circular electronics partnership

Circular electronics system map

An industry blueprint for action

Defining circular products and the system needed for change at scale

Developed with Accenture

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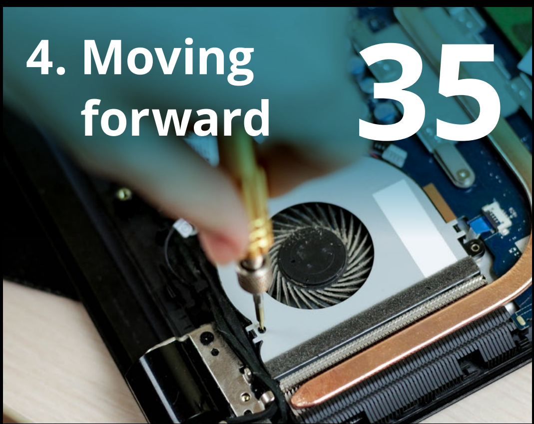


Foreword

Reflections on this work come from a young change maker in the circular economy:

In 2008, Walt Disney Pictures released the movie WALL-E. The film's main character WALL-E, short for Waste Allocation Load-Lifter: Earth-Class, was the last robot left on Earth. The planet was deserted – uninhabitable – and WALL-E was responsible for cleaning up its mounds of garbage. While kids enjoyed the film, it also acted as a warning from the future for adults. This message stuck with me as a teenager and I have kept reflecting on it in my ventures as a social entrepreneur and youth leader as part of the World Economic Forum's Global Shapers Community.

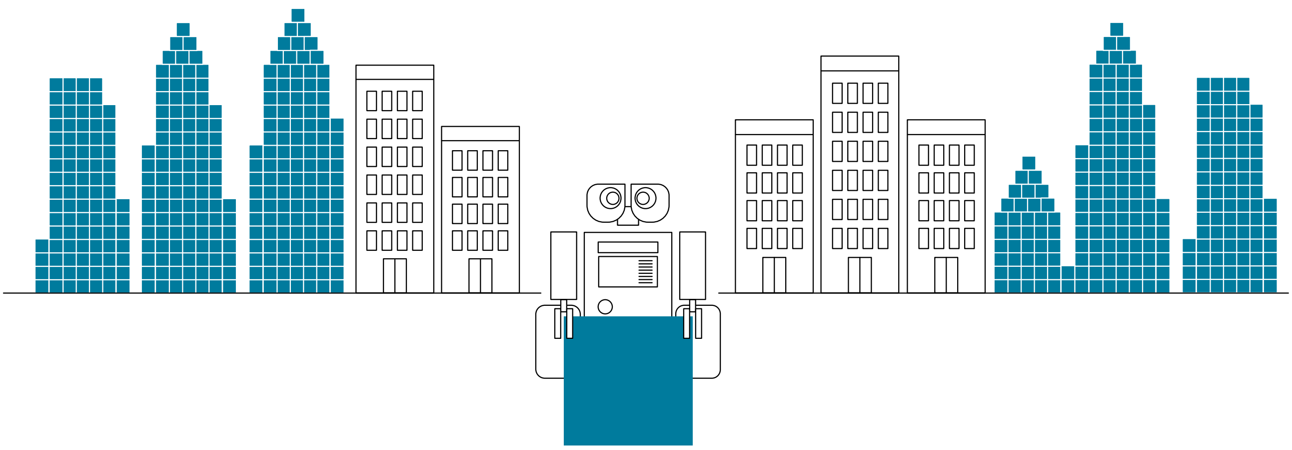
As the Head of Circular Economy at a pan-Asian venture capital firm, I'm privy to those new technologies and innovations that are pushing forward the digital economy in a region where estimates suggest more than 1 billion people will join the middle class in the next decade.

However, every time I reflect on where our world is heading, technology seems like a double-edged sword. Just as in the fictional WALL-E, where technology is both the cause of and the solution to the waste problem, technology has improved quality of life but gadgets, devices and machines, and the constant need to update them, have also driven an unsustainable increase in resource consumption in our real world. By 2040, the information and communication technology sector alone is expected to produce around 14% of emissions globally.

As we move at high speed toward a WALL-E type of world, I wish to build a different kind of future for my generation and the ones to come. This report shows that it is possible to reach such a circular future for electronics if industry has the right map and compass at hand, as well as the impetus to act now. It is clear that we have a long way to go to achieve full circularity, but we can all agree on things that are pragmatic for the industry. First, waste is cost and there is value in cycling it back. Next, material passports are a mechanism that enables upstream and downstream innovation for both industry and consumers. And finally, the world is hyperconnected, so unlocking its circular prowess involves borderless collaboration. The Circular Electronics Partnership provides the building blocks for a circular world and invites everyone to participate.

Carlo Delantar
Circular Shaper, World Economic Forum

Circular Shapers are young grassroots leaders who leverage the World Economic Forum's Scale360° methodology to design, organize and deliver circular economy projects tailored to local needs, all while engaging with public, private and civil society stakeholders in cities across the globe.



About this publication

The Circular Electronics Partnership (CEP) drives a coordinated transition toward an economically viable circular industry.

It strives to maximize the value of products, components and materials throughout the full life cycle, using safe and fair labor and depending only on circular resources.

This CEP publication, representing the collective perspectives of its members* and partners, was made possible by the extensive support of Accenture.

"Transitioning to a circular economy is essential for addressing our current planetary crisis – but also represents a tremendous business opportunity. For us at Accenture, it was instrumental to support CEP in defining a pioneering vision for a circular future in the electronics industry."

Wesley Spindler
Managing Director & Global Circular Economy Lead

CEP members

CEP partners

* Membership does not mean all companies endorse all individual conclusions and recommendations in this report.

Introduction

The modern world relies on electronic products every day. People connect with friends and family via their smartphones, work on their laptops or receive assistance at home from their washing machines. Companies combine digital infrastructure such as servers with new technologies like artificial intelligence or blockchain to enable completely new products, services and business models. But as critical as electronic products are to society, so is the challenge to make the steadily growing industry more sustainable.

The production, use and end-of-life treatment of electronics have many unintended environmental and social consequences. Like any large industry, the electronics sector emits considerable amounts of greenhouse gases contributing to climate change. By 2040, the information and communication technology (ICT) sector alone is expected to produce around 14% of emissions globally, up from about 3% today.[1] Add to this the waste from electronic products, which in many cases is classified as hazardous, and the environmental and social problem grows in significance. In 2021 alone, the world discarded an estimated 57 million tonnes of electronics[2] – which is heavier than the Great Wall of China, the planet's heaviest artificial object. A key challenge is that less than 20% of this amount is collected and formally recycled.[3] Many electronics end up in landfills, especially in developing countries, causing severe health issues in communities exposed to e-waste.[4]

But the electronics industry also faces economic challenges, including shortages of indispensable materials. The pandemic has highlighted these issues, with spikes in demand exacerbating continuing supply chain disruptions. An example is lithium, which is essential for battery production and for which the price increased by 500% between 2021 and 2022 due to supply shortages.[5] Moreover, it will not be possible to mine many finite materials, such as precious metals, or other critical materials and use them in electronic products indefinitely, causing highly volatile markets and uncertainty for the industry.[6]

The circular economy represents a pathway to mitigate these environmental, social and economic concerns. Keeping products and their materials in the loop can lower carbon emissions, prevent the dumping of e-waste in landfills and mitigate supply chain shortages. But the transition to a circular model also represents financial opportunities, as the world's electronic waste has a material value of USD $57 billion – more than the GDP of most countries.[7] Companies can tap this value potential by adopting new circular business models, optimizing the entire product life cycle along the value chain.

To support the transition to a circular economy in the electronics industry, six global non-governmental organizations (NGOs) and the International Telecommunication Union (ITU) founded the Circular Electronics Partnership (CEP), bringing together the biggest names in technology, consumer goods and recycling. The partnership aims to drive a coordinated transition to an economically viable circular industry. While the literature well describes the need for the electronics industry to transition to a circular economy, what constitutes a circular electronic product and what a circular system looks like to enable such products at scale remain unclear. Hence, the objective of this report, collaboratively developed by CEP, its members, partners and Accenture, is to establish this common understanding within the industry to serve as a vision and guiding element for CEP members (and beyond) in the transition to a circular electronics industry.

The world's electronic waste has a material value of

USD $57B

Chapter 1 defines a circular electronic product based on three attributes and describes what has to happen to the product and its materials during the life cycle to be considered circular. Chapter 2 broadens this view and outlines the importance of a supporting system for products to be circular. Chapter 3 is devoted to the question of what a system that enables circular products at scale looks like. Since such a system does not yet exist, the chapter looks into the future and maps out 12 essential systemic enablers of a future circular system. This report uses many circularity-specific terms, so we provide a detailed glossary at the end of the document.

1. What defines a circular electronic product?

The Circular Electronics Partnership defines the circular economy as an economic model that is restorative and regenerative by design and aims to keep products, components and materials at their highest utility and value while minimizing the input of raw materials in the value chain and reducing waste streams. Against this backdrop, two questions naturally arise. What does this mean for the definition of a circular product? And when can a product qualify as circular?

