Think:Act

Roland Berger

What goes around comes around

The circular economy in industrial manufacturing

Roland Berger

THE BIG 3

Many resources are already scarce

Secondary materials are the answer

COMPANIES MAKE AMBITIOUS STATEMENTS ON DECARBONIZATION

Circularity is the key

CIRCULARITY MEANS MORE THAN JUST RECYCLING WASTE

Reusing, repairing and refurbishing can change the world

Contents

Cover illustration and illustrations on page 10/11, 15-18: Studio Muti/Folio Art

1 – What is the circular economy – And why is it so important for industrial manufacturers?

BACK IN 1966, renowned English-born American economist Kenneth E. Boulding described the closed economy of the future as a *spaceman economy,* one in which the Earth "has become a single spaceship, without unlimited reservoirs of anything, either for extraction or for pollution [...]." He contrasted this with the *cowboy economy* of the past, in which resources appeared infinite and illimitable.

The evidence is clear that we have now entered this new economic phase: Unless we clean up our act urgently and stop acting like cowboys, we will soon have to abandon ship and search for a new planet. Today, 91 percent of material flows in the economy are linear, meaning that they are mined, used and disposed of in a single flow. Our unidirectional produce-to-waste approach destroys socio-ecological systems and the complex and interdependent network of ecosystems that we inhabit. The extraction and processing of natural resources for the production of goods is responsible for an estimated 50 percent of global greenhouse gases (GHG), and sooner or later these resources will become unavailable. For example, the European Chemical Society foresees that half of the 92 naturally occurring elements on Earth are at risk of future shortage – with 17 of the roughly 30 elements currently used in smartphones already facing prospective supply concerns.

Environmental damage goes hand in hand with damage to societies and individuals, of course. Linear resource extraction, production and disposal heavily impacts marginalized communities. Chemical-intensive processing and the improper handling of waste creates high risks of pollution and harms the health of local workers. For example, according to the International Resource Panel, the toxic extraction and processing of metal resources is responsible for 39 percent of particulate matter health effects. And the impact goes far beyond local workers: Research carried out at the University of Chicago found that pollution reduces global life expectancy by 2.2 years, an effect 89 times as impactful as that of global conflict and terrorism.

THE CIRCULAR ECONOMY EXPLAINED

The solution lies in the creation of a *circular economy.* This is the idea that instead of extracting resources to build products that we later discard, we should aim to maintain the value of resources, materials and products in the economy for as long as possible in a circular process.

The circular economy consists of two fundamental cycles, as described in the standard "butterfly" framework suggested by the Ellen MacArthur Foundation. The first is a **biological cycle,** in which nutrients from consumed products such as food and other biodegradable materials, once they can no longer be used, return to the soil. The second is a **technical cycle,** in which products that are not naturally biodegradable are reused, repaired, refurbished or recycled so that they can remain in use rather than becoming waste.

The technical cycle is of key importance for products manufactured by industrial firms, which are the focus of this study – automobiles, factory equipment and machines, consumer electronics and the like. Reusing, repairing, refurbishing and recycling such products can be facilitated by a number of supporting mechanisms, such as redesigning, reducing and rethinking ownership (see Chapter 2: *The technical cycle*). The gold standard, however, is to remain within the inner circles of the framework – that is, *reuse or repair* – as this enables maximum value to be retained. → A

WHAT'S GOOD FOR THE CLIMATE IS GOOD FOR BUSINESS

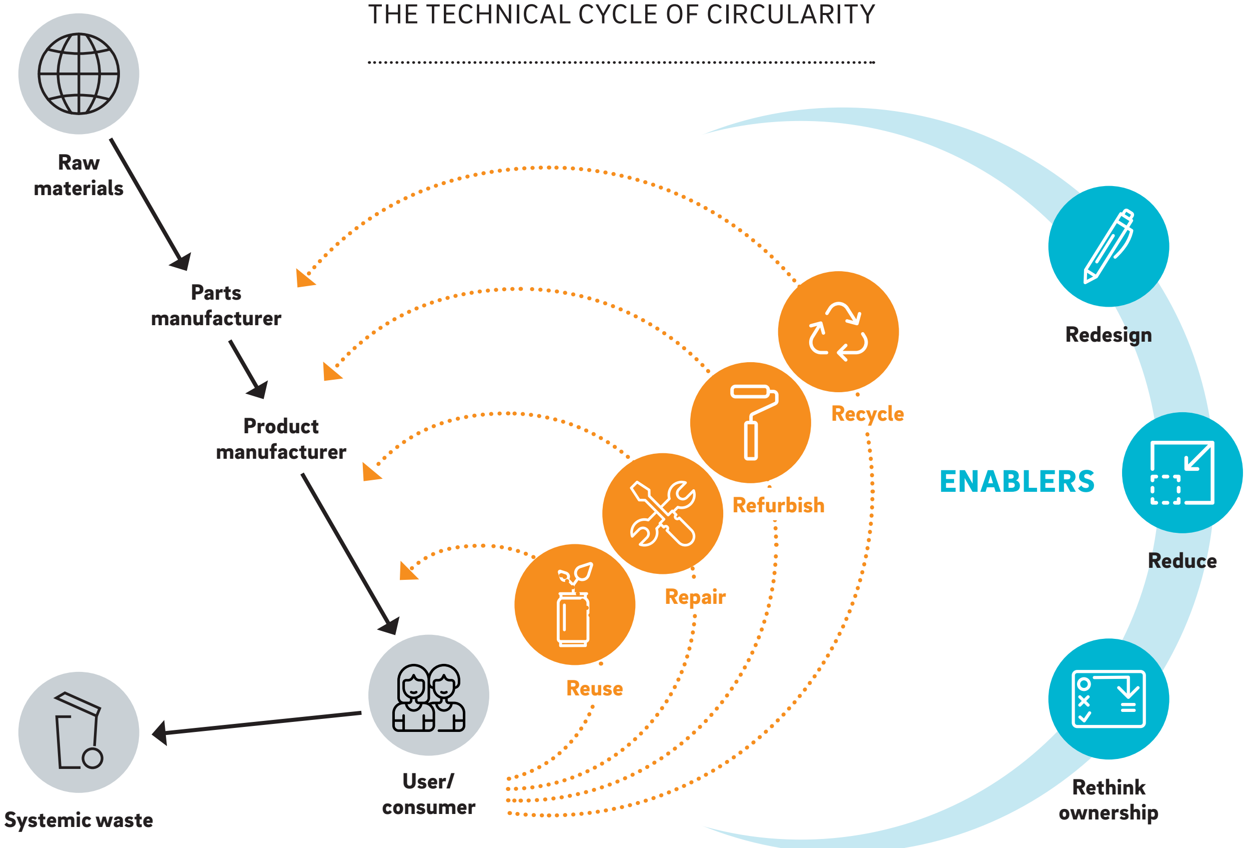
Reducing environmentally and socially harmful resource extraction and energy-intensive processing is crucial if we are to overcome today's cluster of global risks, each one contributing to and exacerbating the other. But embracing circularity is not just good citizenship, it is also good business.

The additional benefits for industrials of becoming more circular include **cost savings,** as companies can save money on procurement by reducing waste and retaining materials. Thus, the European Economic and Social Committee estimates that by improving resource efficiency by 30 percent by deploying circular economy mechanisms, European industry could save as much as EUR 600 billion annually. Companies that go green also enjoy **reputational benefits:** Consumers are increasingly looking for firms that have a positive environmental and social impact, and those

A

From a linear to a circular economy

THE TECHNICAL CYCLE OF CIRCULARITY



Source: Ellen MacArthur Foundation; Roland Berger companies that do often enjoy a competitive edge. Moreover, businesses that have a purpose other than simply making a profit often stand out from the crowd in the war for talent.

Not only that, being circular enables **regulatory compliance.** Regulators, themselves facing growing pressure from activists and resource-related growth boundaries, are increasingly demanding action by business. For example, the European Union has adopted a Circular Economy Action Plan as a prerequisite to achieving its 2050 climate neutrality target, and the United States and China have enacted similar legislation (see box: *Key legislation*).

