WHITE PAPER

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Circular Economy – Impact on Chemicals & Materials Industry

FutureBridge

Circular economy is considered as a relevant solution to overcome issues, such as booming levels of waste, ocean plastics crisis, and depleting natural resources. The circular economy has been pushed across the value chain as a potential solution—an attractive concept that challenges the existing ‘take-make-waste’ linear model and proposes a circular, more holistic approach to growth that works for both, businesses and the environment. In the linear model, raw materials are extracted from the earth to make a product, and after their use, any waste (e.g., packaging) is thrown away.

The circular economy model strives to ‘close the loop’—optimizing the flow of finite resources, designing out waste, and leveraging economic activity to rebuild sustainable systems.

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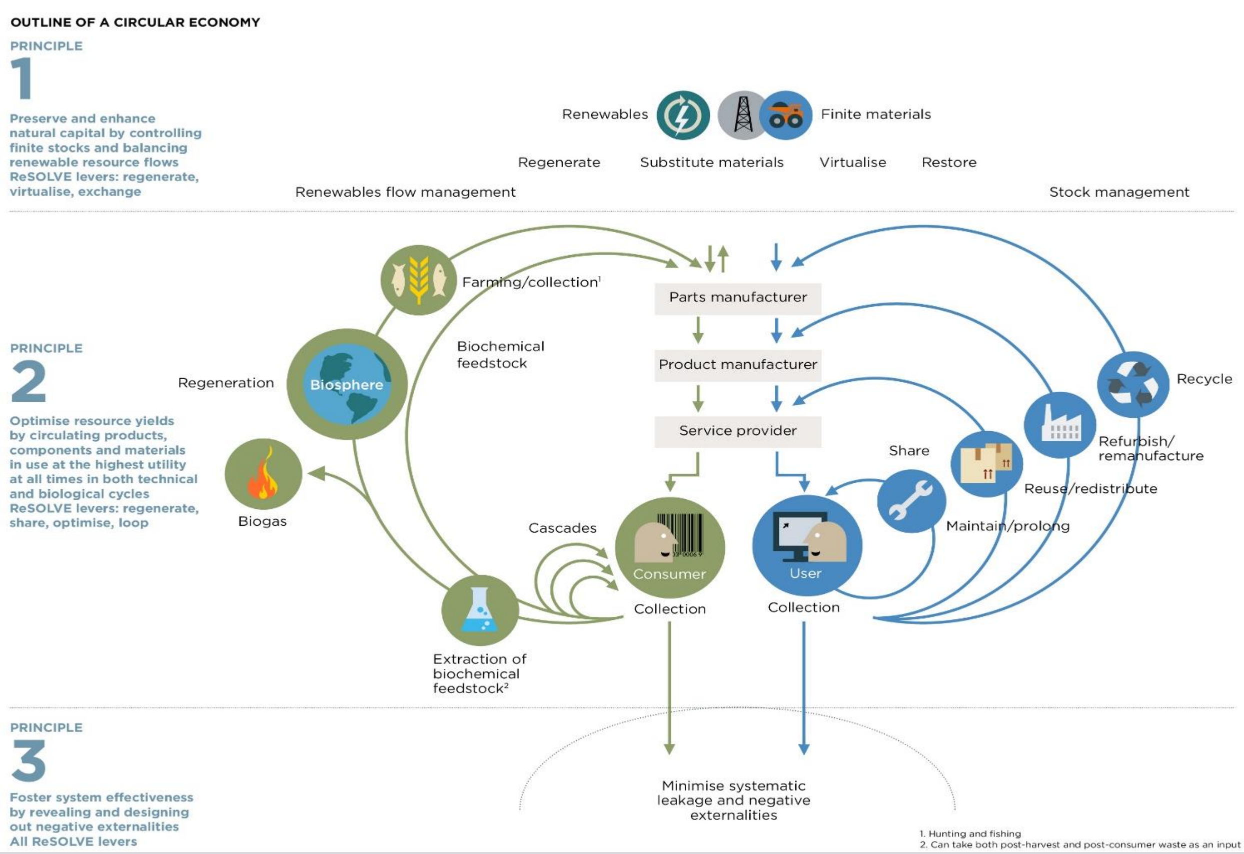
Understanding the Circular Economy

Sustainability has become a vital part of many business strategies across industries, which has prompted growing interest in the circular economy. It is clear that the drive towards a circular economy is likely to lead to significant change for global chemical companies.

A holistic view is fundamental to understanding the circular economy, which is not merely focused on using less. Instead, the circular economy aims to keep products, components, and materials at their highest utility and value at all times. It is restorative and regenerative, and ultimately does reduce resource consumption. But it is also a classic economy in the sense that all activities are aimed at generating an economic benefit.

Thus, the circular economy creates incentives for market participants to contribute to a more sustainable approach to natural resources.

Exhibit 1: Outline of a Circular Economy



Source: Ellen MacArthur Foundation

In essence, the circular economy seeks to replace today's linear, "take-makedispose" approach to resources—where many materials are made into products, the products are used, and then the materials are thrown out. Ideally, in a circular economy, the materials are cycled constantly back through the value chain for reuse, resulting in less energy and resource consumption.
In some industries, elements of the circular economy are already at work. In Europe, for example, 73% of all glass bottles are now collected and recycled rather than thrown away. And scrap steel makes up 50% of the ingredients used in new steel products.

Source:

1. https://www.chemtrust.org/wp-content/uploads/chemtrust-circulareconomy-aug2015.pdf
2. https://www.ellenmacarthurfoundation.org/circular-economy/concept

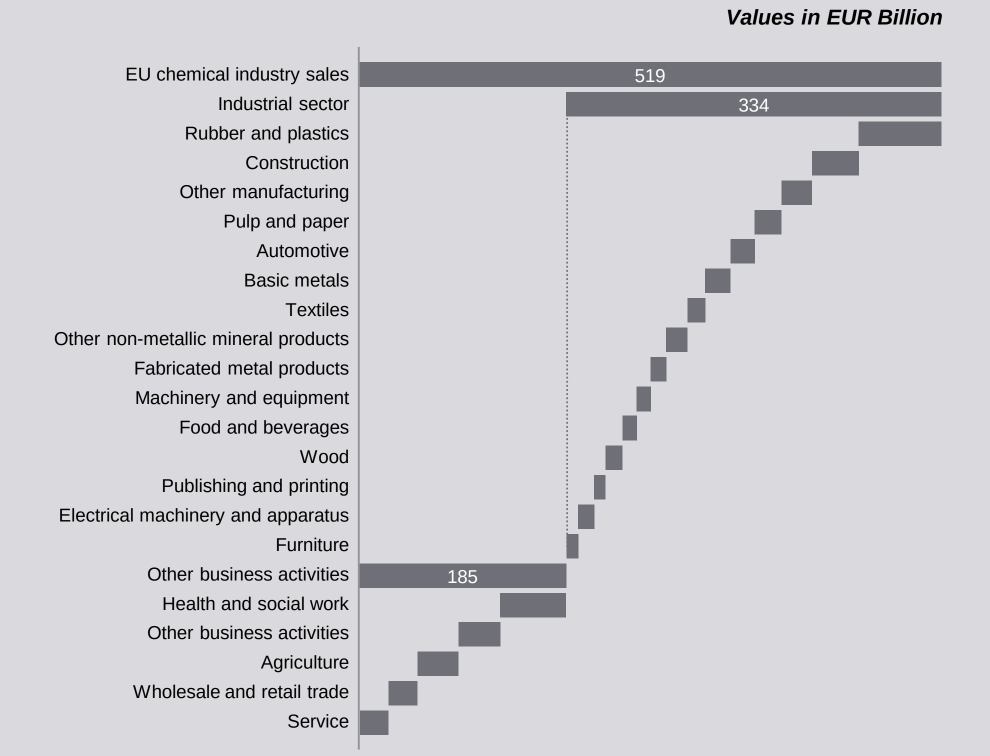
Chemicals and the Circular Chemistry

Awareness of the finite nature of many resources — including the issue of element scarcity as well as the limited environmental tolerance towards our chemical industry has grown tremendously in the past few decades. It has become evident that the linear route of production, in which scarce resources are consumed, and their value-added products are degraded to waste, is a route cause of several impending global crises such as climate change, diminished biodiversity, as well as food, water, and energy shortages.

A circular economy is defined as "restorative and regenerative by design, and aims to keep products, components, and materials at their highest utility and value at all times." Chemistry is crucial for achieving this. Chemists not only understand their role in designing and developing indispensable materials and technologies but also simultaneously recognize the potentially detrimental effects that this may have on their practice. Therefore, they are becoming increasingly aware that each step must be designed or reassessed with sustainability in mind.