1.1. Three attributes define a circular electronic product

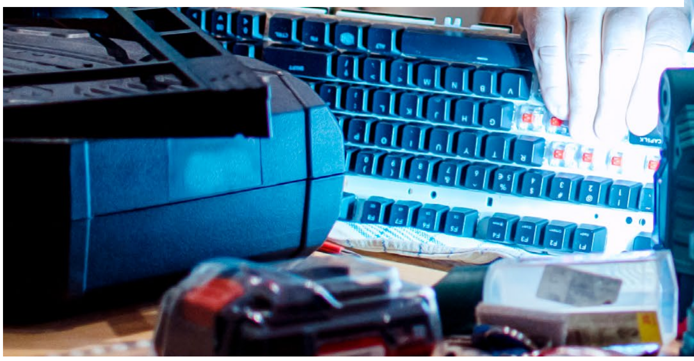
Even though the definition above already focuses on the outcome-oriented notion of the circular economy, it is often circular design principles that are associated with the definition of circular products. These principles include, among others, designing products for durability or recoverability and using secondary instead of virgin materials to produce such products. While these design principles are undoubtedly essential, they represent only one side of the equation. Designing products for circularity does not ensure their resourceful use and recovery at the end of their life cycle. Accordingly, at the time of sale, it is not possible to conclusively answer the question of whether a product can be considered circular, as a large part of its material value retention depends on the actual use and end-of-life handling of a product. Based on this understanding and in line with widely used measurement frameworks for circularity, such as the Circular Transition Indicators (CTI),[8] Circulytics[9] and Cradle to Cradle certification,[10] a product is considered truly circular only if the following three attributes apply:

1. **The product is made from verified circular resources**
2. **The product is designed for use-phase optimization and material recovery**
3. **The product's use phase is optimized and materials are recovered at end of life**

Many companies have already started transforming linear products into circular products by making specific changes to the product, such as in the choice of materials used. These are essential steps on the journey to a circular economy and represent an improvement on the status quo. However, to create a truly circular product, companies cannot just integrate circularity into existing linear products. Instead, they must rethink, design and develop the products and the conditions under which they offer them to the customer from the ground up with the three attributes in mind.

This presents a high bar for all companies wanting to move their products to a circular model, mainly because adhering to the three attributes requires balancing them with cost, quality, safety and performance objectives and other social and environmental aspects, such as carbon emissions. As companies develop circular products, they need to carefully consider potential trade-offs to mitigate unintended consequences. Unfortunately, circularity offers no one-size-fits-all solutions, and companies need to make these considerations on a case-by-case basis. Therefore, it is essential for companies to consider circularity as a key objective from the start of development and not introduce it to the value proposition as an afterthought, when they have already determined parameters such as cost, quality and safety.

The remainder of this chapter describes the three attributes in more detail and outlines particularities for electronic products. Here, the focus lies entirely on the product and what needs to happen to it during the life cycle so that it can be considered circular. Consequently, this chapter does not describe how the larger system enables this.



1.2. Attribute 1 – Made from verified circular resources

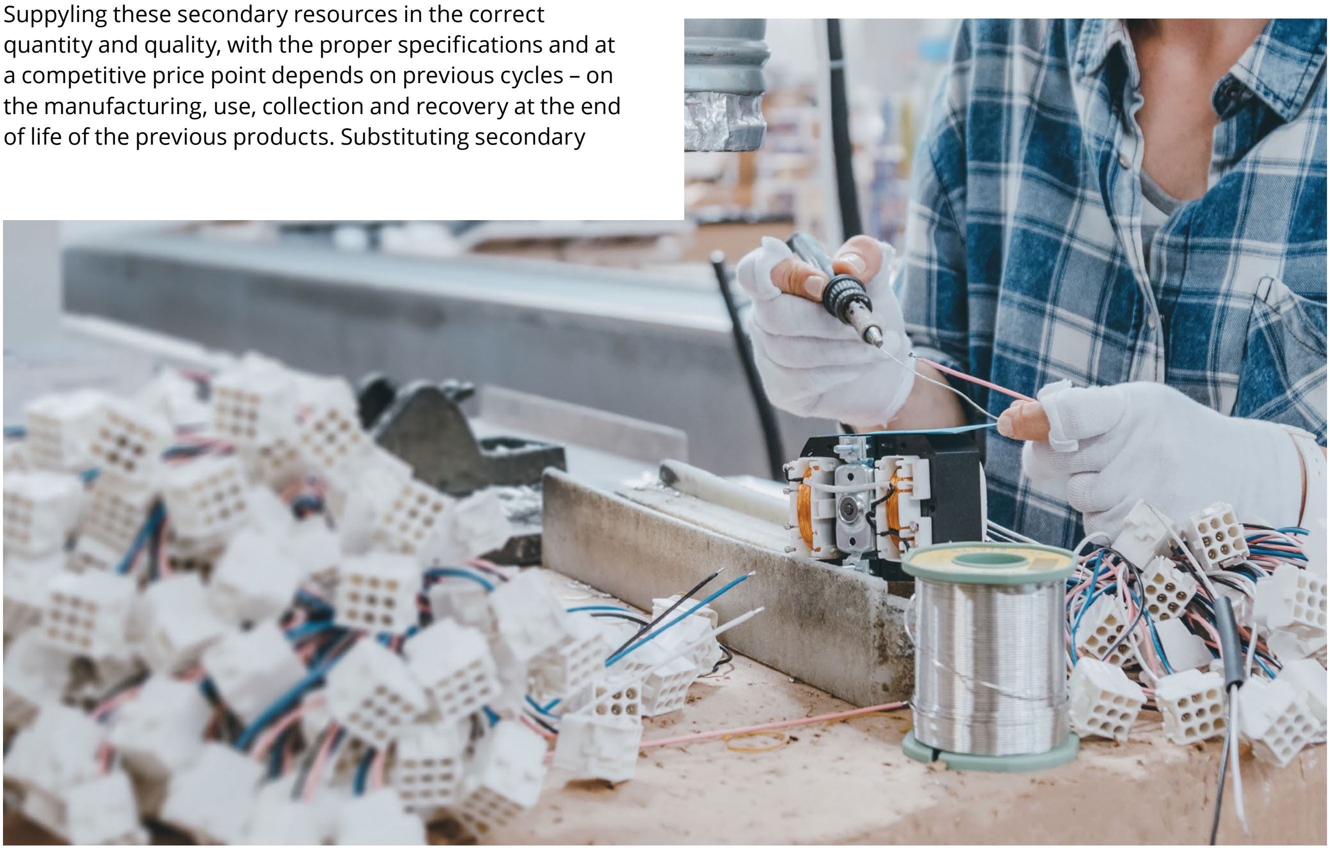
The first attribute of a circular electronic product refers to the inputs that a product is made of. While a linear electronic product mainly consists of virgin fossil and mineral resources extracted from the ground and transferred into workable materials, a circular electronic product contains verified circular resources.

Made from circular resources

Circular resources comprise both secondary and renewable resources. Secondary resources include reused components and parts – often refurbished or remanufactured – as well as recycled materials.[11]* Secondary resources have already circulated in the system one or multiple times. Suppling these secondary resources in the correct quantity and quality, with the proper specifications and at a competitive price point depends on previous cycles – on the manufacturing, use, collection and recovery at the end of life of the previous products. Substituting secondary resources for virgin resources offers an opportunity to prevent many negative environmental consequences from resource extraction, such as erosion and soil and water contamination, and usually to reduce carbon emissions.[12]

Renewable resources are materials nature replenishes at a rate equal to or greater than the rate of depletion. For these materials to qualify as circular, their production needs to be sustainable. This includes, for example, avoiding deforestation and minimizing water consumption. The above-mentioned measurement frameworks for circularity outline further guidance on the sustainable production of renewable materials.

Ideally, a circular product consists as much as possible of reused components and parts, given that reuse maximizes the value retained and requires less additional processing compared to manufacturing new parts and components out of recycled or renewable materials. Whether the use of secondary components and parts is beneficial is decided on a case-by-case basis, also considering potential performance differences between reused components with older technology and newly manufactured ones.