Key legislation

EUROPEAN UNION

The European Union's Green Deal entails the region becoming net zero by 2050 and decoupling growth from resource use. One of the building blocks of the plan is the second **Circular Economy Action Plan,** addressing all the steps along product value chains. Besides non-legislative actions, such as gearing public spending towards renewable products, the Plan includes developing legislation in areas such as product design, information, circular production, waste management and key value chains. In the area of **product design,** the aim is to increase durability, reusability, upgradability, repairability, energy and resource efficiency, recyclability and remanufacturing of products from the design stage onwards. Regarding **information,** EU consumer law will be revised to empower consumers to make circular choices, with increased requirements for information on product lifespans and repairability. The Plan also includes action on **circularity in production,** establishing circular economy practices in Best Available Techniques documents, promoting tracking and tracing resources, and working towards industrial reporting and certification schemes. In the area of **waste management,** the aim is to harmonize waste management systems and enhance the implementation of extended producer responsibility schemes. Finally, the Plan focuses on high-impact industries and includes sectoral actions, such as developing a new regulatory framework for batteries, reviewing end-of-life vehicle rules, reviewing packaging requirements and setting mandatory requirements on recycled plastics content.

CHINA

China enacted its **Circular Economy Promotion Law** in 2009. Among other things, this legislation introduced producer responsibility for recycling and disposal of end-of-life products. It was followed in 2017 by the **Operation National Sword** initiative, which regulates the import of waste, effectively banning the import of contaminated secondary materials, such as difficult-to-recycle low-grade plastics. This policy dramatically impacted European and North American waste management approaches. China's current circular economy strategy is largely covered by the **14th Five-Year Plan** (2021-25), which serves as a directive for regional regulations. In line with its ambition to achieve carbon neutrality by 2060, the Plan outlines qualitative ambitions for improved waste recycling, reuse and refurbishment, and aims to increase energy and resource efficiency. It also sets fixed targets for the five-year period, such as reducing energy consumption per unit of GDP by 13.5 percent and utilizing 320 million metric tons of scrap steel, equivalent to 23 percent of China's annual output in 2021.

UNITED STATES

In the absence of strict Federal legislation on circularity, the US Environmental Protection Agency (EPA) drives the country's circular economy ambitions. The EPA's **National Recycling Strategy** (2021) aims to achieve a 50 percent recycling rate by developing improved infrastructure, reducing contamination and standardizing data collection. In addition, the Federal government provides grants for developing improved recycling infrastructure. It is also starting to embed the idea of a circular economy in its environmental ambitions, announcing an **Interagency Policy Committee on Plastic Pollution and a Circular Economy** in April 2023. Stricter action on the circular economy is being taken at state level. In California, for example, **State Bill 54** established producer responsibility and set targets for reducing single-use plastic packaging.

CIRCULARITY COMES WITH CHALLENGES

Achieving *full* circularity is likely to prove an impossible task due to physical limitations. Above all, the resources and energy needed to recover and recycle used materials grow in a non-linear fashion as the share of recycled materials increases. However, it is crucial that *maximum* circularity – at levels that will depend on the precise material in question – is top of the agenda for industrial companies and policymakers alike.

Circularity supports decarbonization by removing certain steps in the value chain. For example, *recycling* aluminum avoids using bauxite ("aluminum ore"), the mining of which is highly energy-intensive and therefore carbon-intensive. The situation is similar for other metals, and for industrial products in general: *Reusing* these items means that only their initial production generates carbon emissions. However, not all circular technologies reduce emissions at present, leading to a certain tension in the pursuit of circularity. Thus, chemically recycled plastics currently generate significantly more GHG than plastics produced from crude oil naphtha. While the higher emissions from recycled production are balanced out by lower emissions compared to incineration, this exemplifies the need for further technological advancement – and careful comparison of environmental impacts across different approaches.

Industrials have a critical role to play in creating a circular economy. According to the World Economic Forum, in the automotive industry – responsible for around ten percent of industrial emissions – materials are contributing less and less to the total lifetime emissions of vehicles over time, and by 2040 will account for just 60 percent of the total lifetime emissions. This reduction is being driven by the shift to battery-electric vehicles (BEVs) and greener energy during the use phase. If the industry introduced cost-neutral, circular approaches to address the growing need for sustainable materials, material-related emissions could be reduced by a massive 97 percent as soon as 2030.

Of course, responsibility for the circular economy does not lie solely with industrial companies. Other stakeholders also have a role to play. As discussed above, the technical cycle for industrial products involves four mechanisms: *reuse, repair, refurbish* and *recycle*. The latter two mechanisms depend mainly on decisions by industrial companies. But the former two – *reuse* and *repair* – depend on decisions by service providers and users. That said, even here industrials can play a role through supporting mechanisms, redesigning their products and motivating customers to reduce consumption and rethink ownership.

B

Milestones

THE IDEA OF CIRCULARITY HAS BEEN THERE FOR A LONG TIME

1966
Kenneth E. Boulding popularizes the term ***Spaceship Earth*** to describe **humanity's need to conserve natural resources**

1987
The *Report of the World Commission on Environment and Development: Our Common Future,* commonly known as the **Brundtland Report,** recognizes the ecological limits to economic growth and establishes the **idea of "sustainable development",** which it defines as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs"

1990
The **term "circular economy"** is first defined, in *Natural Resources and the Environment* by R. Kerry Turner and David Pearce

1999
The **idea of "natural capital"** as humanity's scarcest resource is established by Paul Hawken, Amory Lovins and L. Hunter Lovins

2002
William McDonough and Michael Braungart publish a **manifesto for eliminating waste** in *Cradle to Cradle: Remaking the Way We Make Things*

2009
After initial regional pilots, **China passes its *Circular Economy Promotion Law,*** pioneering dedicated legislation on a major scale

2010
Professional sailor Dame Ellen MacArthur, having experienced the importance of resource conservation while sailing single-handedly around the world, **launches the thought-leading *Ellen MacArthur Foundation***

2015
The **European Union** adopts its first ***Circular Economy Action Plan,*** aiming to transition to a circular economy through legislative and non-legislative action. Later, in 2020, it is revised and extended as part of the ***European Green Deal***

2022
The **European Commission** proposes new regulation on **eco-design requirements,** emphasizing the structural impact of redesigning products

2023
US legislation on the circular economy increasingly rises to Federal level, with the White House announcing an ***Interagency Policy Committee on Plastic Pollution and a Circular Economy***

2 – The technical cycle – Four Rs for changing the world

AS OUTLINED BRIEFLY IN CHAPTER 1, the technical cycle involves reusing, repairing, refurbishing or recycling products that are not naturally biodegradable, so that they can continue to be used rather than going to landfill or incineration. Industrial manufacturing companies need to take urgent action here. Below, we discuss in detail what that action might look like. For each of the four Rs, we divide our suggested actions into "small steps", "big leaps" and "moonshots" – the last of these being ambitious, innovative and often radical ideas that could pay off handsomely in the future but whose impact is difficult to predict at present.

#1 Reuse

The idea of reusing products is quite simple in theory. In a narrow definition, products are used again in their original purpose after only smaller modifications or cleaning, thereby prolonging their lifetime. An example might be a cell phone that is reused after cleaning or repair. For manufacturing companies, a second, broader definition of "reuse" exists, in which products are used again but for a slightly different purpose. An example would be a car battery that is reused for stationary energy storage at home. Besides reducing or avoiding use altogether, reuse is the only lever that does not require any new material inputs.

Let's look more closely at the example of cellphones. In the United States the average lifespan of such phones – that is, the moment from which they are sold to the moment when they are discarded – has been just two and a half years, since 2014. According to market data platform Statista, this lifespan is expected to drop to 2.3 years by 2025. For companies that provide cellphones to their employees, the expected lifespan is even shorter: Cellphones are replaced on average ten percent faster by companies than by consumers. Yet, most phones are still working well after two and a half years, and those that are not are generally easy to fix with minor repairs, such as replacing the battery, changing the screen and so on. This is an area where companies can take action: Extending the lifespan of the cellphones they give employees would not only reduce resource consumption, it would also save them money by reducing their overall spend.

