would have to be regulated, infrastructural conditions created and an EU-wide monitoring system introduced. The diversity of products makes implementation enormously complex.

In order to be able to use the strengths of the product-specific recyclate input rate, an analysis of product groups from an ecological, economic and regulatory perspective is necessary. As a result, product groups should be identified that have a high ecological impact and that could be addressed as a first step. These could be product groups that have a high market volume and homogeneous quality requirements.

The strength of the **polymer-specific recyclate input ratio** lies in its possible overall effect on the market, independent of individual (small) product cycles. This has advantages in terms of operational and, in particular, regulatory implementation. Ultimately, the impact with regard to the transformation of the overall system of the plastics industry towards a circular economy is high if a corresponding quota level is achieved.

When introduced, the level of the statutory requirement would be critical. If it is set too high, there would be a threat of supply bottlenecks and price increases. The polymer-specific substitution quota should be further tested in studies and pilot projects, particularly with regard to its ecological effectiveness. One challenge also concerns the traceability of the recyclates used. At present it is often difficult to trace which recyclates are used in which products. In addition, border adjustment mechanisms for imports should be introduced at EU level to ensure global competitiveness.

Market-based steering instruments, particularly in addition to regulatory instruments, can provide more flexible options for actors in the cycle to achieve the specified goals for the circular economy and to reduce the costs that may arise through regulatory measures. At the same time, this creates economic incentives for companies to invest in innovations that are necessary for transformation.

However, in the context of the transformation of plastic recycling, market-based steering instruments only make sense where it is possible to directly price the use of a scarce resource, and where the resulting revenues are used in a targeted manner (more circularity). They fizzle out in cases where they are linked to unattributable, complex circumstances and used for a specific purpose. The possible designs of market-based steering instruments outlined above illustrate their diverse modes of action. Possible rebound and diversion effects must be avoided during implementation through precise examination and criteria-based evaluation.

Combination of different steering instruments

Since the steering instruments have different strengths and weaknesses and are not mutually exclusive, their combination is seen as a sensible approach. The exact procedure for such a combination would have to be analysed and, for example, thought through for different scenarios, also with regard to the effects.

It would also have to be examined which recycling processes would be permitted to meet the quotas and how the use of renewable raw materials would be integrated. For the evaluation of recycling processes or non-fossil plastics to be used, it is necessary to reflect sustainability criteria on a case-by-case basis and to derive benchmarks for an ecologically sensible mix of materials and technologies. Research findings in this regard are urgently needed and must be taken into account in the implementation of regulations and constantly checked against the state of the art.

For the implementation of a mix of steering instruments, a roadmap for planning would be necessary, outlining the synchronisation of measures as well as the successive introduction of steering instruments up to the target state.

The platform proposed in this paper (see Recommended Action 1) is therefore an essential prerequisite for the necessary adjustment and coordination of the cycle against the background of appropriate regulations.

FIELD OF ACTION 4

Designing products for a circular economy

For a functioning circular economy, recycling-capable products are needed in addition to reusable products and systems. Product conception and design are therefore a key tool when it comes to closed plastic loops. A wide variety of concepts and standards for construction and design that are suitable for recycling have existed for a long time (cf. for example,VDI Guideline 2243 or the EU Ecodesign Directive (Directive 2009/125/EC)), but the consistent orientation towards sustainability criteria has only come into focus in recent years.

One-dimensional recycling capability is not sufficient for a circular economy

The discussion often focuses on the question of how products can be designed in a recycling-friendly way. For circular value creation, in which plastics are to be recycled and reused not just once but several times in the form of recyclates, the demand for a one-dimensional recycling-friendly product design is not sufficient, however. If we take Section 3 of the Closed Substance Cycle Waste Management Act (KrWG) as a basis, recyc-ling is defined as all "recovery processes" that reprocess waste into products, materials or substances either for the original purpose or for other purposes (cf. § 3 Para. 25 KrWG). This means that just because a product is recyclable, it does not automatically mean that it is also suitable for reprocessing into high-quality recyclates or that it is actually recycled in practice. To date, adhesives that are difficult to remove, variations in materials or dark printing inks, for example, still only allow downcycling at most, in which only park benches or poles for street signs, for example, can be cast from the recyclate. Material separability also plays a major role here.