The chemical industry produces essential products and solutions that are used by all other industries, often in several steps throughout their value chains, as well as by end users. As a supplier of products and solutions to a variety of customer industries, the chemical industry today enables greater durability and performance in many industrial and end-use applications. For example, it supplies insulation that reduces thermal energy loss in buildings, lightweight materials that reduce the weight of automobiles and coatings that protect materials—along with a multitude of lesser-known applications.

EXHIBIT 2: Downstream Chemical Industry Customers, By Sales



Source: Accenture-Cefic Circular Economy Brochure

The enablement of circular economy models in end-uses and downstream industries represents a massive growth opportunity for the EU chemical industry. Enabling circularity and maximum utility of resources in downstream sectors increases the demand for chemical products. For example, reducing energy consumption in housing requires more insulation material, but it also requires more performance-enhancing chemicals, such as air sealants and special coatings. On an aggregated level, this implies volume and value growth for virtually all chemical segments—from standard chemicals to performance and specialty chemicals.

Source:

1. https://sci-hub.tw/10.1038/s41557-019-0226-9
2. https://cefic.org/app/uploads/2019/02/Accenture-Cefic-circular-economy-brochure.pdf

Understanding Circular Chemistry

Perceiving waste as a resource is a prerequisite for circularity. Redirecting waste streams and using them as chemical feedstocks should become ubiquitous in the synthesis of marketable products in order to achieve complete recirculation of molecules and materials. It is imperative to reduce uncirculated waste in any given process, yet it will not be possible to eliminate degraded materials or products completely. Waste management will, therefore, always be required for the effective circulation of materials.

Eutrophication and climate change are two of the biggest global environmental concerns, largely caused by excess use of phosphorus and nitrogen-based fertilizers, and the utilization of fossil fuels, respectively. The excess of carbon dioxide, nitrous oxide, ammonia, and phosphate waste lost to air, water, and land, perturbs the carbon, nitrogen, and phosphorus cycles, creating a host of adverse environmental impacts. To mitigate these environmental concerns and reduce the impact of the resulting waste products on the environment, novel chemical and biochemical conversions are urgently needed that allow for their efficient recovery and recycling.

In order to succeed in eliminating or reusing waste, optimal process design is needed that allows for the efficient separation, purification, reuse, and recycling of waste products in an environmentally benign way. In organic chemistry, Trost's atom-economy concept stimulated the synthetic efficiency of individual steps. In a similar manner, at the process level, circular chemistry targets maximizing atom circulation in chemical products along with their entire life cycles, regardless of whether chemical bonds are modified or not. Using waste as resource presents a tremendous challenge for the development of novel chemical conversions that can cope with complex waste mixtures as feedstocks for the production of value-added molecules and materials. Addressing this during the initial design of an entire process will mean that products will lend themselves well to being turned into separated waste-streams at the end of their lifecycle. In turn, this approach should enable the subsequent full recycling of any feedstock and product.

Circular chemistry seeks to replace the current linear 'take–makedispose' approach with processes in which materials are continuously cycled back through the value chain for reuse, thereby optimizing resource efficiency and preserving limited feedstocks. Renewable resources offer the chemical industry an opportunity to diversify its raw materials base, but 'greenwashing' (presenting a process or product as greener than it actually is) should be prevented: bio-based materials are typically classified as being sustainable, simply because of renewability of the resource, yet these resources are often created in a linear production process without sustainable end-of-life options.

Principles of Circular Chemistry

1. Collect and use waste: Waste is a valuable resource that should be transformed into marketable products.
2. Maximize atom circulation: Circular processes should aim to maximize the utility of all atoms in existing molecules.
3. Optimize resource efficiency: Resource conservation should be targeted, promoting reuse, and preserving finite feedstocks.
4. Strive for energy persistence: Energy efficiency should be maximized.
5. Enhance process efficiency: Innovations should continuously improve in- and post-process reuse and recycling, preferably on-site.
6. No out-of-plant toxicity: Chemical processes should not release any toxic compounds into the environment.
7. Target optimal design: Design should be based on the highest end-of-life options, accounting for separation, purification, and degradation.
8. Assess sustainability: Environmental assessments (typified by the LCA) should become prevalent to identify inefficiencies in chemical processes.
9. Apply ladder of circularity: The end-of-life options for a product should strive for the highest possibilities on the ladder of circularity.
10. Sell service, not product: Producers should employ service-based business models such as chemical leasing, promoting efficiency over production rate.
11. Reject lock-in: Business and regulatory environment should be flexible to allow the implementation of innovations.
12. Unify industry and provide coherent policy framework: The industry and policy should be unified to create an optimal environment to enable circularity in chemical processes.

Impact of Circular Economy on Chemical Industry Segments

Higher-performance chemical products are likely to see significant demand increases, while more basic chemical products are likely to see less demand. This will stem from two factors: a shift towards higher-performing grades of same material types, and a substitution of individual basic chemicals with higher performing material classes. Examples include higher usage of lightweight composite materials, and coatings with higher performance (i.e., scratch resistance and more air sealing). It is likely that this will open up new opportunities for research and development, too.

Numerous circular economy-related trends — such as car sharing, adoption of e-mobility, increasing efficiency of industrial equipment, and additional insulation for the preservation of thermal energy in buildings and industrial plants — might have a tremendous impact on the consumption patterns of chemical products, both positive and adverse.

TABLE 1: Expected Impact of Circular Economy-related Trends on Demand for Chemical Products until 2030

Product class	Demand driver	Current output	Impact on output until 2030	Demand change
Polymers	Carsharing	45 Mt	-1.5%	-0.7 Mt
	E-mobility		2%	+0.9 Mt
	Housing insulation		30%	+13.4 Mt
	Pipe insulation		10%	+4.5 Mt
Specialties	Carsharing	28 Mt	5%	+1.4 Mt
	E-mobility		23%	+6.5 Mt
	Plant efficiency		10%	+2.8 Mt
Fertilizer	Digital farming	17 Mt	-5%	-0.8 Mt
Others[1]	–	16 Mt	–	–
Total	**–**	**106 Mt**	**–**	**+28 Mt**

[1] Include inter alia resins, rubbers, solvents
Source: Accenture-Cefic Circular Economy Brochure

Demand Drivers for Chemicals

The nature of demand drivers for chemicals will vary as per the industry and as per the needs of the particular industry. In the automotive segment, ‘durability & recyclability’ would be the positive demand drivers while ‘low weight & fewer cars’ could have a negative effect. Similarly, the need for more sealing and advanced coatings, more construction chemicals, and more insulation would be the positive demand drivers in the construction segment.

EXHIBIT 3: Demand Drivers for Chemicals

	Overall volume	Volume of standard products	Volume of specialty products
MOBILITY/ AUTO	Smaller & fewer cars (Car sharing)	Lower weight Fewer cars	Durability, recyclability
RESIDENTIAL CONSTRUCTION	More construction chemicals	More insulation Pipe material substitution	More sealing Advanced coatings
FOOD AND AGRICULTURE	Environmental awareness	Less NPK Advanced food packaging	Stricter pesticide release
SOAPERS	Less naphta, more plant based/ sugar surfactants	Substitution plant-based materials	More plant based, new applications

Adverse impact Mixed impact Beneficial impact Not applicable

Source: Accenture-Cefic Circular Economy Brochure

Impact on Basic Chemicals and Intermediates

In the automotive and construction industries, the impact is expected to be positive, driven by an increase in demand for industrial gases and organic intermediates.

Basic chemicals and intermediates could see a fall in demand in the food and agriculture industry, as well as the soap industry as the demand in these industries, would be shifting towards plant-based chemicals, biofertilizers, and etc.

EXHIBIT 4: Impact on the Chemical Industry from the Circular Economy Perspective

	Industrial gases	Primary chemicals	Organic intermediates	Inorganic intermediates
MOBILITY/ AUTO	Rising hydrogen demand	Smaller & fewer cars (Car sharing)	Methanol/ alternative fuels	
RESIDENTIAL CONSTRUCTION		More residential floor space per capita	More residential floor space per capita	
FOOD AND AGRICULTURE		Dosed NPK/ pesticide application	Dosed pesticide application	Bio-fertilizer, more phosphate recovery
SOAPERS		More plant-based	More plant-based	

Adverse impact Mixed impact Beneficial impact Not applicable

Source: Accenture-Cefic Circular Economy Brochure

Impact on Chemical Products

Overall, the impact of the circular economy on chemical products will be positive in the construction industry, driven by an increase in demand for insulation, coatings, and pigments. The food and agriculture industry would see a mixed impact with the trend shifting towards more bio-based and fewer volume applications. In the automotive industry, the trends toward smaller and fewer cars and a greater focus on sustainability are likely to reduce the demand for chemical products.