Businesses can take many immediate **small steps** in the area of reuse to improve circularity. We recommend looking first at the main resources consumed by the firm's manufacturing operations. For example, unpolluted cooling water can be reused to clean production equipment, as is done by leading consumer goods brand L'Oréal. Another easy win is to reuse non-production materials (NPM), such as unused equipment. Companies can utilize resell/sharing marketplaces to transfer or sell used equipment, such as forklifts or office furniture, to other divisions within the company or external parties. Besides impacting emissions, this can generate a direct monetary benefit in the form of additional revenues and reduced spending on NPM.

Big leaps could involve using the same production equipment for other products, for example. Here, creativity is key: Who would have thought, for example, that the German liquor company known for its brand Jägermeister would produce over 100,000 liters of alcohol for the medical sector during the COVID-19 epidemic? Similarly, the introduction of bi-directional charging in the automotive industry enables vehicle batteries to be used as home storage for energy, as mentioned above. When renewable sources produce more energy than needed, the car battery can store the surplus and at night households can use it to run domestic electrical appliances.

In the future, industrials should aim to integrate circularity into the design phase of product development. Rather than just defining first-phase uses, design engineers should define use cases for the following phases. Initially, this will make life more challenging for engineers and developers, but it will also significantly ease the transition from the first-use phase to a second-use phase. To build the foundation for this change, companies should rethink their current development processes from a holistic perspective – for example, integrating market research and strategy into the process.

Moonshots are ideas whose ultimate impact is difficult to predict today. In the area of reuse, we can imagine a device that scans a complex product (for example, a vehicle and its subcomponents) and identifies pieces that can be reused in other contexts – such as reusing automotive LiDAR (light detection and ranging) sensors in surveillance cameras, traffic flow management or crowd control. Or a universal wear tracker, used to gather information on use types, use cycles and mechanical stress. Wear-tracking hardware and software standards could easily be integrated into products to estimate their potential for reuse. In the automotive industry, for instance, this could take the form of a single, small trip recorder that translates usage patterns into reuse assessments for surface materials, air filters, brake discs, brake calipers, and rubber and plastic pipes.

#2 Repair

Repair means bringing back the original functionality of a damaged product or component. We have become a throwaway society, less concerned with repairing goods and components than in previous decades. Indeed, according to the European Environment Agency, a strong correlation still exists between the generation of waste and economic growth.

Many products have also become more complex in terms of their functionality and the number of parts used. Motor vehicles originally provided the basic functionality of transportation, whereas modern cars are full of technology, such as stability control, airbags, infotainment systems and so on. As a result, modern cars now feature up to 30,000 single parts and counting, a trend that even the lower complexity of battery electric engines compared to internal combustion engines (ICEs) will not be able to turn back.

The European Union has recognized this shift away from the repairability of goods and products and responded with its Ecodesign Directive for Sustainable Products (ESPR). This proposed legislation lays out repair requirements, such as easier access for professional repair services and enhanced supply of spare parts.

Small steps for companies include ensuring compliance with current regulations on repairability and thinking ahead about how to increase repair quotas. That means more modular designs for products, plus practical things such as less adhesive connections, good physical accessibility of machine parts and easier access for third parties to perform repair tasks. Governments and industry associations should support this with easier certification of third-party repair and maintenance staff. The EU vehicle aftermarket proves that this is feasible, as demonstrated by its 2002 regulation ensuring third-party access to technical repair information and regulation, ensuring that vehicles can be serviced by third-party shops without invalidating their warranty.

One technological advancement that is key for repair is the use of augmented reality (AR). AR can perform or train repair tasks on products and components. For example, aircraft component manufacturer Jamco has developed an AR training tool together with mixed reality developer Object Theory that allows its customers' trainee mechanics to work on aircraft seats without having to refer to a manual.

Fully predictive maintenance will be the next **big leap** in the field of repair, reducing repair activity and at the same time extending product life. For example, German national railroad company Deutsche Bahn has been employing predictive maintenance for a number of years already but is still some way off fleet-wide implementation. By using a digital twin of a train, various subsystems such as doors and air conditioning can be simulated using real-time data. Maintenance tasks are no longer performed in fixed cycles but only when a breakdown is expected.

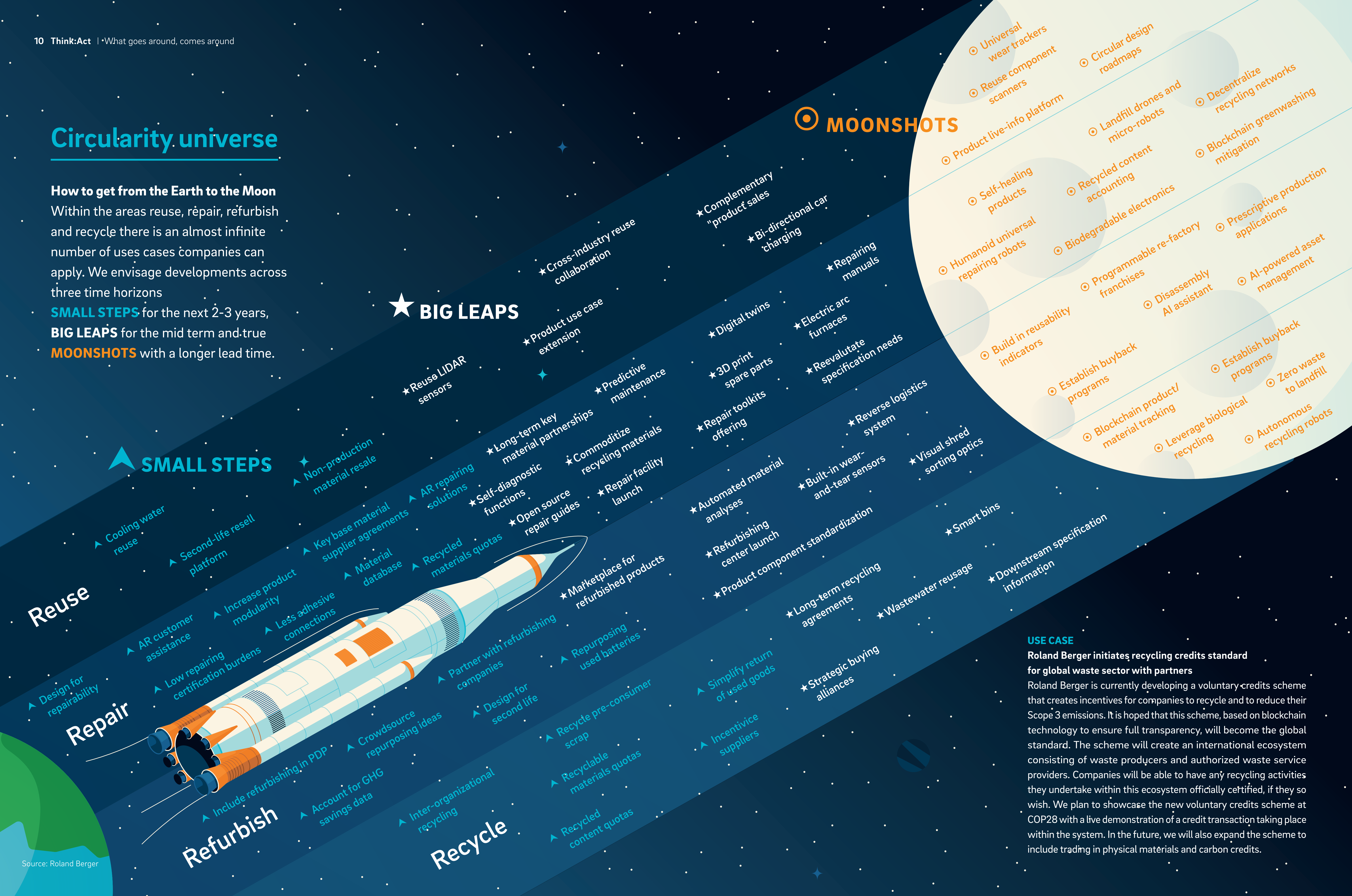
New technology, such as additive manufacturing (3D printing), is also set to revolutionize production processes. Additive manufacturing reduces the size of spare part inventories and leads to much lighter, less carbon-intensive components, among other things. Mercedes Benz Group, for instance, is already implementing 3D printing on a small scale for a range of spare parts in their trucks and buses. Besides freeing up space, this approach generates monetary benefits and reduces overall emissions.