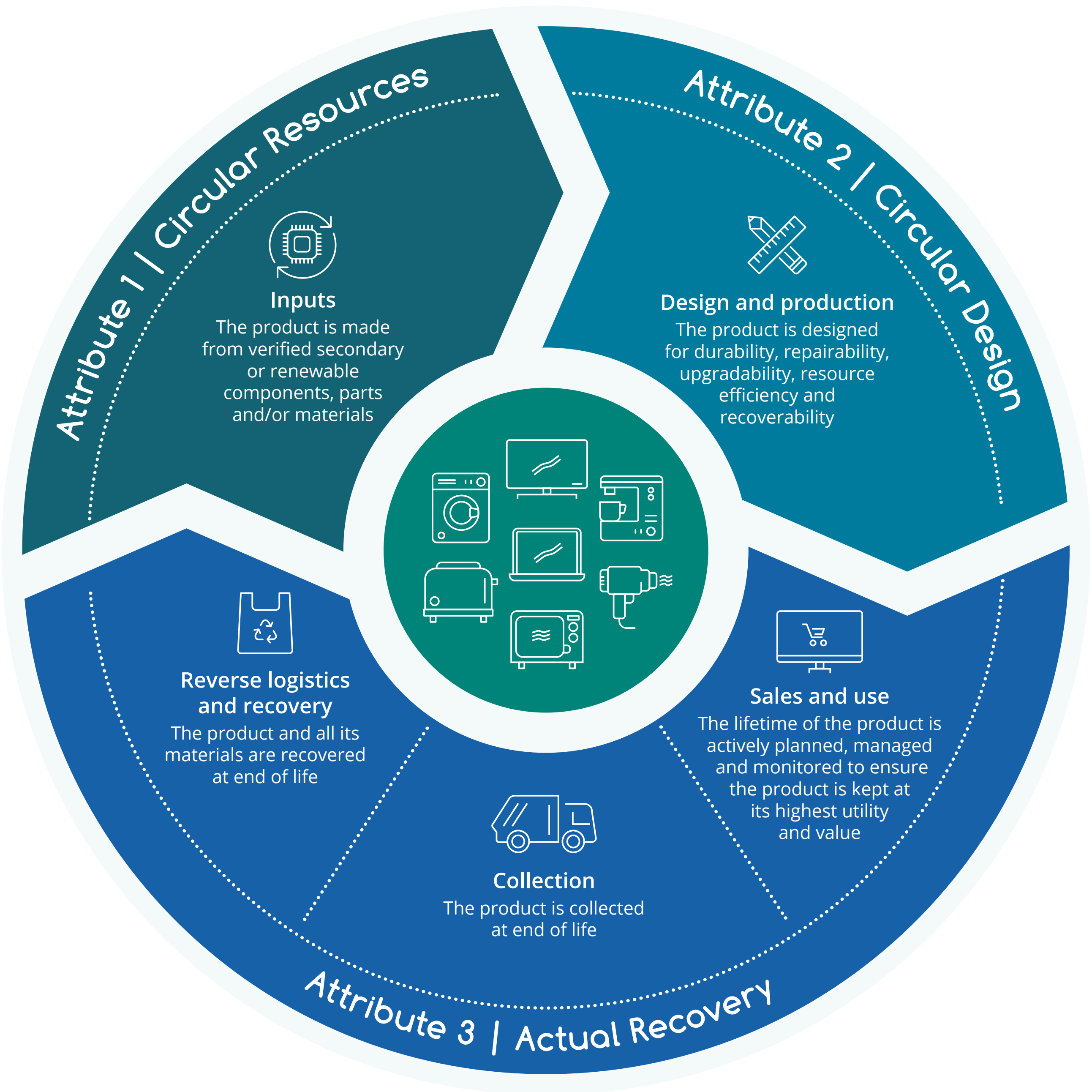


* While renewable materials are included in this chapter for the sake of completeness, they are deliberately neglected in the remainder of the report, as the working group currently does not expect materials from the biosphere to play a significant role in producing electronic products.

Made from resources with verified characteristics

For circular resources, relevant characteristics such as information about the chain of custody are available and verified. Indeed, the complexity inherent in secondary material flows reinforces the importance of verifying and providing evidence that components, parts and materials are undeniably secondary. Hence, for these resources, the origin, recovery facilities and country of processing, as well as other important characteristics, such as environmental, health and safety (EHS) practices during the recovery processes, are transparent. For renewable materials, information about sustainable production processes is available and verified through certification and labeling schemes, such as the Forest Stewardship Council (FSC) and Programme for the Endorsement of Forest Certification (PEFC).

Figure 1: Definition of a circular electronic product



1.3. Attribute 2 – Designed for use-phase optimization and recovery

The second attribute regards the design of the product. Generally, a circular electronic product is designed to be durable, repairable, upgradable, resource-efficient and recoverable. A product's design can fundamentally impact the decisions and actions of various stakeholders, such as consumers or recyclers, during the use phase or at end of life, acting as an enabler of circularity.

Designed for durability

Keeping a product at its highest utility and value requires optimizing the design and materials of a circular electronic product for durability. Doing so extends a product's technical lifetime, avoiding premature obsolescence due to technical or material defects. Durable design and materials also ensure that the product's external appearance remains in good condition. For example, scratch-resistant materials can prevent minor impacts from damaging the screen of an ICT device. Ultimately, more durable products can slow down replacement rates. While the propensity to buy a new device is also dependent on factors like consumer trends, research suggests that extending the technical lifetime of products by 50% can reduce replacement rates by at least a third.[13]

Designed for repairability

The design of circular electronic products allows for efficient and effective repair if something breaks, contributing to the product being used for as long as possible. Products that are easy to disassemble through simple, modular and standardized design are essential for efficient and effective repair. For example, parts connected by screws or click-fit solutions instead of glue allow for ease of disassembly, ultimately reducing the time and resources needed to remove internal components for replacement. Consumers can even do minor repairs themselves when considered safe and with no risk of permanently damaging the product.

Designed for upgradability

While the design of a circular electronic product tends to be timeless and optimized to retain long-term appealing aesthetics even with intensive use, where possible, it also allows for upgrades in case the appearance or functionality is no longer to the consumer's liking or requirements. These upgrades can be either physical or software-based for certain types of electronic products. For physical upgrades, modular design allows for the easy exchange of parts or add-ons. An example is the design of a laptop that enables the easy removal and replacement of a hard drive to meet consumers' changing requirements without purchasing a new product. Software-based updates can also increase a consumer's willingness to use a product longer, especially in combination with the growing importance of cloud computing. As the primary function of electronic hardware in ICT devices is increasingly limited to providing access to applications or data stored in the cloud, the importance of hardware specifications is diminishing. Instead, operating systems and software increasingly dominate the user experience. For the consumer, this reduces the need for a new device, provided software updates happen regularly and continue to be made available for the duration of the product's lifetime.

Designed for resource efficiency

Further, the design of a circular electronic product is optimized for resource efficiency. On the one hand, this means the product's design focuses on using a minimum of resources during manufacturing. On the other hand, it means that the product's design also focuses on being as resource-efficient as possible during the use phase. For electronic products in general, this concerns energy efficiency. Yet water efficiency can also be relevant, for example to cool data centers or for whitegoods (large electrical goods used domestically, such as refrigerators and washing machines). Kitchen appliances can, for instance, have intelligent standby modes for better energy efficiency by design. Where relevant, optimized circular products limit the use of consumables, such as printers that use as little ink as possible for a specific printing output.

Designed for recoverability

Lastly, the design of a circular electronic product is optimized for material recovery by enabling effective and efficient processing at the end of life. Here again, ease of product disassembly is critical for the removal of components and parts without physical destruction to ensure they can still be refurbished or remanufactured. In addition, the materials used must be recyclable, since it is not possible to conclusively predict the reuse of the components and parts in new products at the time of product development. For this, the design of a circular electronic product ensures that no hazardous materials or chemicals, such as flame retardants, that impede or prevent recycling are required to produce the desired material properties.

Trade-offs

Trade-offs between the different dimensions may well occur. For example, a reduction in the amount of material in the product can generally be seen as positive. However, it can also have potentially negative implications for the product's durability and thus contradict the objective of keeping components and materials in use for as long as possible. Since there is no definite hierarchy of design principles, product-development teams should evaluate these trade-offs with a life-cycle analysis based on the product's intended use, the services offered linked to the product and the larger circular system for its intended collection and recovery. CEP is not the only collaborative platform for the industry working on broader topics regarding circularity. The Open Compute Project (OCP) is an industry collaboration focused on speeding the pace of innovation in and around the data center. Within OCP, the Sustainability Initiative is developing a detailed study of and guidance on circular design principles specifically for data center hardware. This collective of electronics companies is planning to launch its *OCP Design for Circularity Guide* later this year.