EXHIBIT 5: Impact on Chemical Products

	Standard polymers	Engineering polymers	Consumer chemicals	Dyes and coatings	Agricultural chemicals	Other specialties
MOBILITY/ AUTO	Smaller & fewer cars (Car sharing)	Durability, recyclability		Smaller & fewer cars (Car Sharing)		E-Mobility
RESIDENTIAL CONSTRUCTION	More insulation	More insulation		Air sealing Reflective coatings/pigments		Photovoltaics/ energy storage
FOOD AND AGRICULTURE	More food packaging	Advanced food packaging			Less volume application, more service models	
SOAPERS			More veg. oil/sugar surfactants	Less packaging		Concentrates, e.g. photovoltaic cleaning

Adverse impact Mixed impact Beneficial impact Not applicable

Source: Accenture-Cefic Circular Economy Brochure

Circulating Molecules: Where and How in the Chemical Industry can Circular Economy be Applied?

As the term suggests, circulating molecules means reusing existing molecules—either in the form of hydrocarbons contained in biomass or in the form of chemical materials contained in end-consumer products.

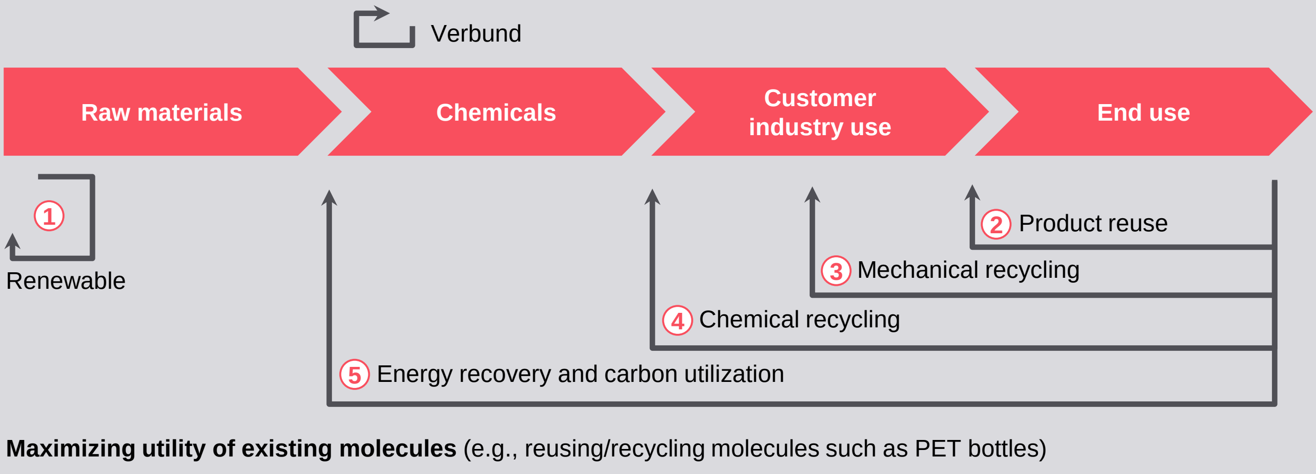
As more existing molecules are circulated, the need to produce chemical precursors from fossil-based raw materials will be reduced.

This level of recycling could be accomplished through the maximized use of five molecule-circulating loops in the industry:

- Loop 1: Circularity based on renewable feedstock
- Loop 2: Circularity based on increased reuse of products containing chemical industry outputs
- Loop 3: Circularity based on molecule reuse (mechanical recycling)

- Loop 4: Circularity based on modification of molecules and reuse as precursors (chemical recycling)
- Loop 5: Circularity based on energy recovery and reuse of CO_2

EXHIBIT 6: Circulating Molecules through Five Lopes



Source: Accenture-Cefic Circular Economy Brochure

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1. https://sci-hub.tw/10.1038/s41557-019-0226-9
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Materials and Circular Economy

Plastic Industry and Circular Economy

Plastic is an essential and ubiquitous material in our economy and daily lives. It has multiple functions that help tackle a number of challenges facing our society. Light and innovative materials in cars or planes save fuel and cut CO_2 emissions. High-performance insulation materials help us save on energy bills. In packaging, plastics help ensure food safety and reduce food waste. Combined with 3D printing, bio-compatible plastic materials can save human lives by enabling medical innovation.

However, too often, the way plastics are currently produced, used, and discarded fails to capture the economic benefits of a more 'circular' approach and harms the environment. There is an urgent need to tackle the environmental problems that today cast a shadow over the production, use, and consumption of plastics. The million tons of plastic litter that end up in the oceans every year are one of the most visible and alarming signs of these problems, causing growing public concern.

Current Plastic Production and Waste Scenario

The production of plastics increased by more than twenty-fold between 1964 and 2015, with an annual output of 322 metric tons (Mt), and is expected to double by 2035, and almost quadruple by 2050. Plastics contribute to economic growth, but their current production and use pattern, on a linear model of ‘take, make, use, and dispose,’ is a primary driver of natural resource depletion, waste, environmental degradation, climate change, and has adverse human health effects.

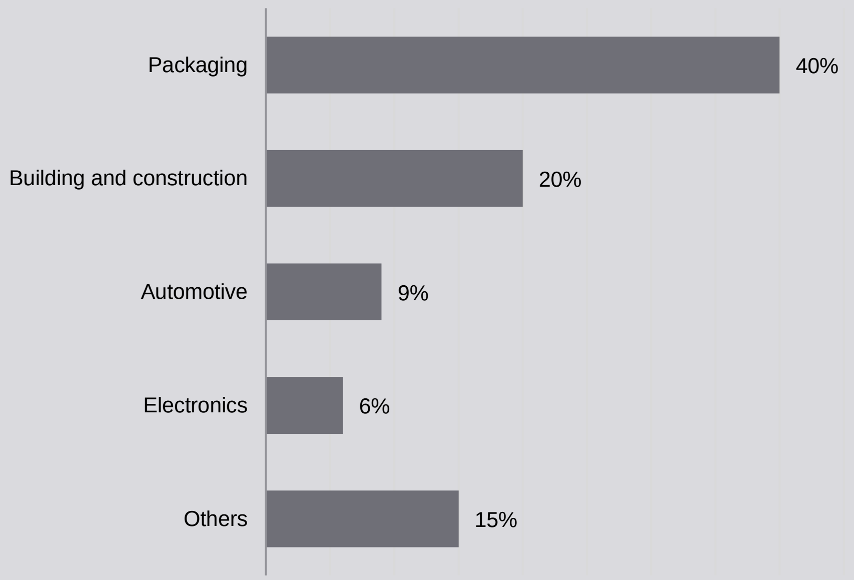
About 4,900 Mt of the estimated 6,300 Mt total of plastics ever produced have been discarded either in landfills or elsewhere in the environment. This is expected to increase to 12,000 Mt by 2050 unless action is taken. The ocean is estimated to already contain over 150 Mt of plastics; or more than 5 trillion micro and macro plastic particles. The amount of oceans plastic could triple by 2025 without further intervention. By 2050, there will be more plastics, by weight, in the oceans than fish, if the current ‘take, make, use, and dispose’ model continues.

Plastics stay in the environment for a long time; some take up to 500 years to break down; this causes damage, harms biodiversity, and depletes the ecosystem services needed to support life. In the marine environment, plastics are broken down into tiny pieces (microplastics) which threaten marine biodiversity. Furthermore, microplastics can end up in the food chain, with potentially damaging effects, because they may accumulate high concentrations of POPs and other toxic chemicals.

The circular economy is an alternative to the current linear, make, use, and dispose economy model, which aims to keep resources in use for as long as possible, to extract the maximum value from them whilst in use, and to recover and regenerate products and materials at the end of their service life. It offers an opportunity to minimize the negative impacts of plastics while maximizing the benefits from plastics and their products, and providing environmental, economic, and societal benefits. Circular economy solutions for plastics include: producing plastics from alternative non-fossil fuel feedstock; using plastic wastes as a resource; redesigning plastic manufacturing processes and products to enhance longevity, reusability and waste prevention; collaboration between businesses and consumers to encourage recycling and increase the value of plastic products; supporting sustainable business models that promote plastic products as services, and encourage sharing and leasing; developing robust information platforms to aid circular solutions; and adopting fiscal and regulatory measures to support the circular economy.