In terms of **moonshots,** self-healing materials could be the next big thing, making repair effectively obsolete. Self-healing materials include polymers, metals and ceramics that first fill in damaged areas and then restore the structure itself. Joint studies by companies and research facilities have already demonstrated the feasibility of such materials. While the technology is still in its infancy, experts expect initial applications to make their way onto the market quickly; indeed, some materials, such as Reverlink from specialty materials manufacturer Arkema, are already being produced and marketed.

Another innovative idea is humanoid robots with a high level of dexterity and adaptive behavior, such as the Figure Robot or TeslaBot, programmed for universal repair. By

Circularity universe

How to get from the Earth to the Moon
Within the areas reuse, repair, refurbish and recycle there is an almost infinite number of uses cases companies can apply. We envisage developments across three time horizons
SMALL STEPS for the next 2-3 years, **BIG LEAPS** for the mid term and true **MOONSHOTS** with a longer lead time.



Source: Roland Berger

USE CASE

Roland Berger initiates recycling credits standard for global waste sector with partners

Roland Berger is currently developing a voluntary credits scheme that creates incentives for companies to recycle and to reduce their Scope 3 emissions. It is hoped that this scheme, based on blockchain technology to ensure full transparency, will become the global standard. The scheme will create an international ecosystem consisting of waste producers and authorized waste service providers. Companies will be able to have any recycling activities they undertake within this ecosystem officially certified, if they so wish. We plan to showcase the new voluntary credits scheme at COP28 with a live demonstration of a credit transaction taking place within the system. In the future, we will also expand the scheme to include trading in physical materials and carbon credits.

downloading repair manuals from purpose-built repair data platforms, these robots could learn the ability to repair diverse, complex machines, feeding their experience back to the humanoid repair platform.

#3 Refurbish

Products that are damaged beyond repair, outdated or that no longer appeal to users are not necessarily lost just yet. By exchanging or repairing components, especially those that have a strong impact on the product's performance, companies can bring them back to a usable standard. "Retouched" products can also be combined with services, such as renewed warranties, to increase their value above that of traditional second-hand products.

This process is commonly known as "refurbishing" or "remanufacturing". The two terms are not strictly interchangeable: According to the American National Standards Institute (ANSI), remanufactured products must be at least as good as new, while refurbishing is often more superficial, only including repainting and functional testing, for instance.

While manufacturers often fear cannibalization of new products through refurbishing, the Ellen MacArthur Foundation has found no negative impact on sales, based on longitudinal data. OEMs offering remanufactured or refurbished products can also benefit directly from their durable and circular design changes.

A useful **small step** for companies is to consider the refurbishing potential of their products early on in the design process. One design with great potential for future remanufacturing is the replaceable battery offered by Chinese electric vehicle maker NIO. While currently focused on improving charging experiences, the design potentially saves NIO's cars from becoming obsolete due to shrinking battery capacity. Customers can lease batteries, swapping them for fully functional ones when necessary. After each swap, NIO checks the battery's health and decides whether to remove it from circulation or not. Battery swaps take just three minutes. Battery degradation is also reduced, as batteries can be charged more slowly at NIO's premises.

Companies should look across the entire product lifecycle. They can potentially embed requirements for "second lives" in the design of components as an additional step in the development process. This maximizes the number of carryover parts, not just across different products but across product generations. Additionally, if the requirements are considered sufficiently, right from the very beginning, components can be assembled for completely different applications at the end of their first life. For example, according to research carried out at RWTH Aachen University in Germany, used car batteries ending their first life with 70 to 80 percent capacity can potentially be used for household-integrated energy storage for an estimated additional decade.

While the capabilities required for refurbishing or remanufacturing products are naturally close to those required for primary production, companies do not necessarily need to take the first steps themselves. By cooperating with refurbishing specialists, manufacturers can gain valuable market experience while providing additional credibility to their partners.

To fully capitalize on the refurbishing and remanufacturing opportunity, companies should consider making the **big leap** of establishing specialized marketplaces themselves. In the consumer sector, many well respected brands such as Dyson and Apple have already taken the plunge here.

Products often differ greatly between generations, so today's refurbishing and remanufacturing processes often focus on cosmetic touchups, renewed warranties and replacing broken parts. Another big leap would be to offer remanufactured products on a "good as new" basis. This would require manufacturers to carry out more significant adjustments, standardizing component characteristics across products and generations to maximize their potential for interchangeable use. For example, standardizing gearboxes can enable them to be easily reused in new products after reinstating their functional performance. This could be combined with advanced assessments of components' reusability. For example, Nike's B.I.L.L. robot can automatically create a 3D model of a shoe and determine its flaws with a wear-and-tear analysis. When wear-and-tear sensors or indicators are directly built into components – which can be as simple as printing measurement reference points on materials to enable monitoring of stretching or abrasion – such assessments become even easier and more reliable.

Among possible **moonshots,** AI-powered asset management software could assess how components or products can be matched or refurbished. Companies could then send clients individual offers for buyback or replacement of products, with prices calculated in real time based on current inventory and order levels. Alternatively, prescriptive applications for production could include automatic waste-to-resource matching and execution. Depending on the parts/products needed, an autonomous model would route materials in production based on a prior cost-benefit analysis. By leveraging these opportunities, industrial manufacturers could streamline their operations, reduce waste and downtime, and so improve their bottom line.

Another moonshot idea is programmable re-factory franchises. "Re-entrepreneurs" could create factory-like facilities and operate under a scalable franchise model, paired with easy-to-deploy tools (3D printing, no-code robotics, AI, CT scanning for non-invasive inspection) to transform disposed products into new. The facility would be organized into modular systems that can be easily configured along incoming material streams, such as electronics, or outgoing market demand, such as rare earth metal extraction. Locating these facilities in urban areas would reduce collection complexity and transportation costs, while at the same time creating new jobs and fostering community engagement.

#4 Recycle

Recycling, or the decomposition of goods into their base materials for reuse, is the least value-preserving of the four Rs. But although it uses resources for collection, transformation and redistribution, it nevertheless helps to slow down the bleeding, so to speak. Recycling cellphones or large items such as motor vehicles, ships or even airplanes have major advantages for industrial firms, but recycling any sort of waste is already beneficial. In some countries, recycling materials such as glass, aluminum and so on is commonplace for both households and industry. Of the countries observed by the OECD, Slovenia leads on material recovery, with 72 percent of its municipal waste materials being recycled or composted, followed by Germany at 66 percent. By contrast, the United States recovers just 32 percent of these same waste materials, with around 50 percent going to landfill.

Besides the creation of suitable waste streams, the most urgent issue with many recycled alternatives is lack of supply. For example, according to Plastics Europe, the European market for post-consumer recycled plastics has grown by just two percentage points since 2018, while growth of the market for fossil-based or "virgin" plastics has been nearly nine times as high. The need for companies to secure recycling streams as a source of raw materials is clear.

Small steps for companies include gaining transparency about what proportions of raw materials and purchased parts are already recycled. With this knowledge in hand, they should set secondary material quotas for materials for the coming years, aligning those quotas across all departments (procurement, R&D and so on). For example, quotas should be established for polymer types such as PP and PC-ABS, for which products with up to 100 percent post-consumer recycled (PCR) plastics are already available today. Firms should also align with their key base material suppliers and agree on framework contracts for overall volumes.

Another step for industrial manufacturing companies is to collect sorted waste, such as aluminum scrap from presses, and return it directly to their suppliers for reuse. The more sorted the scrap is, the better it is for immediate reuse. This sort of "closed loop concept", as it is known, was recently announced by aluminum producer Novelis and Smart Press Shop, for instance.

In terms of **big leaps,** manufacturing companies need to start engaging more in their upstream supply chain. This means cooperating not only with direct suppliers but with base material producers, too – that is, their suppliers' suppliers. In the steel industry, for example, effective routes exist such as using electric arc furnace (EAF) technology to produce steel with recycled content. Thanks to this method, companies can introduce recycled steel into their products and at the same time reduce CO_2e emissions by up to 88 percent, assuming they use renewable energy. This entails them reevaluating their required specifications, as some qualities through the EAF route are more dependent on the steel waste quality used as input.