1.4. Attribute 3 – Optimized use phase and recovery at end of life

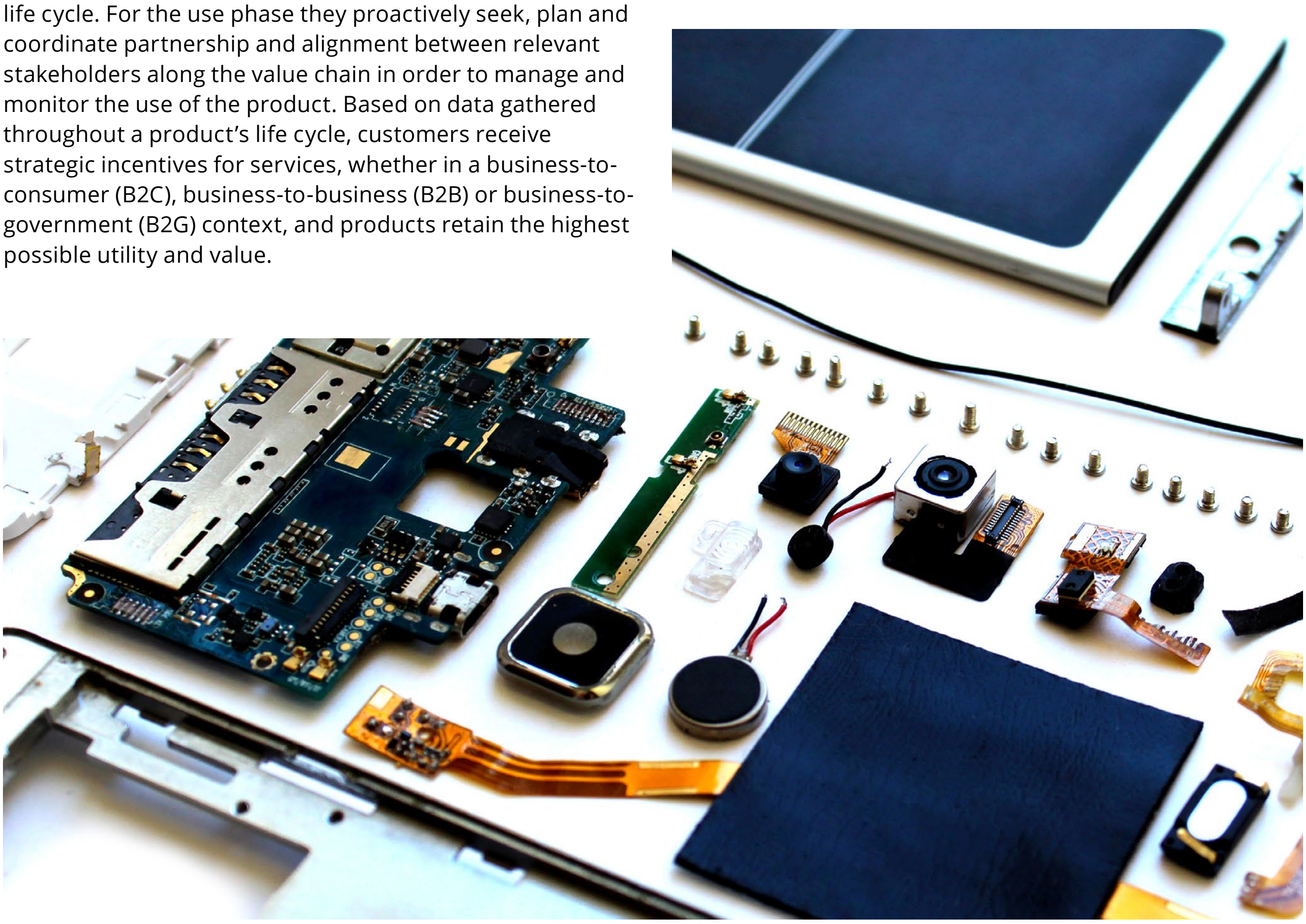
The third attribute concerns the use phase and recovery at end of life. Although a product may have been designed for circularity, the larger share of the job is still to come. Despite all previous efforts to enable circularity, ultimately the use phase, collection and recovery determine whether the product will suffer a linear demise or its loop can be closed.

Optimized during use phase

In contrast to conventional sales of linear products, companies that offer circular products develop and apply strategies that ensure the closing of the loop across the full life cycle. For the use phase they proactively seek, plan and coordinate partnership and alignment between relevant stakeholders along the value chain in order to manage and monitor the use of the product. Based on data gathered throughout a product's life cycle, customers receive strategic incentives for services, whether in a business-to-consumer (B2C), business-to-business (B2B) or business-to-government (B2G) context, and products retain the highest possible utility and value.

Such data may, within the scope of relevant data protection policies, provide information about how the customer uses a product, the condition of the product and its components, or the remaining life expectancy of the product. Based on this data, for example, a company offers services to maintain the product at regular intervals to prevent the premature wear of components. If the product breaks, the company or its value chain partners provide repairs when the additional resources for the repair service and spare parts justify the additional lifetime forecast.

In addition to such services, software updates and support for circular products remain available and continue, as these can be essential to the proper functioning and security of the device. If consumers decide not to use the product any more even though it is still functioning, they will receive information about how to resell the product via peer-to-peer platforms or through the original equipment manufacturer (OEM), retailer or dedicated resale companies. If necessary, it is possible to refurbish the product and erase data on it, which is especially important in a B2B or B2G context, to facilitate reuse.



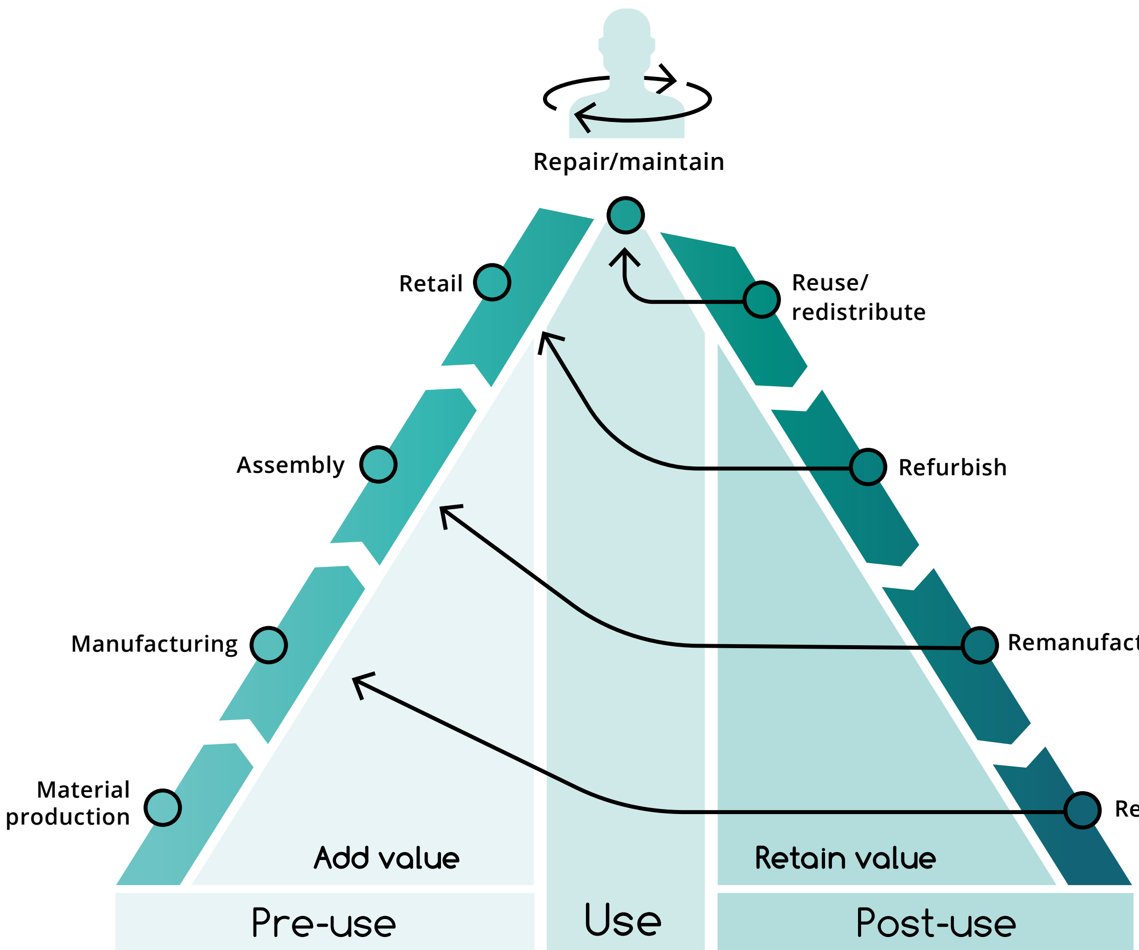
Collected at end of life

At some point, potentially after having been used by multiple consumers, a circular product reaches the end of its life. The reasons for this can be manifold, such as when consumers or, in a B2B or B2G context, the organization are no longer interested in using the product or when the product is broken and repairing it would be too resource-intensive to justify the additional lifetime. This is when the product needs to be returned to a collection agent. Unlike other aspects along the value chain that may influence the quality or the cost of product recovery, collection can be a real showstopper. Without collection, there is no way to recover a product's components, parts and materials. Therefore, collection at end of life has particular importance for circularity.

Recovered at end of life

After collection, all materials of a circular electronic product are recovered.[14] This is done either at the level of components and parts or at the material level. The former means that after the product has been disassembled, its components and parts are reused in products of the same type or entirely different applications. This may require the refurbishing or remanufacturing of individual components and parts and the sanitizing of data stored on the components. If reuse at the component and part level is not possible, the sorting agents further disassemble these components and parts and recycle the materials. For a circular product, this means recycling both the materials with inherent value, such as precious metals like gold, silver, palladium or copper, and other materials, such as plastics or rare earth metals that are only used in very small quantities. Recyclers take further care to ensure that there is no unnecessary downcycling of materials of a circular product and that they retain the inherent value of the materials as much as possible.

Figure 2: The value hill in a circular economy



2. Products can't beat the system

Based on the proposed definition of a circular electronic product, it is clear that it is not just the physical product that matters. The definition requires a holistic circular system of products, services, networks of actors and supporting infrastructure. For example, to extend a product's lifetime, service providers and suitable infrastructure are necessary to provide repair, upgrade and refurbishment services. In addition, product recovery requires the existence of adequate collection and reverse logistics infrastructure.

Companies that want to offer circular products to their customers will have to actively establish such a system with value chain partners. Due to the nature of the circular economy and the network of dependencies that enable it – for example, supply chain dependencies – any weakness or gap in a circular system can cause the circle to break. Some elements of a circular system are product-generic, such as a marketplace for secondary materials or certifications that confirm the secondary nature of materials. Other elements are more product-specific, like repair or upgrading services. Product-specific elements require alignment between product and system. This can mean aligning a product's design with existing services or infrastructure or vice versa, introducing and establishing new services to match the characteristics of an innovative new product.