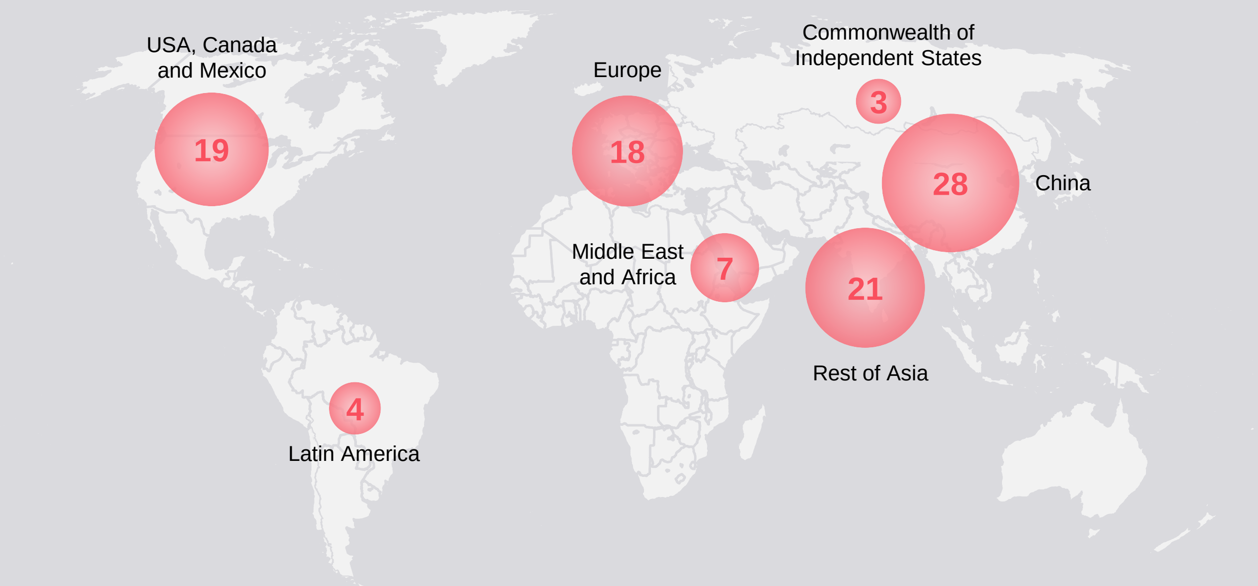
Circular economy solutions will help in ‘closing the material loop,’ to minimize waste and to keep materials in the economy and out of landfills and incinerators, but the circular economy will not completely solve the global plastic problem. An all-encompassing solution should seek to ‘slow the material loop,’ that is to reduce demand and produce only essential plastic products, including through discouraging non-essential production and use of plastics, and promoting the use of renewable and recyclable alternatives to plastics.

EXHIBIT 7: Percentage of Plastic Production across Industries



Source: FutureBridge Analysis

EXHIBIT 8: Global Distribution of Plastics Production



Source: Stapgef.org

Introducing Circular Economy in Plastics: By Design

Material design of plastics can be altered to facilitate the circular economy. For example, the design of plastic components to facilitate dismantling and the capability to recycle the polymers. In the value chain, it is mainly the simulation, material, and manufacturing steps that are the key stages to reach an optimum for a circular economy by design.

The technologies are categorized according to their desired path to increase circularity.

A. Extend lifetime

Specific challenges:

Repairing and preserving polymer properties. These technologies aim to reduce end-of-life plastic waste by extending the lifetime of polymer materials (and hence product/ article lifetime). Repairing and preserving polymer properties (e.g., self-healing polymers) are a solution in the medium to long-term.

Improving aging performance. External conditions such as (extreme) temperature, pressure, UV exposure, humidity, mechanical stress, and others can, over time, degrade material properties, and decrease their performance. In order to increase article lifetime, it is desirable to limit the degradation due to the aging mechanisms and improve aging performance. Different approaches have been developed like the addition of additives in the plastic or composites matrix and their well-controlled application in relevant areas throughout the matrix structure. To control these improvements at the nano-reinforcement and polymeric matrix interface, there is a need to improve chemical compatibility and dispersion stability as well as increasing mixing efficiency as necessary.

B. Decrease material usage

Specific challenges:

Improve performance. Ever growing demand for high performing materials and more complex products increases the need for material usage, in terms of quantity and variety.

C. Improve sorting

Specific challenges:

Technologies are aiming to improve the inherent sorting characteristics of polymers. The wide variety of plastics and their diversity of characteristics make the plastic sorting process very complex and inefficient, resulting in large losses of material value. The identification of different types of polymers among plastic waste is not efficient enough due to the variety of colors, properties, and shapes. Multilayer materials, dark, and especially black, colored plastics and compostable plastics are especially challenging when it comes to detection, sorting, and separation.

D. Improve separation

Specific challenges:

Technologies are aiming to improve the inherent separation characteristics of polymers. Multilayer or multi polymer structures are some of the plastic waste streams which need an efficient separation in order to improve the quality of recycled plastics and to decrease landfill. Multilayer polymers and composites present severe limitations for separation due to the different properties of each component. For example, the presence of dynamic chemical crosslinks in thermoset fiber reinforced polymer composites (TS FRP) could enable the chemical separation of the matrix from fiber reinforcement.

E. Increase recyclability

Specific challenges:

Recycling of multi-layer films or recycling of waste from electrical and electronic equipment (WEEE) is difficult due to the multiple types of polymers included in such products and the difficulty in separating them. The transformation from multicomponent (multilayer or blend of polymers) compositions to one compatible multiphase mixture (which can be more easily reprocessed) by incorporating compatibilizing substances is necessary.

Introducing Circular Economy in Plastics: By Recycling

A. Plastic stream preparation (waste pre-treatment)

Specific Challenges

Plastic articles to be recycled contain solid and liquid contaminants that result from their specific use and history. These contaminants can significantly affect the quality of the recycling output and are not easily removable. In addition, they may convey to the plastics notable odors that do not modify their physical or chemical properties but can make the recycled materials unfit for some specific uses. The contamination of used farm films is a typical example. In mulching and semi-forcing techniques, the contamination of the plastic films can represent up to 70% of the volume collected, leading to high additional costs in terms of recovery operations and treatment. In the specific case of plastics used in packaging, an additional challenge is the removal of the inks which are often directly printed on the polymer films. Removal of these inks is difficult, costly, and energy intensive. As a result, plastic waste with printed inks is often recycled and used in lower value products, such as plastic shopping bags. To decrease this value loss, cost, and energy, efficient technologies for ink removal need to be developed.

B. Sorting and separation

Specific Challenges

The composition of the waste streams of polymer articles can vary from a stream composed solely of rigid bottles (mainly PET and PE) to streams containing additional trays, pots, and films, with a wide range of different polymers. Rigid plastics can contain films that are often multi-layered and difficult to separate. Bottles can be covered in PVC sleeve labels, or PET grade materials need to be separated from bottles and trays. Furthermore, applications polymers are often mixed with other materials (e.g., wood, metals, oil, etc.) and can contain legacy additives, such as Brominated Flame Retardants (BrFR) and also organic additives such as plasticizers and dyes for which sorting and separation are difficult. In order to recycle these streams efficiently, the sorting of polymer articles by their constituent materials is of primary importance. This sorting ensures a minimum of waste and high quality and high purity end product. This sorting is particularly tedious for small or light plastic items due to their specific geometry, morphology, and low weight. The two main routes currently employed, namely wet and dry sorting, still require further technical enhancements and cost reduction to ensure a wide deployment and an increase in the overall recovery yield of plastics. Special attention should be given to both the construction and the packaging sector as well as to bio-based polymers for which the current level of recycling is not as high as for fossil-based polymers due to the lower market volumes. The final goal of recycling is to reduce the environmental impact; solutions developed should avoid using consumables, which generate a negative impact on the environment.

C. Recycling

1. Mechanical recycling

Specific Challenges

Even with super-precise selection and sorting methods, polymer streams will often consist of a mix of different grades of polymers. Mechanical recycling allows the production of decently clean and defined materials without chemical treatment. Recyclability of FRP articles is however more difficult, usually shows low yield (particularly for the matrix), and fibers are significantly degraded, resulting in secondary use in lower value applications after each lifecycle.

2. Chemical recycling

Specific Challenges

Post-consumer waste is often not completely clean and contains impurities, color pigments, or legacy hazardous additives such as DEHP and Pb. This generates an issue with post-recycling output, as these impurities are typically diluted and not completely removed, which creates restrictions on the sectors that the secondary material can be used in.

3. Thermal and thermochemical recycling

Specific Challenges

Thermal-based processes for molecular chain cutting systems are highly energy intensive, and, in some cases, they degrade the surface of the recycled material. The addition of chemical processes can enhance the overall process and provide a better alternative. However, issues of the high cost of utilities (steam, electric power, water), low yields, and low-quality of the final product need to be addressed in order to make it more financially, industrially and environmentally attractive. The main outcome of the process is an oily liquid (synthetic crude oil), which can be upgraded into raw materials for chemicals and materials. The composition of the liquid varies depending on the input waste. Some purification technologies to remove hazardous chemicals exist and new ones are under development. Chemical recycling could be applied to many plastics streams which are not suitable for mechanical recycling.

Introducing Circular Economy in Plastics: By Alternative Feedstock

A. Plastic waste-based:

1. Thermal recycling

Specific Challenge

Fiber degradation in FRP. Limit fiber degradation (mechanical resistance, length, fiber structure) along with increasing polymer matrix recovery.