Companies should aim to establish strategic partnerships for their main materials by signing long-term agreements with suppliers. It is important for firms to identify suitable partners across industries that require a similar range of materials. The European Raw Materials Alliance (ERMA), for example, helps companies discuss joint investment opportunities along critical raw material value chains, such as waste recovery.

Another big leap is to establish chemical recycling plants in countries in the Global South that have good access to renewable energy – solar power, say – and large amounts of plastic waste. This plastic waste can then be recycled rather than going to landfill or incineration.

In the future, companies will be held fully accountable for their products and their residuals, in what is called the "extended polluter principle". A prerequisite for recycling is to know the material composition of products. Companies must devise solutions for this, providing accurate information on materials' ingredients and origins based on a decentralized authentication system, such as blockchain. They must also come up with effective ways to gain access to their products from customers after usage. The easiest way to do this is by retaining ownership of the products, for example, through financing mechanisms. Another way is for companies to buy back their own products. Here, cooperations with other companies can be the easiest way to gain relevant size and efficiency in reverse logistics.

Moonshots can involve looking at the different material and technology routes that are likely to emerge in the future. Greenwashing can be avoided through the use of blockchain to determine the exact recycled volumes to be used, depending on the volume of products and materials sold. Decentralized production networks will also be important, including recycling facilities. Companies need to invest directly in new technology, such as pyrolysis recycling, and in innovative recycling facilities to ensure recycled material streams for themselves.

Other moonshot ideas include micro-scale robots combined with visual-sensing drones, released into landfills with the aim of locating, assessing and extracting valuable metals and minerals for reuse. Researchers are also working on biodegradable electronics, such as circuit boards made from flax fibers that disintegrate in hot water in five to ten minutes, biodegradable cases made out of polylactic acid, and water-repellent coatings such as chitosan, which is found naturally in the outer skeleton of shellfish. Most likely, not all of these ideas will prove ultimately successful – but those that do could be transformative for specific industries.

Enablers

The four Rs are facilitated by two overarching enablers, which we label "Redesign & reduce" and "Rethink ownership". These two enablers make it possible to close the loop with the help of the other levers for a circular economy, eventually leading to reduced resource demand.

REDESIGN & REDUCE

"Redesigning" means rethinking how products are designed, how they are manufactured and that materials are used in the process. Manufacturing companies should design products for longevity and durability, using materials that are either plant-based renewables or which are already being retrieved. Designing products for disassembly, for example by being modular, also helps when it comes to separating materials for further processing or reprocessing. An example of a redesigned product that leads to reduced material use is automaker Polestar's fully vegan-based interior option, which uses flax fabrics and natural fiber composites, among other materials. This approach, which won Polestar a PETA Award, not only employs renewable resources, but those resources are also recyclable at the end of the vehicle's life.

RETHINK OWNERSHIP

Traditionally, companies purchase products to use them for a certain period of time and then discard them once they no longer need them. Firms that have optimized their operations in line with this model over decades, now see themselves confronted with changing customer demands and new business models. Instead of simply being sold, products function as door openers to sell associated services. Business models such as Product-as-a-Service and Material-as-a-Service are gaining momentum and will eventually pave the way for a world in which virtually anything can be provided as a service – known as an X-as-a-Service model.

Business models in which the producer retains ownership of the asset facilitate maximum usage, normally through financing options such as leasing, rental or pay-per-use agreements. Extended or lifetime warranty offers, on the other hand, do not directly change the ownership equation but rather force companies to design products that last until they can be returned to them by customers – and ideally then rented out to subsequent customers.

US-based technology giant Dell is a good example of a manufacturing company that, as part of its offering, provides products while retaining ownership of them. Dell's traditional business model was to sell personal computers to customers, but nowadays the company also offers a subscription service for both hardware and software, combined with maintenance and support. In this way they not only provide a broader overall offering to their customers but are also motivated to develop products that are durable, repairable or can be refurbished or recycled. It also encourages them to implement policies that make customers treat their products responsibly.

INTERVIEW

Interview with Andrew Morlet

CEO, Ellen MacArthur Foundation

How far are manufacturers in moving towards a circular economy? Are we still not doing enough or the wrong things?

Andrew Morlet: We are making progress – and what's particularly encouraging is how we are seeing momentum towards a circular economy across a wide range of industries. For example, in plastics, many manufacturers are part of the Business Coalition for a Global Plastics Treaty. We convened this along with the WWF to support the development of an ambitious, legally binding global treaty to end plastic pollution. Having the voice of manufacturers aligned with other businesses across the plastics value chain is important as it demonstrates to policymakers that companies from across the entire industry want change. Despite progress being made across a range of industries, we're not hitting the speed and scale required. We need greater investment and innovation if we're to make systemic change and switch to a circular economy. Making this switch would allow us to tackle some of the biggest challenges facing our world right now – from climate change to biodiversity loss.

Is there any 'R' which you consider as most important for manufacturers?

Reuse. This is essential to a circular economy. We need to keep materials within the economy for longer and at their highest value. Reuse allows us to do this. When we talk about reuse in plastic packaging, for example, we're talking about business models in which a single piece of packaging is used for the same purpose across multiple cycles. For example, with standard containers, much greater efficiencies can be achieved, while where needed also allowing branding identities through labelling. Manufacturers will play a crucial role in helping us all adopt reuse models on a much larger scale. Reuse schemes can cut life cycle emissions of a product by up to 80% compared to single-use products and reduce pressure on natural resources such as water. We speak to manufacturers about focusing on the whole lifecycle of their products – not just the endpoint. It's important we don't just look to another 'R' – recycling – as the primary solution.

Car maker Renault offers an example of a manufacturer that is actively applying principles of reuse, remanufacturing, and recycling in their circular economy models. Its Re-Factory just outside of Paris takes used vehicle components such as gearboxes and turbo compressors and remanufactures them. It's an example of a manufacturer keeping materials in use and reducing the demand for virgin materials.

What are key challenges manufacturers must overcome to be circular?

Design, design, and design. We need to redesign existing products, services, and systems – or create new ones – using the principles of the circular economy. That means designing out waste and pollution. It also means designing products for durability, reuse, remanufacturing, and recycling, to keep products circulating in the economy.

How can we solve the chicken-and-egg problem of demand and supply for circular materials?

It needs to start with innovation, offering better choices, and making the circular economy easy for customers. This means innovation for new models and circular product service systems, that meet customer needs better and which align with circular economic principles – this will drive demand. Japanese electronics company Ricoh is an example of a manufacturer that has been employing circular economy principles for many years. It's designed a business model that works for customers and our planet. Ricoh makes photocopiers. Instead of selling them to companies, they retain ownership and lease them. It means they are responsible for the products when they break down or the customers have finished with them. This business model incentivises manufacturers to design products that last, and that can be easily repaired and rebuilt. Customers value the ease of not being responsible for the maintenance and disposal, and Ricoh makes the economics work for them.

These types of business models demonstrate how we can change the way we make and use products to reduce waste, ease the pressure on natural resources, and maintain profits.

What do policymakers need to do to improve the circularity for manufacturers?

Leading businesses are calling for policy changes that both enable circular economic systems innovation and that level the playing field. – and encourages investment. We see this with the plastics industry for example. Through the Foundation's Global Commitment Report – which we launched five years ago with UNEP – many manufacturers have been taking voluntary action to apply circular economy principles to their businesses. But the patchwork collection of national initiatives is slowing progress. Policymakers have recognised this, and negotiations are currently underway with UN member states looking to create a legally binding global treaty. We know many manufacturers within the plastics industry are hopeful this will be an ambitious and robust treaty. Similarly, businesses in other industries are looking to policymakers to deliver certainty so they can invest in circular economy strategies with confidence. We need this if we're to hit the levels of innovation required to drive systemic change.

Do you see any regional differences in manufacturing on circular economy readiness? If yes, where do they arise from?