These decisions need to be aligned with the company's objectives, competitive strategy and business model for each product. Companies offering circular products need to determine which elements of a system they want to build or operate on their own and which elements they wish to address via partners or pre-competitive industry collaborations. This can mean establishing new external partnerships with upstream or downstream actors or building new internal capabilities. Depending on the product and industry, some companies may rethink sales models, channels and the type and extent of customer engagement and relationships. Above all, companies need to reshape a product's value proposition and financial model, as establishing circular product systems will inevitably disrupt existing cost structures and revenue streams. This can mean, for example, increasing the share of service fees in a product's total revenue or creating new revenue streams for end-of-life products.

Rethinking a product's financial model is especially relevant since, in most cases, establishing a circular system is only feasible through the interplay of various actors along a product's value chain, including aligning financial incentives so that all relevant actors benefit from their role in the system. Mechanisms must be in place to ensure that it is still worthwhile to undertake even those activities that do not constitute an economic benefit, such as the collection and recovery of low-value items. Pricing in externalities, for example, enforced through legislation, can help ensure that environmentally friendly activities do not suffer a financial disadvantage.

Once value chain stakeholders have collectively established a circular system, companies offering circular products need to proactively collaborate with value chain partners to manage the different dependencies and monitor the system's effectiveness. For this, the availability of relevant data throughout the life cycle is most relevant, which is why technologies to generate this data and the mechanisms for sharing the data between relevant actors are crucial.

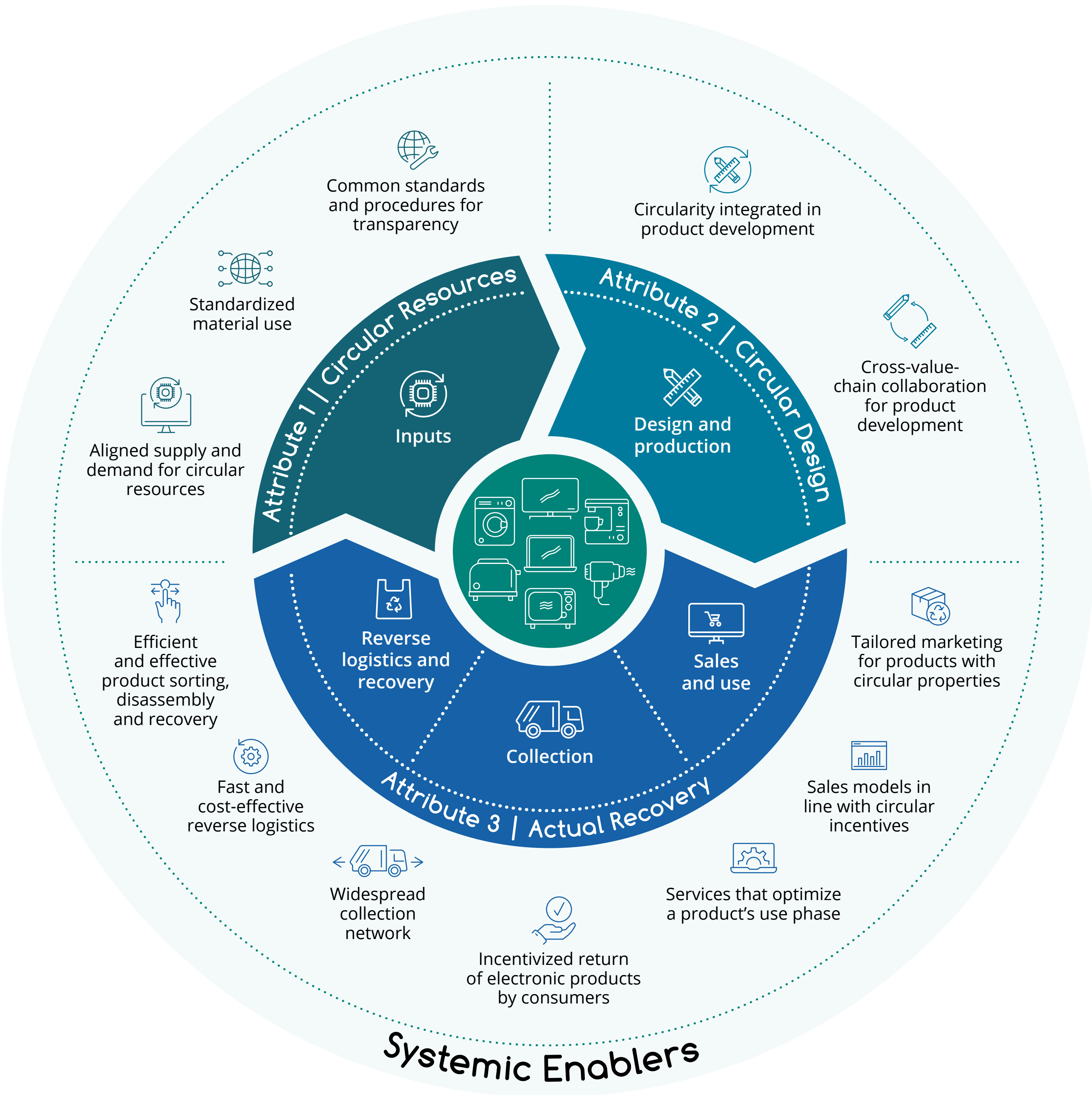
3. What does a system that enables circular electronic products look like?

Electronic products that meet the three attributes do not yet exist at scale. While companies are slowly transforming their products and starting to build systems that keep products in the loop, a fully circular system is more of a hypothetical construct at this point.

However, to clarify what companies need to work toward, this chapter describes what a circular system could look like based on 12 systemic enablers essential for circular products at scale. CEP and its members have worked out and prioritized these enablers. This chapter is written in present tense to better illustrate how such a system would operate and how the different elements interlink. However, some of the preconditions of the system, such as regulations or technological advancements, are not yet present.

This might seem discouraging but it is precisely because a fundamental change in many areas is required that companies striving for a transformation to a circular economy have to start working on these systems today. That this is already happening to some extent is illustrated by the various case studies in this report, which present practical examples of how organizations contribute to building a circular electronics system.

Figure 3: Circular electronics system



3.1. Systemic enablers for products made from verified circular resources

In a circular system, there is a functioning market for verified circular resources as supply and demand are aligned. Standardization drives critical material mass in the system and state-of-the-art technologies ensure that the verification of resource origin and properties enables transparency on upstream activities.

(1) Aligned supply and demand for circular resources

To ensure that secondary resources are available in the right quantities, with the right quality and with the right specifications when and where needed, a circular system operates with high transparency on both supply and demand requirements. Digital platforms forecast demand and supply and share these vertically between material suppliers and manufacturers. Suppliers know the quantities and qualities of secondary components, parts and materials they can provide in the near future by studying and planning incoming secondary resource flows. This is enabled, for example, by the internet of materials (IoM), a decentralized system connecting and aggregating data on product and material levels through standardized communication protocols. A neutral governing body manages the IoM, working with industry players to shape data standards, privacy requirements and related access authorizations.

On the demand side, manufacturers of electronics assess demand early on and communicate this to their suppliers, including an indication of the requirements for secondary components, parts and materials. This is relevant because suppliers, in turn, might need to specify the state of recycled feedstock they receive from recyclers. When detailing material requirements for secondary resources, design teams involved in product development evaluate which material properties are actually relevant to the particular product, rather than specifying requirements that they are used from virgin materials, avoiding over-specification that unnecessarily limits the use of secondary resources. Publicly available environmental targets set by electronics manufacturers, such as quotas for post-consumer recycled content, signal the demand for secondary resources in the medium to long term and provide trust so that suppliers can build their capacity. Such signals represent an important pull to grow the overall market for secondary resources.

Supply chains for secondary materials operate with similar fluidity and flexibility to those for virgin materials, enabled through close partnerships between recovery facilities and production plants, as well as efficient logistics solutions. In some cases, harmonizing recovery facility and production plant locations can be sensible, minimizing logistics between the point of recovery and new production. This can reduce turnaround time and improve the environmental performance of secondary materials. The latter is essential, as shipping end-of-life products around the globe to reduce recovery costs can lead to adverse environmental impacts that at least partly outweigh the benefits of secondary materials over virgin materials.

Further, in a circular system, secondary material markets are financially viable for suppliers and procurers. As everything is optimized to maintain the value of the materials and allow efficient and effective recovery, the costs of supplying secondary materials will conceivably be below the prices for most of their virgin counterparts.[15] Fiscal incentives and other policy instruments, such as reduced value-added tax on secondary materials or pricing in externalities, for instance through a carbon price, further ensure the competitiveness of secondary material prices. In addition, better alignment between supply and demand also lowers commodity prices and contributes to less volatility due to fewer unexpected demand drops or spikes. Finally, even if some prices for secondary materials remain slightly higher than for virgin ones, the pressure on electronics manufacturers to reduce corporate and product carbon footprints ensures that institutional purchasers are willing to pay a price premium, as secondary materials help to reduce these metrics.