2. Thermo-chemical recycling

Specific Challenges

Replace only-thermal based processes. Thermal-based processes for molecular chain cutting systems are highly energy intensive, and in some cases, they degrade the surface of the recycled material. Chemical processes can provide a better alternative, but issues of the high cost of utilities (steam, electric power, water); low yields; and low-quality rate of the final product needs to be addressed in order to make it more financially, industrially and environmentally attractive. The main outcome of the process is an oily liquid (synthetic crude oil), which can be upgraded into raw materials for chemicals and materials. The composition of the liquid varies depending on the input waste. Some purification technologies to remove hazardous chemicals exist and new ones are under development. Chemical recycling could be applied to many plastics streams which are not suitable for eco-efficient mechanical recycling.

3. Biological recycling

Specific Challenges

Depolymerization of polymers back to monomers. The biological recycling (controlled biodegradation) of condensation polymers (PU, PET, etc.) needs to be done in a controlled way so that monomers or new molecules can be consistently recovered from such a process.

B. Agricultural, forest biomass, and waste-based raw materials

Side streams of both agricultural and forest feedstock are a good source of feedstock for bio-based polymers.

Challenges

Forest and agricultural residues represent an abundant and potentially sustainable source of biomass, which could be used as a feedstock for chemicals, fuels, and materials in the future. The C6 sugars can be converted into chemical intermediates, and lingo-cellulosic biomass, in general, can be converted to thermoplastic materials by chemical and/or enzyme treatments. Materials in which natural fibers are combined with bio-based thermoplastic matrix, such as Sulapac, can provide sustainable bio-based solutions for specific applications, e.g., in the area of packaging. Major challenges are associated with conversion inefficiencies for this biomass-to product approach.

C. CO_2/CO-based

Technologies convert CO_2 (and/ or CO from gaseous industrial effluents) into polymers or chemical building blocks, which, in turn, can be converted into polymers.

Specific Challenge

Energy efficiency and cost-effective purification of gaseous industrial effluents, up to the appropriate level of purification required for the chemical conversion process, are essential to the deployment of CO_2-to-plastics technologies, in particular for commodity plastics. The optimization of state-of-the-art technologies should be complemented by new capture and purification technologies.

Improving the economics and quality of plastic recycling

Stepping up the recycling of plastics can bring significant environmental and economic benefits. Higher levels of plastic recycling, comparable with those of other materials, will only be achieved by improving the way plastics and plastics articles are produced and designed. It will also require increased cooperation across the value chain: from industry, plastics manufacturers, and converters to public and private waste management companies.

Specifically, key players should work together to:

- Improve design and support innovation to make plastics and plastic products easier to recycle
- Expand and improve the separate collection of plastic waste, to ensure quality inputs to the recycling industry
- Expand and modernize the EU's sorting and recycling capacity
- Reate viable markets for recycled and renewable plastics

Recent activities in plastic recycling

In order to move to zero waste, the chemistry industry sees opportunities to triple mechanical recycling rates from 15% to as much as 40%, noting that this shift will take monumental changes to product design, consumer behavior and waste management activities. The industry also foresees a limited increase for energy recovery by converting plastic waste into energy (currently at 15%), due to a lack of public desire to increase this share. By 2040, that still leaves 40% of post-use plastics to be diverted from landfill.

Innovations in plastics recycling to fuels (e.g., diesel) and chemicals, via advanced conversion technologies, will be key to meet this gap. Where plastics can't be mechanically recycled, the industry is exploring capabilities to process these materials back into chemicals used as feedstock to manufacture new items. Where that isn't possible, plastics can be converted into fuels to replace coal and coke in the cement industry, used in industrial boilers and furnaces, or they can be converted into liquid fuels to lower the greenhouse gas footprint of diesel and heavy fuels.

An important principle of the circular economy is increasing the capture of materials in waste streams so that they can be recycled, recovered, and reused in new products. But a circular economy involves far more than just upgrading traditional mechanical recycling — it's a new economic model where, ultimately, the waste of one process becomes a feedstock for another process, and ultimately, waste is eliminated. The guiding principle is to use products and resources in the best way possible without any loss in performance and value or any increase in environmental life-cycle impact. We will never be able to reach 100% diversion / zero waste goals from mechanical recycling alone. Other waste management options for energy recovery and chemical recycling are needed to advance a circular economy.

EXHIBIT 9: Plastics in a Circular Economy

Source: Canadianchemistry.ca

Hard to recycle plastics

Dow Chemical has teamed with municipal and industry partners to implement an innovative program to collect hard-to-recycle plastic items — like juice pouches, straws, stir sticks, candy wrappers, and plastic dinnerware — and convert them into valuable resources such as low-sulfur diesel and waxes and kept out of the landfill.

Through the HEFTY ENERGYBAG program, residents in several North American municipalities are putting these plastics into special orange bags, where they are picked up and sent to a local material recovery facility, sorted and sent to locally approved energy recovery facilities. By recovering the embedded energy in plastic to make new products, Dow and its partners are helping keep plastic waste out of our landfills, reduce greenhouse gas emissions, and extract maximum value from our resources.

Fully recyclable stand-up food pouches

As the leading suppliers of polyethylene in the Americas, NOVA Chemicals and Dow have developed a versatile, all-polyethylene (PE) version of the popular stand-up pouch package used for food products. The structures are compatible with #2 HDPE recycling streams — which are widely accepted at recycling centers — while retaining the performance, processability, and cost-competitiveness of existing mixed-material structures. The stand-up pouches are used for a wide variety of applications including dry foods, frozen foods, liquids, confectionery, pet foods, and non-food items. However, most existing stand-up pouch packaging is made from mixed materials and therefore, cannot be easily recycled.

Using this same concept, NOVA and Dow have also developed an easily recyclable, oxygen-barrier film for food packaging. Products such as cheese, meat, nuts, and other food that have traditionally required rigid or non-recyclable mixed-material packaging can now be sold in high-performance, recyclable flexible packaging.

Biodegradable plastics

In the 1990s, BASF was the first major plastics manufacturer to develop a biodegradable plastic, called ECOFLEX. This certified compostable and biodegradable polymer is an important raw material for many compostable and bio-based plastics. It is elastic, water and tear-resistant, processable with conventional film plants (for polyethylene), printable, weldable, and suitable for food contact. ECOFLEX breaks down naturally with no accumulation of toxins to the environment.

A new BASF product, ECOVIO, consists of ECOFLEX and a high content of polylactic acid. ECOVIO is used in organic waste bags, dual-use bags (shopping, then for organic waste) or agricultural films. Compostable packaging solutions such as paper-coating, shrink films, foam packaging, and injection molding products can also be produced with ECOVIO.

Converting Polystyrene

ReVital Polymers, Pyrowave, and INEOS Styrolution announced a partnership in 2018 to recycle polystyrene packaging collected in consumer curbside and depot recycling systems as well as other sources such as restaurants, offices, schools, and universities. This made-in-Canada collaboration will use advanced recycling technology from Pyrowave that will recycle single-serve polystyrene packaging and use recycled polystyrene in the manufacturing of new products and packaging. This Canadian solution will help reduce the amount of polystyrene packaging going to landfill regardless of color, food residue, or odors.

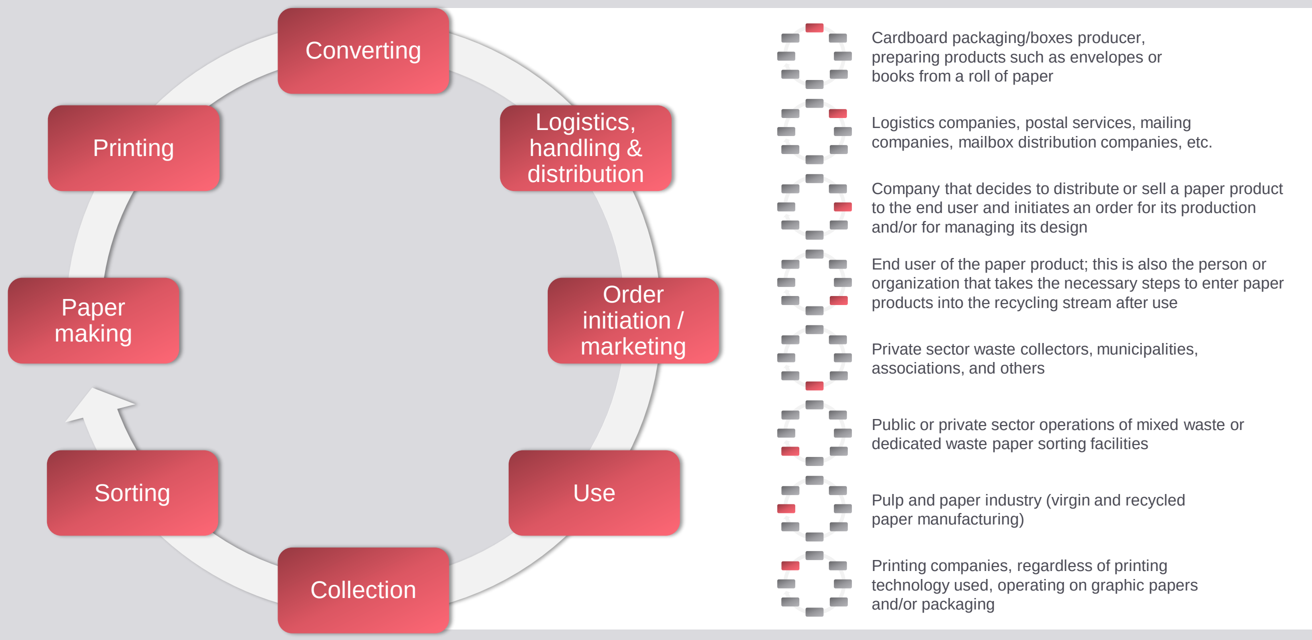
Source:

1. https://sustainability.com/our-work/insights/creating-a-circular-economy-for-plastics/ - Creating a Circular Economy for Plastics
2. http://ec.europa.eu/environment/circular-economy/pdf/plastics-strategy-brochure.pdf - EU strategy for plastic in circular economy
3. https://www.treehugger.com/plastic/how-plastics-industry-hijacking-circular-economy.html - How the plastics industry is hijacking the circular economy
4. https://www.unilever.com/sustainable-living/reducing-environmental-impact/waste-and-packaging/rethinking-plastic-packaging/ - Unilever doc on plastic packaging CE
5. https://www.bpf.co.uk/vision/default.aspx - BPF note on plastic CE
6. http://www.stapgef.org/sites/default/files/documents/PLASTICS%20formatted%20for%20posting.pdf – Plastic & the circular economy
7. https://www.hbm4eu.eu/wp-content/uploads/2019/03/2019_RI_Report_A-circular-economy-for-plastics.pdf - EU commission CE for plastics

Paper Products and Circular Economy

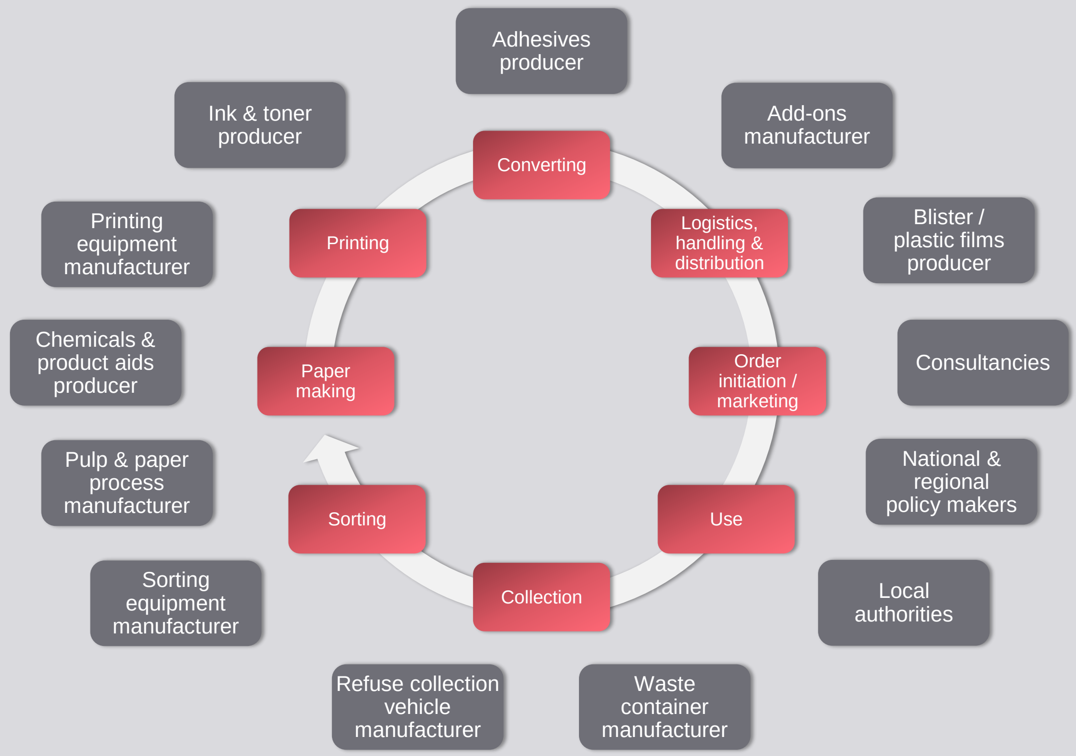
The life cycle of a paper product is composed of a series of value-adding steps, from the extraction of natural resources until the end of the paper product's life. In a circular economy scheme, the product's end of life is reconnected with its production by reusing the already extracted resources, which are contained in used products. This circular economy scheme is particularly suitable for the pulp and paper sector, thanks to the possibility of producing paper and packaging from used paper products. Using the right fiber for an application is essential, as fresh and recycled fibers have different characteristics. As fiber quality deteriorates in the recycling process, fresh fibers are always needed in the recycling loop. Because of fast cycles, the quantity of fiber would run out in about six months if fresh fiber were not constantly added to the life cycle. The addition of fresh fiber starts either with the production of products that need specific fiber properties or with the combination with recycled fibers. For a dramatically improved performance in the circular paper product supply chain, both direct and indirect actors need to understand and familiarize themselves with the recommendations provided herein. The direct actors of the paper life cycle "touch" the fiber in paper-based products or directly influence its quality or lifetime.

EXHIBIT 10: Direct Actors in the Paper Product Life Cycle



Note: The sequence of the actors does not necessarily illustrate the flow of materials
Source: World Economic Forum

EXHIBIT 11: Indirect Actors in the Paper Product Life Cycle



Source: World Economic Forum

Designing and Management of Paper Products to Introduce Circular Economy

A circular economy seeks to maximize not just efficiency, but also effectiveness. Achieving this requires awareness and knowledge of circular economy principles at each step of the value chain and a holistic approach to applying them. The three core principles of the circular economy of paper products are:

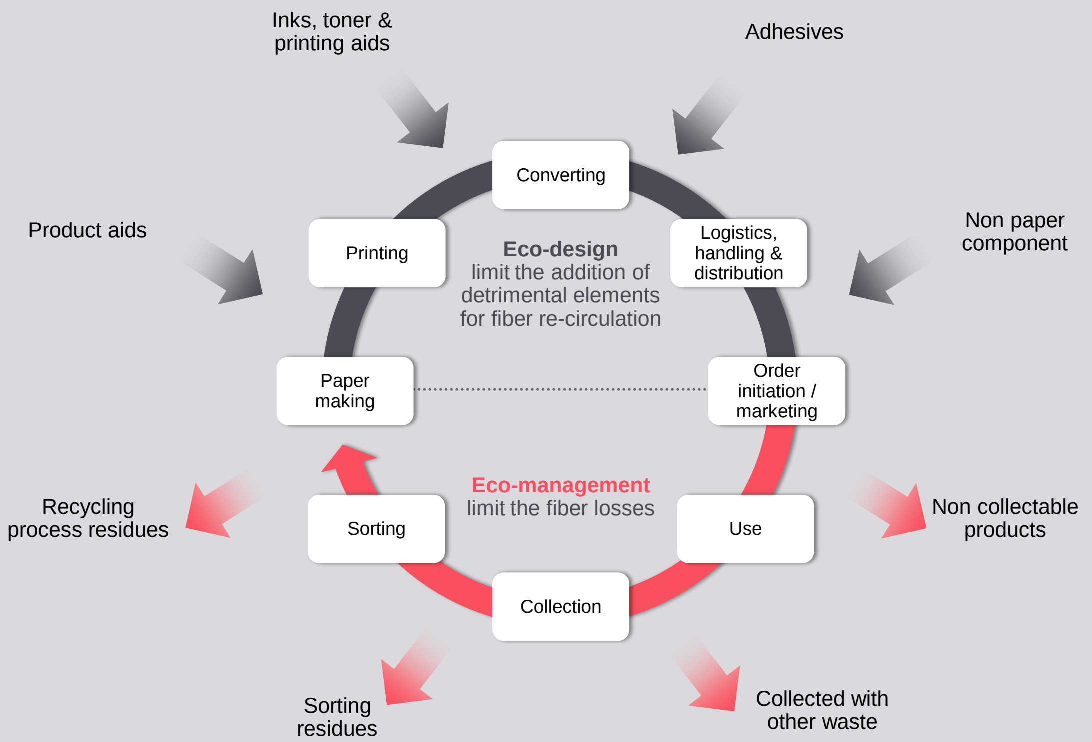
Preserve and enhance natural capital by controlling finite stocks and balancing renewable resource flows; optimize resource use and preserve value all along the value chain.