High-quality recyclability as an indispensable characteristic of plastic products

One goal of a circular economy is to actually keep plastics in the cycle. A recycling-friendly product design is therefore a necessary prerequisite for recyclable products, in which the plastic can be reused as a recyclate at the end of the use phase with as little loss as possible, thereby replacing petroleum-based virgin material in an equivalent market. Only if each value-added partner of the product and its materials raises its potential to achieve high-quality recyclability will efficiently renewable (repairable), reusable products be created that can ultimately be recycled to a high standard. Material-specific requirements also play an important role, e.g., disassembly and separability.

New holistic design approach needed

From the very beginning of the product design process, the material cycle must be considered from start to finish and the entire product life cycle must be taken into account. The shift towards a circular economy requires a design approach that necessitates a rethink on the part of product manufacturers, but also on the part of all other partners in the cycle. What is needed is a holistic view that takes into account the origin, properties and possible uses of the material, as well as information and awareness-raising for the consumer, right through to the recycling possibilities according to the state of the art (on an industrial scale). It is not enough to consider only one part of the cycle. It is important to think in terms of material flows rather than individual solutions. Here, too, the key to successful implementation is cooperation across the entire recyclable materials cycle.

Packaging and other plastic products must be consistently designed to be recyclable and geared towards a circular system. In order to keep the plastic in the cycle for as long as possible and at a high quality, however, products and packaging must also be designed in such a way that they can be made predominantly from recyclates. Currently, the quality and availability of recycled plastics tend to be low (cf. Field of Action 2).

However, the necessary change will not be advanced if a large proportion of manufacturers therefore shy away from using recycled materials and instead wait for a recyclate that perfectly suits their needs. Instead, manufacturers and processors should learn to deal with the current possibilities, make adjustments in product design and use recyclates where it makes sense and is possible. This, too, requires a change: up to now, materials have mainly been geared towards their application. To successfully implement circular value creation, it will sometimes be necessary to look at the available material right from the outset and then design the product or packaging using the most sustainable materials possible, without neglecting quality or product characteristics. The challenge will be to ensure that quality, product properties and function continue to meet customer demands. Best practice examples such as packaging for detergents or cleaning agents show that this balancing act can succeed in certain product areas.

Increasing the effectiveness of design for circularity

In addition to the availability of recyclates, there are several other levers to increase the efficiency of a design optimised for the plastic cycle:

- **Material or product passport:**

  Processors, product and packaging manufacturers and recyclers in particular need information on the exact composition of materials and the manufacturing process in order to create a circular product design. With the rapid implementation of a digital material or product passport, as already discussed at European and German level, this information could be made available at any time to all those involved in the cycle.

- **Consider design in the context of the entire cycle:**

  A product design that is suitable for recycling is not enough on its own, because whether the waste can ultimately be processed back into recyclates also depends to a large extent on the performance of the collection and sorting systems. It therefore makes sense to always design with a view to how the waste is later collected and separated and so on.

- **Criteria and standards:**

  There is a need for criteria and valid standards that define when a product is considered to be optimised for recycling and how a product or packaging design must be created so that it allows the multiple integration of the recyclates produced. These criteria and standards must be based on the state of the art and must not affect quality and functionality.

- **Regular reviews with regard to the state of the art:**

  Intensive innovation and development in the field of waste and recycling technology can and will lead to the development of new recycling solutions for products that cannot be recycled to a high standard today. It is therefore important to review the criteria and standards regularly and to adapt them if necessary.

- **Review existing rules and regulations:**

  The regulatory hurdles that impede the use of recyclate in product and packaging design must be overcome. For example, the regulations of the European Food Safety Authority (EFSA) mean that – using the reprocessing methods assessed as suitable – only recyclate from the closed deposit bottle stream may currently be used for food packaging. In this context, it would make sense to develop safety requirements and quality standards for recyclates from specific product groups.