In a circular electronics system, both open value chain loops and closed value chain loops will exist. What is preferable for a company depends on factors including the quantities of respective products on the market, the scarcity of the materials used in the products, the required logistics to operate a closed value chain loop, or the technologies available for material recovery. However, a general prerequisite for closed value chain loops is that the quality of the materials does not deteriorate more than slightly during recycling; otherwise, the use of these materials in new electronic products is not possible.

Case study

Collaborative material exploration (Lenovo)

Sony Semiconductor Solutions Corporation (SSS) has developed a plastic material called SORPLAS™. Lenovo worked with SSS on a variation of SORPLAS made with 95% post-consumer recycled plastic content derived from recovered water bottles and optical discs on molding, performance and quality evaluation for Lenovo components.

Lenovo started including the material in its 45W and 65W power adapters in 2021. Since then, it has incorporated the material in battery packs, speakers and soon-to-be-announced components with 95%–98% post-consumer recycled plastic content as a new family of SORPLAS.

(2) Standardized material usage

Pre-competitive alignment between value chain partners and competitors facilitates the exploration of new materials suitable for use in circular products (see the Collaborative material exploration case study above). These materials represent a safe, reliable and affordable option to be included in electronic products – also in a recycled form – and can be recovered and kept in the loop without considerable downcycling.

Electronics companies are not only collaboratively exploring new materials for a circular economy. They are also standardizing material specifications and use. Such standardization increases scale and results in more reliable supplies, potentially at lower prices.

In addition, it reduces the complexity of downstream activities, as more products with standardized materials mean more incentives to collect and recycle. Alignment also exists on the use of specific substances that are not easily recoverable. For instance, agreements encourage the avoidance of specific additives in plastic that make such plastics harder to recycle. In general, going beyond pre-competitive alignment, legislation also prescribes standards, as do incentives stemming from circularity labels that, for instance, companies can only obtain if they avoid certain "banned" materials. In this context, organizations such as the ITU shape a common understanding of such standards.

(3) Common standards and procedures for transparency

As described in the first attribute, verified product characteristics need to be present for secondary resources. The establishing of industry-wide standards and definitions for chain of custody and production characteristics, such as recycling processes, material handling, worker safety or the environmental management systems applied, enables transparency and verification. On a material level, multi-party systems leveraging technologies such as blockchain deliver this traceability. Cryptographic anchors, for instance in the form of programmable and tamper-proof chemical codes that can be incorporated into materials to enable traceability beyond the first cycle, enable the identification of materials and provide access to the respective characteristics. The data stored on the ledger might vary for different materials. For conflict minerals such as tin or tungsten, the source of the materials may need to be transparent in compliance with existing regulations, while plastic requires proof that it is actually recycled. By creating such transparency around material properties, technological solutions such as blockchain mitigate fraud (for example, claiming that materials are secondary even though they are not). However, where it is not possible to apply such technologies, there needs to be clear accountability in case fraud is detected.

Excursus: product passport

With the help of a product passport, it is possible to link the digital data flow of a product to the physical material flow. The passport is stored on a product itself, in the cloud or on a blockchain solution. Scanning a unique "cryptographic anchor" attached to or embedded in the product provides access to the passport to authenticate it. These anchors can be physical, such as fluorescent markers or watermarks, digital, such as RFID tags or microcomputers, or biological, such as DNA markers. The information stored in the product passport is either publicly available or accessible by a user with permission to ensure data privacy (such as for use-phase data) and protect sensitive business data (for example, on specific components or designs). Information stored includes the provenance of materials and components, the product's condition and ownership during use. Further information on product passports can be found in the *Harnessing the Fourth Industrial Revolution for the Circular Economy: Consumer Electronics and Plastics Packaging* white paper.[16]

3.2. Systemic enablers of product design for use-phase optimization and recovery

In a circular system, electronics manufacturers can design for circularity collaboratively with relevant value-chain actors. To ensure that products are designed for use-phase optimization and recovery, circular thinking is deeply integrated into product development.

(4) Circularity integrated into product development

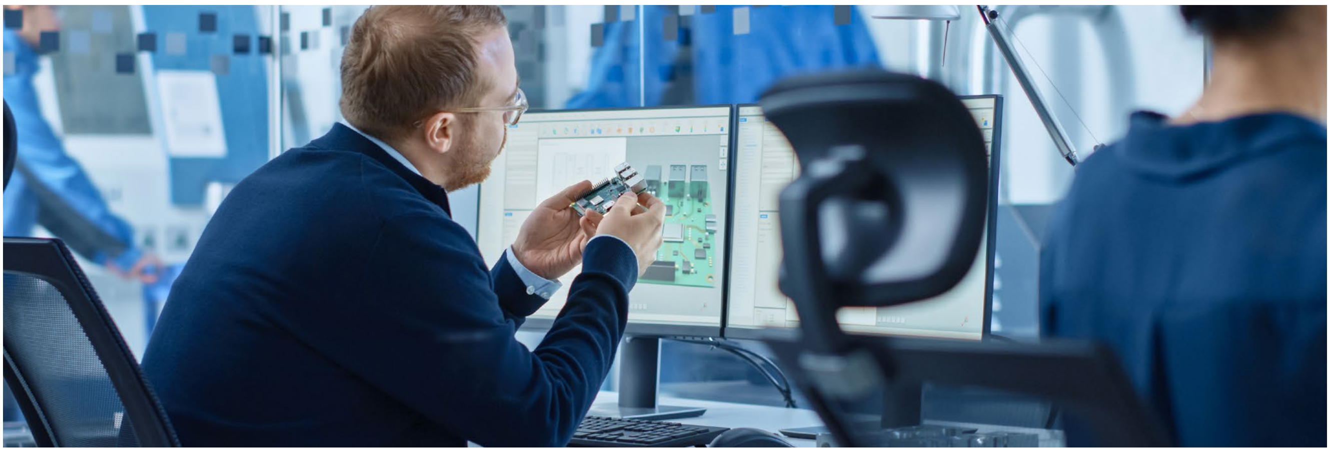
In a circular system, electronics companies design and develop circular products at scale, as they see circularity as a key priority. The principles of circularity align with the company's purpose and mission, and clear focus areas for circularity are defined. The company agrees on and communicates targets, such as a certain proportion of circular products in the overall product portfolio. It establishes key performance indicators (KPIs) and monitoring systems to track and report target achievement. Where appropriate, these KPIs follow common measurement frameworks, such as CTIs or Circulytics.

Electronics companies align operating models with circularity as a strategic priority. They embed circular thinking in the organizational mindsets spanning all functions, including marketing, finance, quality, customer service and procurement. Leadership mandates and enables product managers, developers, engineers and designers to design circular electronic products.

These people receive training to fully understand circular design and the full intended product life cycle at a practical and applicable level and have access to industry-wide agreements, standards and success stories (see the Embedding circularity into the product design process case study on page 25). Developers, engineers and designers have the time and resources for pre-development initiatives, innovation and testing of circular designs, materials and technologies.

The evaluation of circularity and other environmental and social impacts (such as through life-cycle assessments (LCAs)) is seen as indispensable to the product-development process. Therefore, teams have access to data-based intelligence to make informed decisions. To enable better simulations of design decisions along the whole life cycle, product-development teams use state-of-the-art technologies, such as digital twins, combined with machine learning capabilities. For instance, they can design more material-efficient product parts, such as device castings, with the same stability but reduced material usage. Further, they can better simulate and improve the energy consumption of different technologies during development. Such information enables product-development teams to better foresee the life-cycle impacts of their design decisions and thus design more circular products. Finally, if trade-offs occur, the company's governance sets a clear framework to address them – for example, between circular product properties and other product dimensions (such as quality, price and safety).

In cases where original design manufacturers (ODM) partly handle product design, OEMs ensure that these partners understand the circular ambition for the respective electronic product and that they are also capable of designing for circularity so that the individual components do not restrict the circularity of the overall product.



(5) Cross-value-chain collaboration for product development

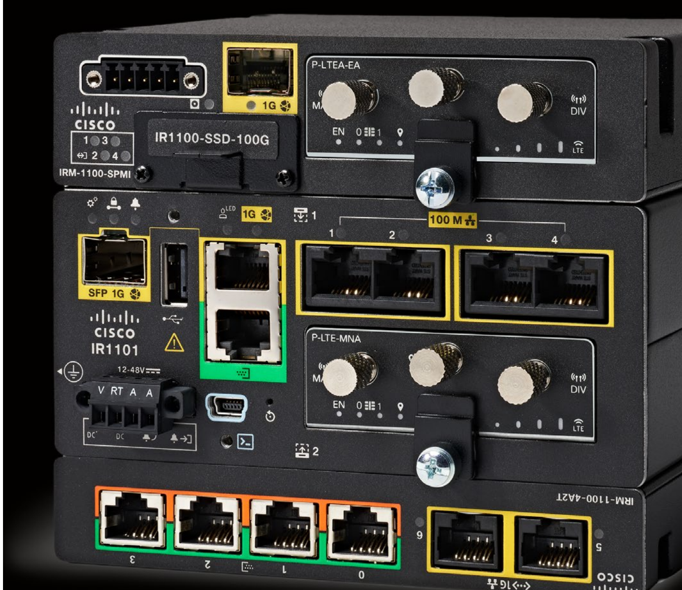
Prior to even starting a product's physical design, development teams need a detailed life-cycle strategy, as product design solutions depend entirely on the product's intended use, repair, refurbishment, collection and recovery. Since a myriad of different actors along the value chain beyond the OEM are ultimately executing this life-cycle strategy, it is necessary to undertake product development for circular products collaboratively. Each stakeholder must articulate their requirements for product design to fulfill their roles and responsibilities throughout the life cycle. For instance, OEM engineering and design teams collaborate with recyclers to explore whether certain materials and their foreseen use in the product allow for efficient and effective recovery at end of life by gaining better insights into the current recovery practices and technologies in the countries in which their products will likely end up at the end of their lives. Only then can OEMs design electronic products with the end of their lives in mind. Another example is that engineering and design teams interact with repair service providers to understand the tools available for repair so that they can adjust product design and the ability for disassembly accordingly.