Optimize resource yields by circulating products, components, and materials in use at the highest utility at all times in both technical and biological cycles, and connecting the downstream value chain back into the upstream value chain.

Foster system effectiveness by revealing and designing out negative externalities; systemic impacts are identified, understood, and potentially mitigated, and are taken into account together with the total value of the paper or packaging item.

By following these three principles, the value of materials will not be destroyed. In cases where current technology does not allow full recovery of all of such materials, those materials will at the very least not destroy the value of other materials that can already be recovered, thus supporting circularity.

EXHIBIT 12: Non-fiber Inputs and Outputs in the Paper Product Life Cycle

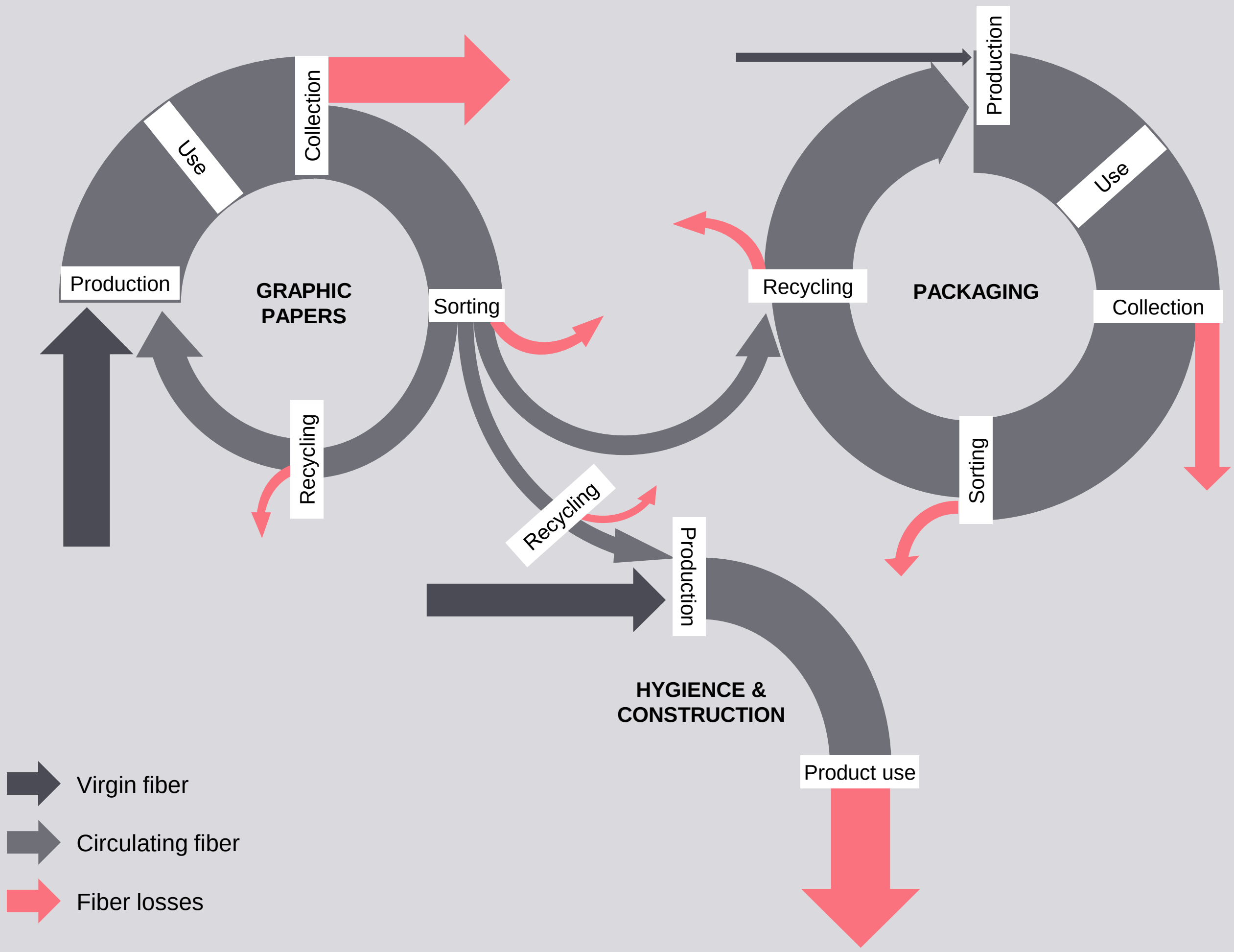


Source: World Economic Forum

Eco-design recommendations will contribute to simplifying the recovery of the fiber and maintaining its properties, considering that the circular economy of paper products is based on reusing the fiber already extracted from wood to produce new products. Thus, it should be easy to separate fiber from all other materials and substances used to produce and utilize the paper-based product. Applicable recycling technologies should be taken into account and developed or optimized as appropriate. Each element that is difficult to separate from the fiber will decrease the fiber's quality and generate fiber losses – which need to be replaced with virgin fiber.

Exhibit 13 illustrates fiber losses (red arrows) and transfers (gray arrows) in paper product life cycle loops and shows the direct link with the request for virgin fibers (dark gray arrows). While virgin fibers will always be needed in the pulp and paper industry, eco-design and eco-management can help reduce dependence on resources and increase the value chain's resilience.

EXHIBIT 13: Fiber Life Cycles



Source: World Economic Forum

Impact on the Paper Industry

Paper and printing is one example of an area that is difficult to imagine in a regenerative and restorative circular economy. The enormous growth in the use of computers, mobile devices, and e-readers have made little impact on the use of paper, and the 'paperless office' utopia remains distant. The paper industry today requires substantial inputs, especially water and energy, and landfill is still a common end-of-use route.

One option could be cleaner, more effective, and more widespread recycling practices. Paper could also be better designed as a biological nutrient, rebuilding natural capital.

Paper is a natural fit for the circular economy model. Paper-based materials are becoming the go-to replacement as companies look for more sustainable ways to produce their products. Wood, paper, and paper-based products, in many circumstances, tie into the circular economy model because of the following facts:

Paper is one of the few truly sustainable products. Each year, forests in North America grow significantly more wood than is harvested. North American forests are a renewable resource that is continuously replenished using sustainable forest management.

Paper is highly recyclable. Paper is recycled more than any other commodity in the solid waste stream and is often the dominant raw material used in paper production. A combination of fresh wood supply and recycled paper allows printing and writing paper to be down-cycled to other products like corrugated boxes, tissue, and other packaging.

Much of the energy used for papermaking is renewable. Roughly two-thirds of the energy used by North American pulp and paper mills is self-generated using renewable biomass in combination with heat and power (CHP) systems. The paper industry uses more renewable energy than any other industrial sector.

The end user's consumption of paper is more “push” than “pull”; this means that most paper products are sent or distributed to end users without them making a specific request. Consequently, the order initiator often dictates the design of circularity choices and orders and/or sells the final paper product, rather than working with end users through their consumption choices. Thus, a checklist was found to be useful specifically for the order initiator's supply chain. Through the order initiation process, the task of detailing out some of these choices may be delegated to other actors in the supply chain.

1. Rethink and define the paper product's goals:

- What type of information is to be communicated and what product objectives are to be accomplished?
- What reactions should be expected from readers/ consumers?
- What is the end-reader/end-user target market?
- Have the number of copies required been adjusted to the real needs of the target? (Be careful with quotations referring to the “additional 1,000” products)
- What is the lifetime of the printed paper/packaging? How long is any information valid? (Or how long is it useful?)
- What image of the company should be upheld?
- How accurate is the size of the audience? How quickly can a response be made to increasing demand?

2. Identify different design choices and their impact

Making conscious choices should take into account the paper product's goals, efficiency, and impacts. For instance, a paper-based product needs to be functional; packaging's primary role is to protect and promote the product inside. Functionality is the key design determinant for the quantity and type of paper used, as well as for the quantity and nature of ancillary materials, such as inks and adhesives. Functionality is essential to preserving both the value of the fiber in the packaging and the value of the materials used in the product

Source:

1. Paper and the Circular Economy
https://twosidesna.org/US/paper-and-the-circular-economy/

2. Paper and the Circular Economy
http://www.paperage.com/2018news/09_20_2018paper_circular_economy.html

3. Paper product lifecycle and the circular economy
http://www3.weforum.org/docs/WEF_Design_Management_for_Circularity.pdf

4. A new circular approach towards paper use in the digital era https://www.ellenmacarthurfoundation.org/case-studies/reep

Glass Industry and Circular Economy

Glass is still a unique commodity in today's materials market, despite it having been around for thousands of years. Used every day throughout the built environment and by billions of people, it is a substance that comes with countless advantages for both consumers and the environment. As it is 100% recyclable, glass can be melted down and remolded an infinite number of times. The container glass industry has the potential to provide a perfect example of a scalable circular economy in action.