Again and again, we see evidence of how manufacturers have the skills and creativity to overcome challenges and embrace circular economy principles - wherever they are based. In terms of policies helping us switch to a circular economy, lawmakers in places like the EU have been quick to embrace the huge social and economic benefits it will deliver. Spain, for example, introduced its own national circular economy strategy in 2020. We are also seeing significant progress in the USA with the adoption of the Inflation Reduction Act, which both stimulates energy transition efforts and is supporting broader industries. But it's important to stress that in our discussions with policymakers around the world – from north to south, east to west – we are seeing a growing appreciation of the circular economy and momentum is building. The journey towards a circular economy is speeding up.

3 – What can we do?

Real-life examples of circularity

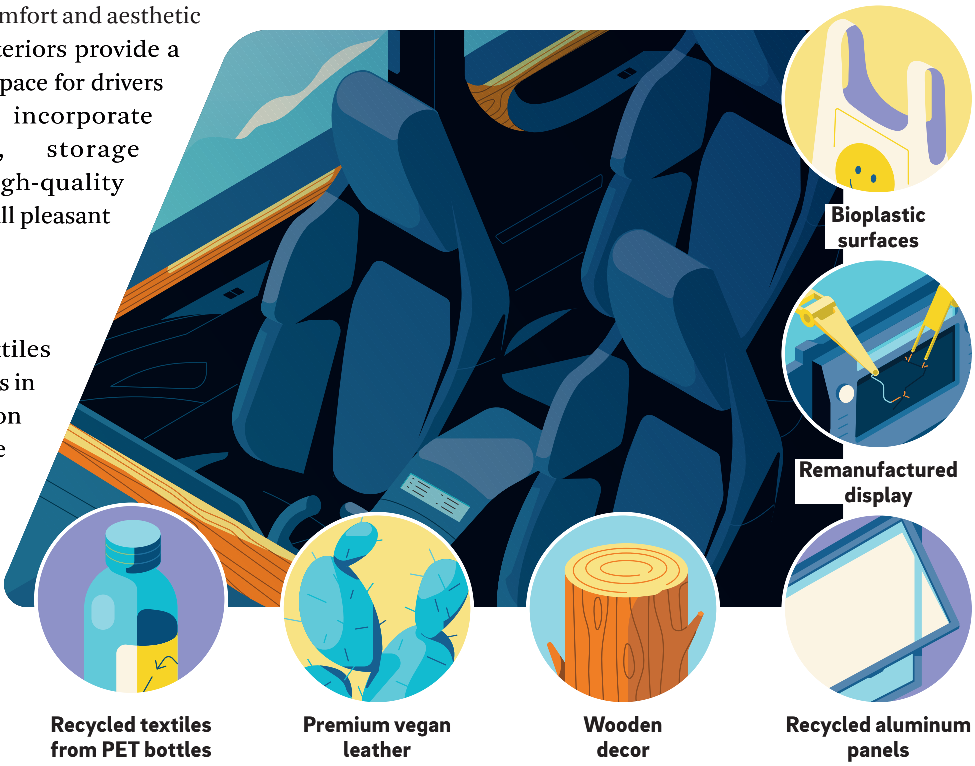
INDUSTRIAL MANUFACTURING COMPANIES will find it difficult to apply the 4 Rs on a one-size-fits-all basis. The precise levers vary from industry to industry, and even from company to company. In one case, a combination of repair and refurbish may be the most effective, in another, pure recycling. To illustrate this point, below we present four diverse product areas and suggest what firms can do to move away from a linear business model and towards a more circular economy through the operation of specific levers.

Car interiors

Designed to enhance the comfort and aesthetic appeal of vehicles, car interiors provide a functional and yet stylish space for drivers and passengers. They incorporate ergonomic features, storage compartments and high-quality materials to create an overall pleasant driving experience.

Circular solutions

- Replace traditional textiles made from virgin materials in seats, foot mats and so on with recycled textiles made from upcycled PET bottles or other waste materials
- Exchange the leather in seats and covers for renewable, vegan materials, such as cactus, mushroom or pineapple leather
- Upcycle plastic waste, biobased plastics and renewable wood for casing elements
- Choose aluminum decor made from recycled aluminum scrap from window frames, aluminum bottles and the like
- Install remanufactured displays and offer replacement and repair options
- Implement "design for circularity" – using materials that are recyclable, with a focus on mono-materials, or easy to repair and remanufacture, for example, by limiting adhesive or bonding of plastic parts so they can be easily dismantled

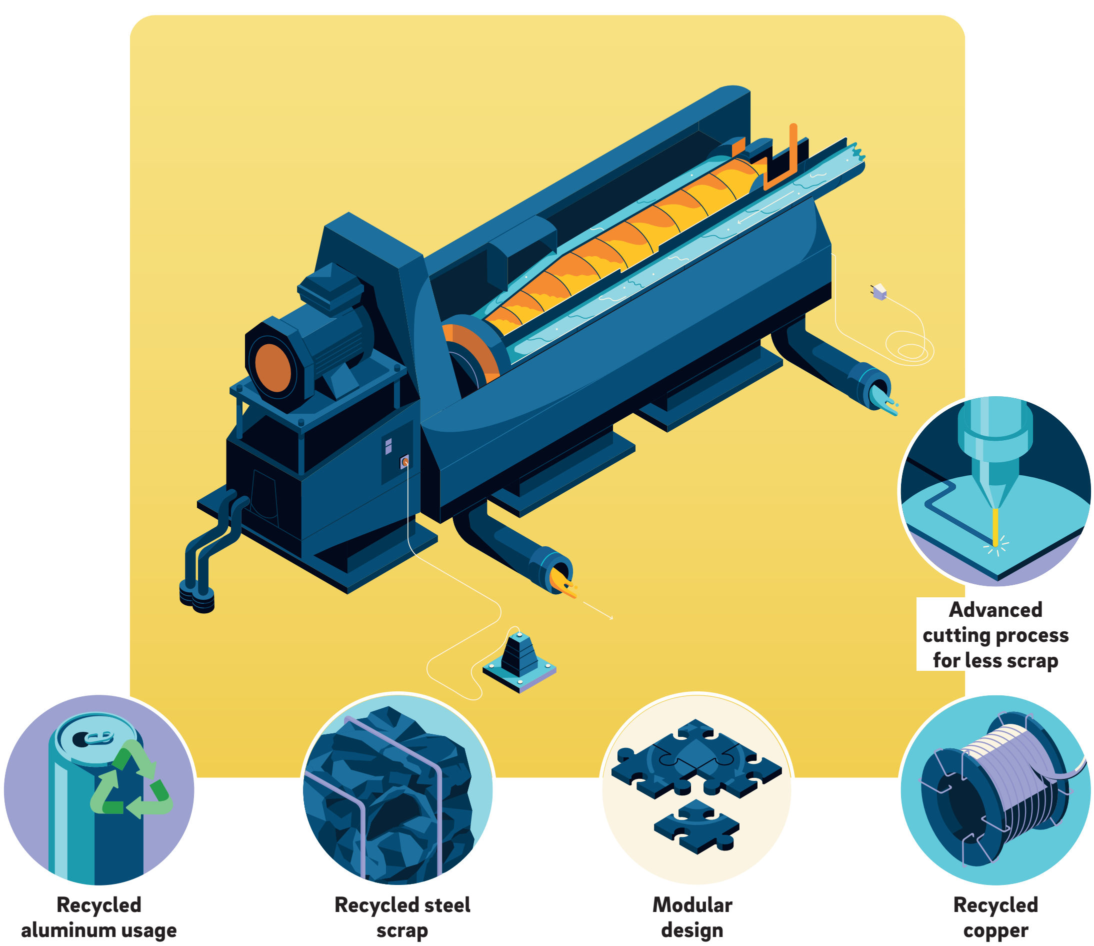


Decanters

Decanters use centrifugal force to separate materials of different densities, enabling their efficient processing and disposal. They spin the mixture at high speeds, heavier materials settling at the bottom and clarified, lighter materials being discharged from the top. This also enables the efficient recovery of valuable substances. Decanters are used in wastewater treatment and the chemical, oil and food-processing industries, for example.