Designing a product for recycling does not only mean making it capable of being recycled, but also deliberately using recycled materials in the production of the product. In this context, manufacturers repeatedly refer to the dependence on the availability of recyclates. As long as no high-quality material is continuously available, this cannot be taken into account in product and packaging design.

For design for circularity to develop its full potential, two development paths are conceivable that are not mutually exclusive but rather mutually reinforcing:

1) If the change in the preceding fields of action is successfully initiated and a circular system is established, recyclable product designs will also become widely accepted – at least if there is then a market with high-quality, continuously available and competitively priced recyclates.

2) If a few major players in the market switch to a circular design for their products, the market will probably quickly follow suit and follow the aforementioned developments in the system. For this to happen, however, it is crucial that design for circularity has caught on in enough product groups and that circularity has become established as an ecological goal and economic principle among all players in the economic chain.

RECOMMENDATIONS FOR ACTION

In order to achieve the goals of greenhouse gas neutrality and independence from fossil resources, a transformation of the entire German, European and ultimately global plastics industry is required. This transformation will only succeed through considerable efforts in all four fields of action mentioned. However, due to complex value-added processes, the aspiration of bringing plastics into a circular economy can hardly be fulfilled by individual actors or initiatives alone. In the opinion of the VDI Round Table, therefore, overarching measures that promote systemic change are of particular importance. The recommendations for action formulated here are therefore based on a holistic and systemic view. They do not aim to address individual actors as a matter of priority, but to formulate recommendations with a view to changes in the system as a whole.

RECOMMENDED ACTION 1

A joint platform for shaping the transformation of a circular economy for plastics

The paradigm shift to circular value creation, the change in business models and the transformation of entire economic sectors require not only a clear commitment on the part of all stakeholders in the circular economy, but also a whole new level of cooperation (cf. Field of Action 2). Conventionally, most stakeholders at each stage in the cycle are organised into their own associations that represent the interests of that stage accordingly. Al-though there are numerous NGOs and initiatives that promote circular value creation across all stages of the cycle, no cross-cycle cooperation and organisational structures have yet been established at the operational level. In the view of the VDI Round Table, this requires a joint platform on which players from all stages in the cycle can together develop a transformation path for the paradigm shift in the plastics industry. In addition to a common formulation of objectives, such a platform should examine and coordinate mutually compatible measures and cooperation models and assess and evaluate the success of their implementation. The role that a platform can assume with regard to further tasks, e.g., policy advice on steering instruments (cf. Field of Action 3), joint communication activities, data requirements within the cycle or the coordination of cycle-related standardisation, should be discussed as a next step.

An essential prerequisite for the operation of the platform is that it has sufficient independence both from economic actors and from politicians and NGOs. Platforms are particularly successful when technical expertise is of greater importance than the representation of different interests. When designing such a platform, already established, practising organisational structures for the ecological transformation of industries should be examined for transferability.

RECOMMENDED ACTION 2

Create structures for cooperation between recycling, raw material production, plastics production and OEMs

All parties involved in the circular economy are required to generate sustainable closed material cycles without generating harmful inputs into the environment and to close the cycle using renewable energies. Each actor can and should, within their stage, optimise processes, drive research and development, and develop new technologies for the implementation of the circular economy (cf. Field of Action 2). In principle, openness to technology should be the guiding principle here, but with consideration and disclosure of ecological assessment standards. Here, too, it is important that optimisations within a stage are undertaken in the context of the overall system so that no contradictory developments and solutions arise.

In addition to the contribution of individual stages to closing the loop, cooperation between recycling, raw material production and plastics production as well as plastics processing and manufacturers of the end products is of central importance for optimising the overall system (cf. Field of Action 2: Recycling companies). The substitution of virgin plastics by recyclates creates new roles, tasks and requirements for the actors. In order to avoid gaps in the cycle, these stages of the cycle are therefore called upon to develop cooperation models and find joint solutions for all issues relevant to the cycle.