But despite this, there is still work to be done in the glass industry to close the loop in its circular economy, especially in the UK, where 32% of all glass being produced is still not being recycled.

The European Container Glass manufacturing industry is a circular model genuinely recycling used bottles and jars to manufacture new ones. Once produced, glass is one of those rare materials that can be 100% and infinitely recycled in a bottle to bottle loop without any loss of quality: recycled glass is not waste, but a precious resource the industry requires to replace virgin raw materials.

Glass recycling has many benefits: more than 70% of all post-consumer glass packaging is recycled in the EU, so keeping valuable resources out of landfills. One ton of recycled glass saves 1.2 tons of virgin raw materials and cuts CO_2 emissions by 60%.

The Container Glass manufacturing industry also highly contributes to the EU economic and social welfare by creating jobs and contributing to the trade value of the goods put on the market. Some 125,000 direct and indirect jobs are maintained by the sector, supporting a wide range of other industries in local regions. Annually, it invests up to €610 million to innovate and maintain a network for 155 EU plants. This equals 10% of the industry's operational costs every year. The industry contributes €9.5 billion directly to the EU annual GDP. In addition, it indirectly contributes to a positive trade balance of more than €21 billion via products primarily packed in glass. The container glass manufacturing model fits perfectly with the EU's ambition to build a circular economy. In order to close the loop and achieve a complete circular economy for glass packaging in Europe, the European container glass industry calls on the European Institutions to consider the following points as essentials of a Circular Economy:

- Multiple recycling of a permanent material is the best option for resource efficiency
- Separate collection and a ban on backfilling for recyclable materials are key to ensure that the best quality recyclates are re-introduced into the production process.
- Manufacturing industries, such as glass packaging, which produce sustainable products, create jobs, and bring added-value to Europe need to be supported, as they already are successful examples of a European Circular Economy.

Source:

1. Circular economy by using glass in concrete
https://www.ellenmacarthurfoundation.org/assets/downloads/circular-economy/The-Circular-Economy-and-the-Promise-of-Glass-in-Concrete.pdf

2. Glass packaging in circular economy
https://feve.org/wp-content/uploads/2016/04/Glass-Packaging-Industry-in-a-Circular-Economy-turning-Waste-in-a-Valuable-Position-Paper.pdf

3. Container glass circular economy
https://feve.org/about-glass/visions/industry/

4. Making Circular Economy a reality: Recognition of flat glass off-cuts as by-products
https://glassforeurope.com/flat-glass-off-cuts-as-by-products/

CASE STUDY: Use of Glass in Concrete

Concerns about glass and concrete

Concrete is an essential component of the built environment. Still, most people spend little time thinking about the materials that go into concrete: gravel, sand, water, cement, and, in some cases, fly ash or slag. Cement, concrete's primary binding element, generates large amounts of CO_2 during its production. The primary substitute for a portion of cement in concrete – fly ash – typically contains varying levels of arsenic, cadmium, chromium, mercury, lead, and other contaminants considered potentially toxic.

At the same time, post-consumer glass is a growing problem in many regions of the United States. Despite glass being 100% recyclable, cities across the country are abandoning their glass recycling programs over profitability concerns and challenges finding effective end markets for the material.

The opportunity provided by the use of glass in concrete is a potential solution that uses circular economy principles to unlock value and create new business opportunities: first, by finding a purpose for the glass of higher value than landfill, and second by decreasing the negative externalities of the construction sector.

By using glass in concrete, it would be possible to:

- Re-utilize 8 million tons of post-consumer glass that are landfilled each year
- Reduce the 90 million ton annual demand for cement, the production of which leads to 90 million tons of CO_2 emissions (equivalent to nearly 20 million cars)
- Minimize exposure to heavy metals and other potentially toxic components in concrete – especially during the renovation and demolition of buildings
- Localize supply chains and contribute to the transition towards a circular economy.

Major challenge for concrete

The construction industry accounts for 4% of US GDP and 80% of its material consumption. In 2015, 600 million tons of concrete were produced to meet the demand of the construction market in the US.

Concrete is usually made with a mix (roughly) of 75% aggregate (gravel and sand), 15% cement, and 10% water. Though it represents only 15% of concrete, cement is responsible for 96% of its CO_2 emissions. One ton of cement accounts for approximately 1 ton of CO_2 emissions (with half of that due to the fossil fuel combustion required to produce cement, and the other half coming from the kilned chemical conversion process involved in making clinker, the fusing of limestone and alumino-silicate materials like clay). This means that US cement production, which amounted to 90 million tons in 2015, generated greenhouse gases equivalent to the annual emissions of 20 million cars (12% of all vehicles in the US). Globally, cement production is responsible for 7% of annual GHG emissions.

To reduce cost and CO_2 footprint of its product, the concrete industry began using two main cement substitutes: fly ash and slag. Fly ash, the most widely used, is essentially a by-product of the coal combustion process used in electricity generation. Ground, granulated blast furnace slag - or just slag - is a by-product of the iron smelting used to make steel. These cement substitutes also help to increase the performance of concrete.

Mixing fly ash into concrete has three main advantages over cement:

- Under certain conditions, it can improve the durability and strength of concrete
- It can reduce the cost of concrete, by 2-10%; savings are driven by the price and availability of fly ash, which depend on the proximity of coal-fired power plants, as stocks of waste fly ash build up and these plants need places to dispose it of
- It reduces the CO_2 footprint of a ton of concrete by 25-40%

Circular economy opportunity

Cities and citizens have been recycling it for decades. Since 1980, the collection of glass for recycling – whether at home, at the curbside, or via bottle bills and deposit programs – has increased fourfold in the US.

The glass recycling problem is worsening, with various cities in the US abandoning their recycling programs. The issue is primarily economic: sorting the different kinds of consumer glass once it has been used is complex, dirty, and costly; while an insufficient market for recycled glass further harms the investment case. As a result, some cities end up paying $40/ton to send recyclable glass to landfill.

Glass can help reduce CO_2 emissions from producing concrete

Recycled glass, when ground into fine powder, can be substituted for a portion of the cement in concrete just as fly ash and slag are. Initial pilot projects are proving the technical viability of this approach, both for concrete used in sidewalks (in Montreal, New York City, and on Google's Campus in Mountain View, CA) and in buildings (in Montreal and soon, in New York City as well).

Using glass as a cement substitute reduces the carbon footprint of concrete by between 20-40%. The grinding of glass into pozzolan requires little energy and emits 18 kg CO_2 per ton of glass. Compare this with fly ash, the production of which emits 201 kg CO_2e/ton.

In California specifically, our current estimate is that the use of glass pozzolan as a cement substitute is 3% more expensive than a standard mix of concrete (on a delivered cubic yard basis). These are real costs, but participating companies purchasing concrete made with glass may value the opportunity to reduce long-term toxicity and lower CO_2 emissions, while at the same time contributing to the development of a product that follows circular economy principles. Building a market relies as much on economies of scale as on mastering the technical challenges.

Glass pozzolan facilities currently operating on the East Coast need about 40,000 tons of glass input per year. A similar level of input for potential new, similar facilities on the West Coast would require the diversion of about 15-20% of the post-consumer glass currently being sent to landfills in California. With the participation of the right stakeholders in the concrete and building industry, it may be possible to achieve this using existing infrastructure and supply chains. The efforts of a few companies like Google and Unilever could be just the push this industry needs. But for this solution to be truly impactful, it will require the involvement of both the private and public sector, and at the federal, state and city level – potentially with the cooperation of municipalities such as Los Angeles, New York, or Phoenix. For cities generating greater and greater amounts of glass debris, while at the same time requiring increasing quantities of building materials, the use of glass in concrete enables them to both divert these resources from landfill and reduce their carbon emissions.

Using recycled glass in concrete

Using recycled glass in concrete would allow companies, building developers, and cities to leverage a local, non-toxic resource in a product that is core to our built environment. The approach offers a viable solution to two pressing problems: concrete's high CO_2 emissions and the increasing difficulty faced by cities in processing their post-use glass. If successful, this project presents a unique opportunity to create a virtuous circle of awareness and adoption, resulting in greater economies of scale and a steeper learning curve.

This virtuous circle can start to eliminate the trade-off in our built environment between reducing carbon emissions and increasing health on the one side, and reducing costs on the other. Diverting glass from landfill to be used to make concrete is an excellent example of cascading a technical material to another valuable use - one of the key principles of value creation in the circular economy.

Source:

1. https://www.ellenmacarthurfoundation.org/assets/downloads/circular-economy/The-Circular-Economy-and-the-Promise-of-Glass-in-Concrete.pdf

2. https://www.buildingproductecosystems.org/glass-in-concrete

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