Circular solutions

- Replace primary copper (for example, in cables or motor spools) with secondary, recycled copper from electrical/electronic waste, such as computers, or from construction and demolition waste, such as copper pipes, wiring and roofing materials
- Switch from primary aluminum to secondary, recycled aluminum scrap
- Choose secondary, recycled steel scrap over primary steel
- Reduce the thickness of the steel used in non-critical parts to reduce material use
- Improve the cutting process so it produces less production scrap across the manufacturing process
- Implement predictive maintenance for wearing and expendable parts, to enable repair and remanufacturing
- Introduce design for circularity and modularity, so that parts of the machine can be replaced or upgraded to increase overall machine lifetime
- Enable a second life for machines by selling old or unused items via internal or external second-life platforms

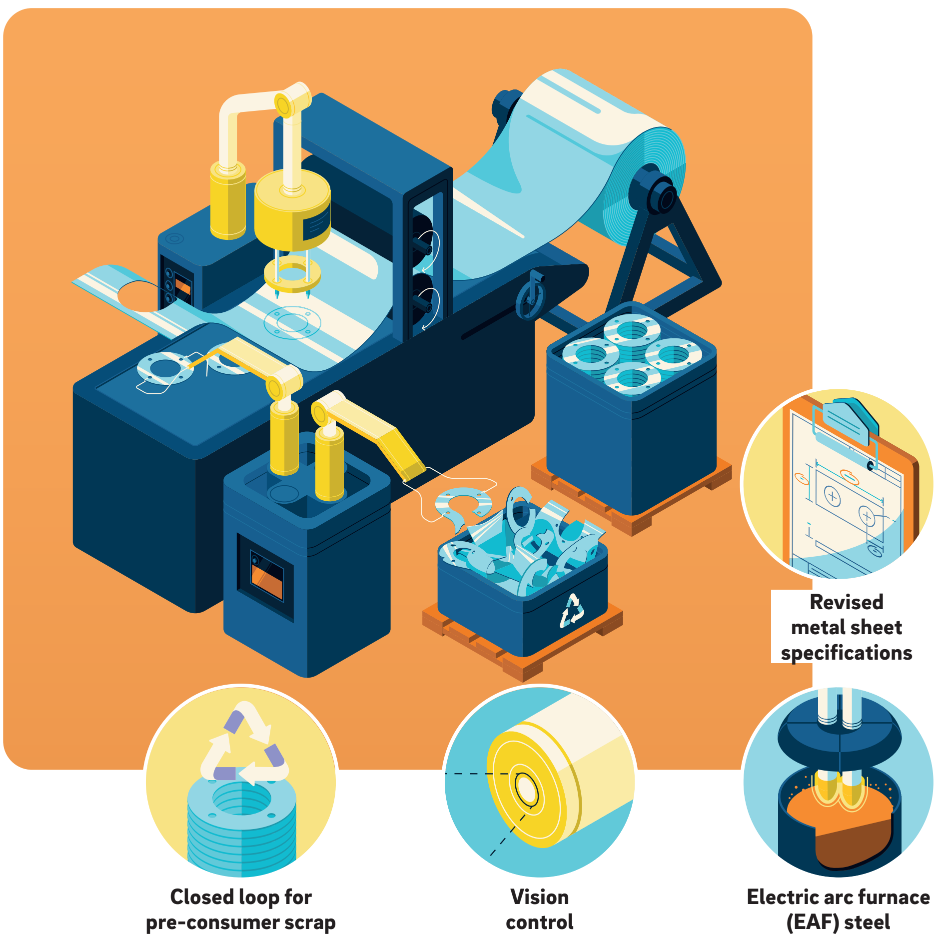


Stamped steel parts

Stamped steel parts are manufactured by stamping flat sheets of steel. Various techniques, such as blanking, bending, piercing, drawing and forming, or combinations of these techniques, are used to fold, stretch, cut and process the steel. Stamping is particularly cost-effective for high-volume parts, making it ideal for industries such as automotive, aerospace and machinery.

Circular solutions

- Use steel coils manufactured using electric arc furnaces (EAF) rather than blast furnaces (BF) or basic oxygen furnaces (BOF) to increase the use of renewable energy and scrap intake – BF and BOF use 25 to 30 percent scrap as a process manufacturing variable to control process heat, compared to 100 percent scrap for EAF
- Implement vision control to identify and remove scrap parts
- Ensure production scrap collection and recycling for use as pre-consumer scrap
- Communicate steel specifications to customers clearly to enable recycling and reduce downcycling
- Implement reverse logistics to collect used steel parts and steel scrap from customers and ensure that this is recycled – this limits the risk of downcycling or parts ending up as landfill

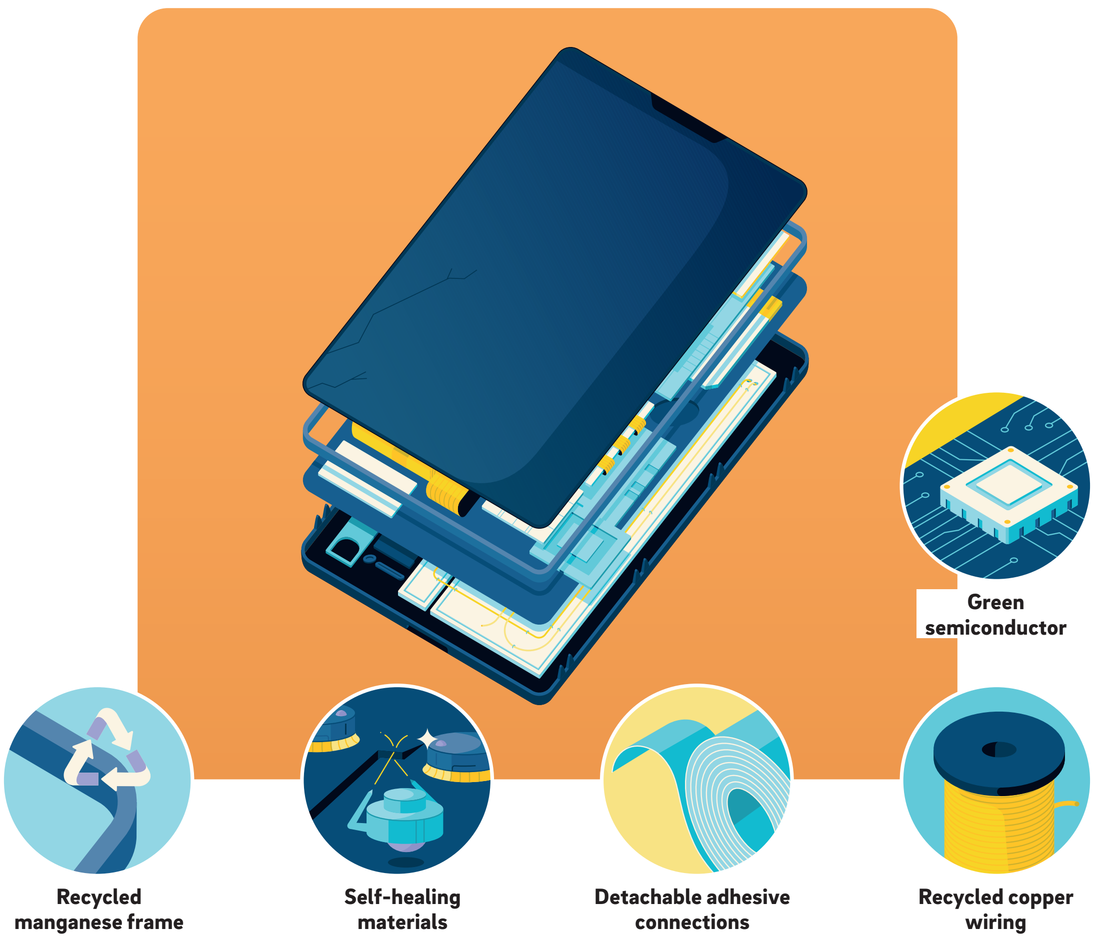


Displays

Displays are visual interfaces conveying information and enabling user interaction. Multifunctional displays often replace buttons for steering and monitoring in industrial processes.