RECOMMENDED ACTION 3

Examine and introduce an intelligent mix of regulatory and market-based instruments

The market alone will not be able to drive the transformation of the plastics industry with the intensity and urgency required for a raw materials revolution. Policymakers are called upon to create a holistic framework here that supports and accelerates this transformation through regulatory requirements and economic incentives. The following fields of action should be addressed through various regulatory and market-based steering instruments:

- Waste-avoiding and recycling-promoting product policy
- Level playing field for the use of high-quality recycled materials
- Reviewing and adapting legislation that impedes the cycle and development of new norms and standards.
- Promotion of research and development of new technologies
- Education and training of those involved in the cycle
- Consumer empowerment
- Green public procurement

The steering instruments presented in this paper and their criteria-based evaluation represent a contribution to the debate on possible measures in politics and industry (cf. Field of Action 3: Criteria). The VDI Round Table recommends following up on this and analysing and reviewing the various design options in more detail. The paradigm shift will not be achieved through a single regulatory measure, but can only be achieved through an intelligent mix of instruments that takes into account all the fields of action mentioned above.

The greatest steering effect is expected from the introduction of binding use or substitution quotas that create a level playing field for recyclate markets. The current political debate in Germany focuses very strongly on product-specific recyclate use quotas. The EU has also introduced product-specific quotas for various product areas in the course of its climate and resource protection strategy and the action plan for the circular economy.

In contrast, the proposal for a polymer-specific substitution quota has been little discussed so far, although this quota could have great potential after an initial criteria-based assessment (cf. Field of Action 3: Steering instruments).De facto, this type of quota would limit the use of plastics from fossil raw materials and would thus be a real game changer. The VDI Round Table therefore advocates examining the effect of a combination of different substitution quotas and economic instruments on the basis of studies and discussing a possible design in dialogue with all stakeholders in the cycle.

RECOMMENDED ACTION 4

Designing products consistently for the cycle through a holistic design approach

Product design will develop its full effect as soon as a level playing field for the use of recyclates has been established. In the view of the VDI Round Table, product design is then one of the key tools for closing the plastics loop. For this reason, the VDI Round Table recommends that a holistic design approach be taken to consider recyclability as early as the product design stage. This holistic approach goes beyond mere recycling capability; instead, products are developed with the aim of closing cycles (cf. Field of Action 4). Accordingly, this approach must also be reflected in the norms, standards, training and further education as well as in the political framework. The OEM also has an important role to play here, as the decision to use recyclates or virgin materials is made in particular during the conception and design of end products. High-quality recyclability also depends on product design and the materials used.

With regard to product design, the VDI Round Table supports the call for a European product passport and the revision of the Ecodesign Directive in order to increase not only the efficiency, but also the sustainability of products.

A circular economy with the aim of conserving resources and protecting the environment and climate must take other aspects into account in addition to the most comprehensive possible cycle management. It is also primarily about the absolute reduction of the use of resources through their efficient use, but also avoidance strategies as well as the extension of life cycles through, for example, reuse or reparability. The aim must also be to avoid waste and emissions.

RECOMMENDED ACTION 5

Expanding and strengthening research into a holistic approach

The path to a circular plastics economy is paved with numerous scientific, technical and social challenges. The VDI Round Table advocates pursuing the holistic approach and the transformation of the overall system more strongly in the area of research and development as well, in order to develop data-based decision-making aids for politics and industry. Examples of research areas are: Material and process innovations to increase the quality of recyclates, the performance of sorting processes, digital technologies for the traceability of products and materials in the cycle, or cycle-oriented business models or product innovations. These and other topics are to be taken up step by step in research and subsequently incorporated into the curricula of education and training in engineering, natural sciences, business and economics and many other disciplines.

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GLOSSARY

- **Circular economy:**
  The circular economy aims to optimise material and energy cycles and to recycle materials as far as is ecologically sensible. This should not only conserve resources and use them more efficiently, but also reduce greenhouse gas emissions. This means, among other things, that materials should be collected after use, processed and returned to production as raw materials.