Analogous to materials, value-chain actors or competitors standardize parts and components – or even accessories such as chargers – in a collaborative effort provided it does not hinder innovation. This eases downstream activities, especially for players working with different brands or product types. Generally, collaboration during product development could, for instance, happen through digital open-source design tools set up as interactive platforms available across the value chain, allowing actors such as recyclers or repair service providers to provide feedback on the circularity of designs. Such solutions allow for collaboration with no risk of increasing the time to market.

Case study

Embedding circularity into the product design process (Cisco)

Cisco has a clear objective: to embed circularity at every stage of a product's life cycle, starting with design. In fact, the company has set a public goal that 100% of new products and packaging will incorporate circular design principles by fiscal year 2025. To build the foundation for this goal, Cisco identified five key focus areas for circular design: (1) the use of materials, (2) standardization and modularization, (3) packaging and accessories, (4) smart energy consumption and (5) disassembly, repair and reuse. Next, a cross-functional team of sustainability and product-development experts worked together to define 25 Circular Design Principles to operationalize impact across these five focus areas. To ensure that engineers are prepared to incorporate the design principles, Cisco developed circular design training. By the end of fiscal year 2021, the training completion rate was 93% across prioritized supply chain and engineering teams. Cisco is increasingly embedding its Circular Design Principles into key design tools and the standard product-development process, from conceptualization to product release.



3.3. Systemic enablers of optimized use phase and actual recovery at end of life

In a circular system, marketing and sales models are in line with circular incentives, services such as repairs or upgrades are available during the use phase, consumers are incentivized and enabled to return their products at the end of the life cycle and reverse logistics, sorting, disassembly and recycling are efficient and effective.

As mentioned in the previous chapter, during product development, the OEM and relevant stakeholders work out a life cycle strategy collaboratively to ensure the optimization of the use phase of a product and its collection and recovery at the end of its life. This strategy encompasses, among other factors, a product's marketing, the sales model, the services offered during a product's use phase, take-back and the definition of preferred recovery pathways. These individual elements of the life-cycle strategy need to interlock and collectively keep the product in the loop, rather than being a multitude of isolated initiatives.

(6) Marketing tailored to products with circular properties

For circular products to come into use, individual consumers and private sector purchasers must prefer these products over linear ones. Consumers and purchasers need to overcome the unjustified perception that the quality and safety of products made from secondary or renewable resources is inferior and understand the consumer, social and environmental benefits these products offer. Companies offering circular products tailor their marketing to this objective. For instance, they highlight product characteristics such as longer lifetime or good repairability, financial benefits such as lower total cost of ownership over the entire life cycle, or environmental benefits such as the lower carbon footprint of circular products. This requires that companies offering circular products thoroughly quantify these benefits and can present them in a fact-based way to differentiate from greenwashing. This is especially relevant for institutional purchasers, for whom potential cost or carbon savings through circular products need to be transparent. Companies who market circular products don't simultaneously put out messaging aimed at quick consumption and seducing the customer with the latest trends and technology.

Ecolabels play an essential role in helping private customers or institutional purchasers make an informed decision on environmental benefits at the point of sale. For institutional purchasers, ecolabels are an easy way to identify products verified to sustainable or circular standards, eliminating the need for procurement professionals to create their own understanding, definition and requirements (see the Sustainability and circularity ecolabel case study on page 27). Ecolabels are an effective tool for organizations to demonstrate core values and goals, as well as to communicate with stakeholders their actions to achieve their sustainability goals. Also, for manufacturers, ecolabels are a simple way to evaluate their products credibly and uniformly against sustainability standards, rather than having to meet various procurement criteria. Although each ecolabel prescribes its own set of requirements in its own terms, they do not contradict sustainability and circular principles. Hence, manufacturers can keep circular solutions universal to comply with all labels relevant in the markets they serve. In general, while ecolabels may have different requirements, it is essential that they consider cradle-to-gate performance, meaning the performance until a product leaves the factory, and all actions taken throughout the whole life cycle to keep a product in circulation.

Case study

Sustainability and circularity ecolabel (EPEAT)

Ecolabels play an essential role in the transition to a circular electronics industry. Current ecolabels on the market covering electronics include Blue Angel, EPEAT, Japan Eco Mark, Nordic Swan, Taiwan Green Mark and TCO Certified. EPEAT, a type 1 ecolabel managed by the Global Electronics Council (GEC), has criteria that assess environmental and social issues related to sustainability and circularity. It evaluates the entire life cycle of electronic products, from the extraction of materials through to manufacturing, packaging and transportation, product use and the end of life of products and components. To register, a product must meet multiple criteria under the four pillars of climate change mitigation, sustainable use of resources, reduction of chemicals and corporate environmental, social and governance performance. There are thousands of registered EPEAT products from manufacturers and brands globally in the following categories: computers and displays, imaging equipment, mobile phones, network equipment, photovoltaic modules and inverters, servers and televisions. Around the world, public and private sector purchasers reference EPEAT as their preferred technology criteria for tenders to meet their sustainable and circular procurement policies as EPEAT supports them in identifying products that contribute to the transition to a circular economy.

(7) Sales models in line with circular incentives

In a circular system, circular products are offered in both sales-focused and as-a-service models. In as-a-service models, incentives are in line with those of the circular economy (see the PC as a Service case study on page 28). First, as-a-service model operators profit from products designed for circularity, as they can internalize the economic benefits from designing for durability or repairability. Because service fees occur over a longer product lifespan and service costs such as for repair are lower, as-a-service models have the potential to be highly profitable in a circular system. Second, as the consumer is required to turn in the product after the service contract ends, operators can better plan collection. Third, as ownership of the product remains with the operator, they can more easily generate and store data, such as on the use, maintenance and repair of the product, in the product passport, enabling better management and monitoring of the use phase of a product and providing transparency over a product's condition at end of life. Despite these advantages, for some products (low-value items, for instance) or certain customers, sales-focused models may be preferable. For models where ownership of the product is transferred to the consumer, offering attractive additional services for the product is even more relevant to keep the product in the loop.

Excursus: What future consumer behavior in a circular system could look like

Consumers value access over ownership and are fine with using devices that are not brand new. They are well-informed and receive adequate compensation for their role in closing the loop on electronics. They find ownership – and the costs that come with it (maintenance, time, space, etc.) – to be too cumbersome and restricting. These consumers prefer privacy and security assurance, convenience and a relationship with a company with an altruistic reputation. They are aware of misconceptions (such as that recycled or used means lower quality) and barriers that kept their parents and grandparents from returning their used electronics, and see hoarding items others could be using as a taboo. They know which companies are genuinely committed to achieving a sustainable future versus those only paying lip service.

Case study

PC as a Service (Dell)

Dell offers PCs as a Service to business customers (B2B). It designed the service with flexibility in mind to meet individual business requirements. The service includes PC technology, software and life-cycle services, including deployment, support and asset return and exclusive Dell technology and tools that automate, troubleshoot and resolve system issues faster. Customers can use all of these solutions for a single monthly fee, which they can potentially finance through Dell Financial Services.

Advantages for customers are manifold. Through this consumption model, budget planning is more predictable and there is reduced IT effort to manage computing needs. In addition, it plans and streamlines system refreshments so that consumers can quickly move to the latest technologies without significant disruptions to their workflow. For Dell, it means closing the loop on these products by securing the recovery of devices at the optimum time for refurbishment and reuse or extracting components to extend the life of other systems.

(8) Services optimizing a product's use phase

Based on the defined life-cycle strategy, companies design services to prevent products and materials from "leaking" out of the system during use and collection. This is where circular service design comes into play. Maintenance, repair, upgrades or reuse services can help consumers to verifiably do the right thing. Hence, companies think carefully about what a consumer needs at what point in time to keep the product in use. Once identified, they develop suitable services that answer this need. While a company who plans to offer circular products is involved in designing the services and implements its life-cycle strategy, it does not have to provide these services itself. Instead, it can find specialized partners and ensure that these services are known to consumers, that they are accessible and affordable and that the partners provide them in a way that preserves the value of the product as much as possible. If done well, these services also have the potential to shape the quality perception of brands as much as product design. Therefore, companies should carefully consider them as a real differentiator over competitors.