Circular solutions

- Use recycled manganese from reclaimed and processed scrap metal, or from waste materials such as discarded batteries, steel scrap and other products containing manganese
- Switch to semi-conductor manufacturers who recycle or recover the majority of their process gases (such as the fluorine used for cleaning) and reuse heating/cooling from their production processes
- Use multi-use rather than single-use packaging for finished or semi-finished products
- Take advantage of innovations in self-healing materials, for example, capsules or channels filled with healing agents that repair themselves automatically when the display is damaged, cracked or exposed to heat – this extends product lifespans and reduces the need for maintenance
- Use detachable adhesive connections so that parts can be easily removed or repositioned – this also allows for temporary applications and reuse of parts and materials
- Employ design for disassembly (DfD) to enable the separation and recycling of components at end of life
- Provide customers with spare parts and repair manuals so they can repair products themselves



4 – The impact on business – How the circular economy affects industrial manufacturers

HOW WILL THE CIRCULAR ECONOMY affect the business of industrial manufacturing companies? We distinguish three types of solutions in terms of their impact. First, some solutions will immediately save costs or have a very short breakeven point – for example, simple design changes that reduce the scrap rate in production. Second, some solutions will have a neutral or nearly neutral impact on today's business parameters. And third, some solutions will have a negative impact on today's business parameters.

Companies should prioritize the first type of solutions, those with an obviously positive business case. But unfortunately, most solutions will be of the second or third type. Decisions about whether to pursue solutions of these two latter types are more complex. Companies need to look beyond the next one to two years and instead consider a horizon of three to five years, or in some cases even longer, which is when these solutions may begin to pay dividends. For example, the cost of buying carbon emissions certificates might easily reach EUR 200 or more per ton of CO_2e in the longer term, making many investments that are questionable at today's prices clearly advantageous from a longer-term perspective.

That said, we advise companies to focus not just on financial aspects but also strategic considerations. In particular, we recommend taking the following into account:

- **Current and planned regulation:** In Europe, for example, this includes the Ecodesign Directive, new regulations on (waste) batteries and the upcoming Carbon Border Adjustment Mechanism (CBAM)"
- **The company's own decarbonization pledge:** For example, its near-term science-based (SBTi) targets. Actions promoting circularity often reduce emissions. Companies will have allocated certain budgets to reducing CO_2e already and should consider these a chance to realize circularity actions, too
- **Customer, investor and stakeholder expectations:** These should inform both the company's priorities and its strategic direction
- **Resource security:** Not all resources will be readily available over the coming decade. Indeed, recent years have shown how prone supply chains can be to scarcity, as has been the case with copper. Companies should consider that entering the circular economy may give them secure access to resources

What does this mean for industrials' bottom line? A cost/benefit analysis – in which the costs are financial or time-related and the benefits might include achieving circularity goals such as decarbonization – will show that the number of "low-effort/high-benefit" cases is probably limited. Many more cases will be "high-effort/high-benefit", some with a long breakeven point and some never paying for themselves in terms of costs, at least under current legislation.

Why, then, pursue solutions that do not offer immediate financial benefits? For a number of reasons. The impact of global warming is increasingly clear, and customers, especially younger generations such as Gen Z, expect circular products. Moreover, they are increasingly looking at potential employers' sustainability records. Regulation is becoming ever tighter, especially in the West. And, ultimately, companies have no alternative: The megatrends are in place, the wheel is turning and investments that companies do or do not make now will either pay dividends in the longer term or come back to haunt them. As we state in the title of this study: What goes around comes around.

5 – A task for the whole company

THE TRANSITION TO A CIRCULAR ECONOMY has consequences for all parts of the company. The innovation, R&D and product development functions need to foster design to circularity, for example, providing clear instructions to the design engineers so that the products they create are easy to repair, reuse, refurbish or recycle.

Procurement needs to achieve full transparency with regard to where their materials and components come from. Logistics needs to reduce packaging and investigate reusable solutions. All the company's functions have their own specific to do's and only by everyone doing their part will it be possible to bring circularity to life.

TO DO'S BY FUNCTION

INNOVATION, R&D, PRODUCT DEVELOPMENT

- Explore **business opportunities** for including **circular products** in the current offering
- Foster **design to circularity** by drawing up guidelines for specifications, indicating the prerequisites for facilitating repairability, reuse, dismantling and so on
- Make **designs open source** to allow for repairability, remanufacture and so on
- Implement a **"design-to-circularity center of competence"** to speed up rollout
- Incorporate **artificial intelligence** (AI) into engineering to **improve circular design**
- Train engineers, for example, by giving them access to **databases on circular solutions**, biological and renewable alternative materials and details of the CO_2e footprints of different materials
- Identify **technologies for the manufacture of circular products**, such as the chemical recycling of plastics, and incorporate them into the company's processes

PROCUREMENT

- Achieve transparency about the origins of materials and components by **establishing a data-sharing concept with suppliers** from Tier 1 to Tier N, for example using blockchain
- Incorporate procedures for **incentivizing circular solutions during supplier selection** and awarding, for example using CO_2e and share of circularity as a key performance indicator (KPI) when evaluating bids
- Secure access to **circular, green and renewable materials** and energy **through take-back channels**
- Scout for opportunities such as **startups and smaller players** who can **support circularity** as suppliers or tech partners
- Build an **ecosystem of solution providers**

PRODUCTION

- **Limit land use** by only building new facilities on former industrial land or choosing more compact layouts
- Reduce waste and establish **recycling routes for pre-consumer scrap**
- Establish **closed loop processes** to bring unavoidable pre-consumer scrap back into the cycle
- **Reduce scrap** by adjusting manufacturing processes
- Introduce joining techniques that allow for **easier dismantling**
- **Cut water consumption** and pollution
- **Minimize air pollution**

LOGISTICS AND SERVICE

- Develop **X-as-a-Service solutions** that ensure the ownership of products remains with the original manufacturer
- Establish **buyback programs,** including giving customers incentives to trade in used products
- Prolong the **usability** of products, for instance **through predictive maintenance**
- Introduce **reverse logistics** so that products can be reworked, remanufactured and recycled
- Reduce packaging and devise **reusable packing solutions**

BACKBONE

- **Set goals and standards,** breaking them down by function. For example:
  - **Define a minimum share of secondary material** per product category and material group
  - **Define a blacklist of forbidden materials**
- **Introduce** a documentation and **data-sharing concept** for information that facilitates circularity, in particular **details of CO_2e footprints** and the **composition of materials** by component
- **Employ digital tools,** such as digital twins, to **monitor products' energy** and material use, waste and pollution
- **Raise awareness for circularity** among employees

In conclusion

A checklist for decision makers

UNLESS WE CLEAN UP OUR ACT urgently and stop acting like cowboys, we will soon have to abandon ship and search for a new planet. As harsh as it sounds, this is particularly true for industrial manufacturing companies: Unless they start offering products designed under circular conditions, they will lose their right to exist. No company can afford to ignore the imperative of circularity – even if it means making short-term investments that do not pay off financially within the typical timeframe of business-case calculations.

But along with the stick, there is also a carrot. Circular products can fill niches and meet customer demands that did not exist just a few years back. For companies, that translates into more sales and potentially the chance to balance out extra costs by adding a "green premium" to sales prices.

To make sure that circularity stays firmly at the top of the management agenda, we have drawn up a checklist for decision makers. The list includes critical tasks such as clarifying stakeholders' expectations, selecting appropriate actions and implementing them in the company's processes, as well as important supporting actions such as changing the company's mindset. But most of all, top management must ensure that building a circular economy remains not only top of the agenda but also front of mind – for the sake of the business, humanity, and the planet.

Checklist

- Clarify your stakeholders' expectations, including customers, investors, employees and regulators
- Check your need for decarbonization and work out how circularity can help you meet it
- Prioritize your company's business fields: Where can you have the biggest impact? Which areas are essential? Where are you creating the most pollution today?
- For high-priority areas, devise appropriate actions and calculate their impact
- Consolidate options, then run another round of prioritization
- Implement your chosen solutions
- In parallel, create the right environment in each function so that a mindset of circularity can develop and flourish across your organization

Credits and copyright

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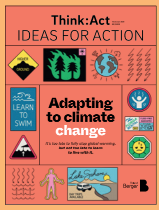
Further reading

Think:Act Booklet
Accelerating decarbonization

Think:Act Magazine
Circular economy

Think:Act Booklet
Act and win: The sustainability game



Think:Act Ideas for Action
Adapting to climate change

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