- **Design for circularity:**
  Design for circularity is a holistic design approach that aims to design products in such a way that they can be recycled. Materials and products must therefore not only be capable of being recycled, but must be recyclable to a high standard. Design for circularity takes into account the entire life cycle of products, the specific recycling options according to the state of the art, and the possible uses of the recycled material. Possible design for circularity principles include: Rethink, Reduce, Reuse, Repair, and Recycle.

- **Design for recycling:**
  Design for recycling aims to support the retrieval of materials for further use. This means that the recyclability of the material used is already taken into account during design and production. Various criteria such as materials used, colours or additives such as adhesives and bonding agents affect the recycling capability of products.

- **Downcycling:**
  Downcycling refers to the reprocessing of materials where the original quality is not retained. In the case of recyclates, downcycling means that they are used in applications with lower requirements, e.g., park benches. Nevertheless, downcycling also replaces fossil-based raw materials with recyclates. Even with downcycling, another cycle may be possible further down the line.

- **End-of-life:**
  "End-of-life" describes the last phase in the product cycle, when the product is disposed of after use and consumption. In a linear economy, the end-of-life phase ends when the product is released into nature as waste. In a circular economy, on the other hand, this phase ends when the waste is recycled and thus enters the life cycle of another product.

- **Fossil raw material:**
  Raw materials that originate from primary extraction or production and are among the fossil carbon sources (crude oil, natural gas, coal).

- **Basic material:**
  A raw material which is used unprocessed or only slightly processed as a starting material for further processing or as an end product for consumption.

- **New plastic products:**
  Plastic products that are supplied to the plastics processor in a quality-assured manner, today usually on the basis of fossil raw materials.

- **Plastics industry:**
  The entirety of all actors along the value chain that produce or process plastics or offer services related to plastics (or plastic products). In the course of the circular economy, the overall system of the plastics industry includes the chemical industry and plastics producers, plastics processors, OEMs and users, retailers, consumers, logistics companies and waste disposal companies as well as recycling companies.

- **Mass balance approach:**
  Method to determine the proportion of defossilised materials in the final product.

- **Renewable raw materials:**
  Organic raw materials that are not used as food or animal feed, but are used as materials or to generate heat, electricity or fuels.

- **Recycled raw materials:**
  In this paper, the term recycled raw materials covers all raw materials that have undergone the process of reprocessing. This includes mechanical recycling processes as well as chemical recycling processes.

- **Recycling capability:**
  The capability of a product or its components to allow the collection, sorting and separation of product materials for subsequent recycling. Properties that facilitate recycling include, for example, the grade purity or ease of separation of the materials used.

- **Recyclate:**
  Recyclates are raw materials that result from recycling processes. In the recycling of waste, a distinction is made in accordance with DIN EN ISO 14021 between waste after use (post-consumer) and waste before use (pre-consumer, also known as production waste or "post-industrial waste"). Accordingly, "post-industrial recyclates" (PIR) can be differentiated from "post-consumer recyclates" (PCR).

- **High-quality recyclability/recycling to a high standard:**
  A product has all the necessary properties to be reprocessed as a recyclate by recycling processes according to the current state of the art, to be reused and to replace virgin material in an equivalent market.

- **Raw material revolution:**
  The raw material revolution refers to the transition from a linear economic system based primarily on fossil raw materials to an economic system in which material cycles are closed and raw materials are saved or replaced by renewable raw materials.The aim here is, for example, to keep emissions-relevant carbon and its compounds within the cycle as far as possible in order to end the use of fossil raw materials in the long term.

- **Circularity:**
  A property of products: that all materials used in a product can be recycled several times and, as far as possible, kept in almost closed cycles.

- **Circular value creation:**
  Circular value creation is an economic system that works restoratively and regeneratively. It replaces the end-of-life concept with closed cycles and avoids or recycles waste by designing materials, products, systems and business models in a holistic manner. As a result, the material flow and energy system are sustainable, and the climate and environmental impact is minimal.

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