In a circular system, OEMs, retailers or telecommunications companies inform the consumer at the point of purchase about the product's use and maintenance and what services are available. Further, as these companies can track product conditions and use through sensors and derive information about past repair and maintenance transactions through the product passport, they can strategically incentivize the services necessary to maintain the highest value of the product when needed. For example, through predictive maintenance, they can inform the consumer that a part of the product is about to break if not maintained or repaired. Through such predictions, it is usually possible to repair the product at a lower cost and with fewer resources than if the part or component is used until it breaks completely.

In a circular system, services are accessible for ICT equipment and all other types of electronic products. Widespread service networks, where possible, are responsible for individual products or brands and cover a large number of different products. If local accessibility of services is not possible, they are made available through other channels. For instance, for smaller items, mail-back options are available. To ensure that services such as repair or upgrade services can be offered over a long period, the corresponding spare parts are available for circular products for longer than for linear products.

Further, services need to be affordable. From an industry perspective, revenues from services will compensate for reduced product sales in a circular economy; hence, it is necessary to maintain a certain level of profitability. However, from a consumer perspective, prices for maintenance, repair and upgrade services should not represent a significant financial burden that could be a barrier to their use. In an as-a-service model, the respective operator will carry the costs for these services. However, when the customer purchases the product, the company could mitigate the financial burden by offering these services directly with the sale of the product as a sales bundle, such as through dedicated insurance or by extending the warranty, which is already common practice for some ICT equipment such as phones. In addition to the absolute cost of these services, the relative difference compared to the price of new product versions is also decisive. Therefore, the price difference should represent a clear incentive for consumers to repair or upgrade existing products instead of buying new products prematurely. To achieve such affordable prices for these services, reducing operating costs is a key priority. In particular, in developed countries with high labor costs, better product modularity in combination with automation enables more cost-effective ways to perform these services.

To ensure the sufficient quality of these services, providers have access to training and certification programs for repair and refurbishment in a circular system. These programs are aligned with OEM specifications for maintenance, disassembly or repair. In addition, consumers can receive manuals for the products that they can repair and have access to manufacturer-approved parts.

Case study

Incentivized collection (Currys)

Research by Recycle Your Electricals highlights that homes in the UK have over 527 million unwanted electronic items and that the population discards 155,000 tonnes of electronics annually instead of reusing or recycling them. Many of these items are data-bearing devices, so concerns about what to do with them or a lack of awareness of options usually leave people storing them. Currys has been offering take-back in all its stores since 2007, but awareness of this service among the general public is low.

To address this problem, Currys offered a financial incentive to its UK customers to bring back e-waste (even if the product is not working any more). The main challenge was understanding the financial implications of providing a GBP £5 voucher for any item purchased at Currys (customers are required to spend GBP £25 to use the voucher). The other challenge was creating awareness of the month-long campaign. The company used PR in local and national newspapers alongside its social media channels to promote the campaign. The final concern was not knowing the uptake and potential space and operational issues at the store level.

Results from the incentive have been hugely positive. Currys saw 267 tonnes of small electronics collected in UK stores during the month-long initiative. This is an 84% increase on the yearly average for that period. This increase represents over 43,500 pieces of extra tech collected for reuse or recycling. In addition, the trade-in volumes also increased 22% due to the increased awareness of both store trade-in and recycling propositions. The success of the promotion led Currys to repeat it in August 2022.

(9) Consumer willingness to return a product

A prerequisite for keeping products in the loop is consumers being willing to bring back products at the end of the product's life to a proper collection agent. All stakeholders that want to drive change to a circular system take part in educating consumers (such as through communication and marketing channels) on the importance of returning electronic products. Where needed, companies can incentivize bring-back schemes through discounts and cashback schemes or centrally mandate them in a B2B context (see the Incentivized collection case study on page 29).

To stimulate collection, consumer trust in the proper handling of end-of-life electronics by collection and subsequent value-chain actors is essential. It is especially critical when any sensitive data is stored on the device. Whether personal or company-related, fear of data misuse through the collection agent represents a very real barrier for consumers to bring back their electronics. In a circular system, simple and secure data sanitization solutions are required (see the Data sanitization for data-bearing devices case study below). Electronics manufacturers have jointly developed a best-practice approach to integrating secure data-wiping software into all electronic devices that store personal data. Where feasible, the user of the device or equipment is empowered to perform data cleansing themselves.

Case study

Data sanitization for data-bearing devices (Iron Mountain)

Technology is driving the availability of data about consumers, products and services. With this increased amount of data comes great responsibility, and every organization is liable to protect proprietary and personally identifiable information. As a result, organizations go to great lengths to secure sensitive data. It is therefore common to physically destroy data-bearing devices (DBDs), such as hard disk drives and solid-state drives, despite advanced encryption and security features on devices and near-zero risk of data leaks.

However, the destruction of DBDs becomes a significant barrier to circularity for these devices. DBDs are made of rare earth metals, the manufacturing of which is a sizable source of scope 3 emissions – all indirect emissions that occur in the upstream and downstream value chain of the reporting company. When DBDs are shredded, they create a great deal of e-waste and lose long-term value. In addition, the heavy metals, including their associated toxicity, are indirectly released into the environment.

Iron Mountain's proprietary data-erasure software Teraware provides an efficient and complete solution to every data-wiping challenge imaginable. Teraware wipes most storage types and functions onsite or remotely. It guarantees compliance, and is certified with a fully traceable audit trail for each serialized asset, from wiping to final disposal. In addition, this data-erasure step enables subsequent steps, such as testing and refurbishing the components for remarketing and reuse.

Excursus: advantages and examples of various collection pathways

Collection pathway	Advantages of collection pathway	Example
Cities and municipalities	• Cities and municipalities know how to reach the public • Locations for drop-offs for electronics can be plentiful (might vary across countries) • Cities and municipalities occasionally offer pickup services or events for take-back • Cities and municipalities take back a large variety of electronics, which is easy for the consumer and creates the necessary scale on the side of cities and municipalities; consumers are already used to waste collection through cities and municipalities, so less education is needed	An example of cities and municipalities involved in collection can be found in the sustainable city of Dubai. The government has installed a 24-hour e-waste drop-off station. Drop-off is free of charge. After collection, the city partners with an e-waste management company that transports the e-waste to a recycling facility, where it is sorted. Manufacturers reuse components still in good condition for new electronic products, while the crushing of useless parts takes place without harmful emissions.[17]
OEMs	• Physical stores of OEMs can be used for returns • Collection represents an opportunity for OEMs to strengthen customer relationships • Makes the return of electronics for consumers more fragmented, as there is not one place to dispose of old items across brands (assuming that only products of the respective brand can be turned in) • OEMs know their products and their materials best and are well positioned to decide how the product should be recovered (refurbished, remanufactured or recycled)	Cisco has established multichannel infrastructure to collect end-of-life products from consumers. A mobile app called "Send IT back" facilitates one of the channels by allowing consumers to take a picture of old electronics and organize easy pick up. In addition, to incentivize collection, Cisco offers a discount of up to 7% on new products for every end-of-life product turned in.
Retailer	• Great coverage, as networks of electronics retailers are very extensive, offering greater convenience for consumers to return electronics (however, the collection is more manageable for large retailers, as small ones might face space limitations in shops) • Products can be disposed of regardless of type or brand • Online retailers can use pre-existing delivery services for product pickup, making consolidation and collection more efficient	See the Incentivized collection case study on page 29.
Informal sector	• The informal sector can ensure collection even in those geographies where no formalized collection pathways are available, such as in developing countries (it is important that mechanisms be in place incentivizing informal collection actors to comply with a certain standard of EHS measures) • Individual actors in the informal sector have a financial incentive to sell products secondhand if the product is still functioning, thereby maximizing the value retention of the materials	Actors in the informal sector collect end-of-life phones as part of a waste-compensation model with Vodafone Germany and Closing the Loop (see the Waste compensation case study on page 32).

Case study

Waste compensation

Vodafone Germany and Closing the Loop teamed up to implement a waste-compensation strategy for every new device sold to a consumer in the German market. The basic notion of this highly pragmatic circular service is that a new device can become waste-neutral. This means that for each new device added to the market, one end-of-life device (or an amount of electronic waste that equals the new device) gets collected and recycled in a country where waste usually is not collected. Waste compensation is used to take a first, simple step toward making devices such as phones more circular. Companies can add the service to any procurement approach (including leasing), which means that tech procurers can compensate for the waste caused by putting new devices on the market, effectively making them waste-neutral. The Dutch government, for example, has implemented this service in their requirements for public tenders, citing the TCO Certified Edge, E-Waste Compensated certification as a standard for this service. It does not limit the possibility for the buyer to choose its preferred devices. As such, even though waste compensation is by no means a perfect solution, it is a way to get started on the journey to more responsible tech consumption.

At the same time, the benefits of waste compensation go beyond those of the buyer of new devices. In the developing world, the service funds the increased collection and proper recycling of electronic waste that would otherwise not be collected and processed in a safe and responsible manner. Here, the partnership between Vodafone Germany and Closing the Loop will ensure local communities get paid to safely collect over 1 million scrap phones every year. Waste compensation thus creates jobs and income for these informal actors and reduces pollution and damage to human health through the proper recycling of electronic waste. It also helps extract scarce materials from hazardous waste and bring them back into production processes.

(10) Widespread collection network

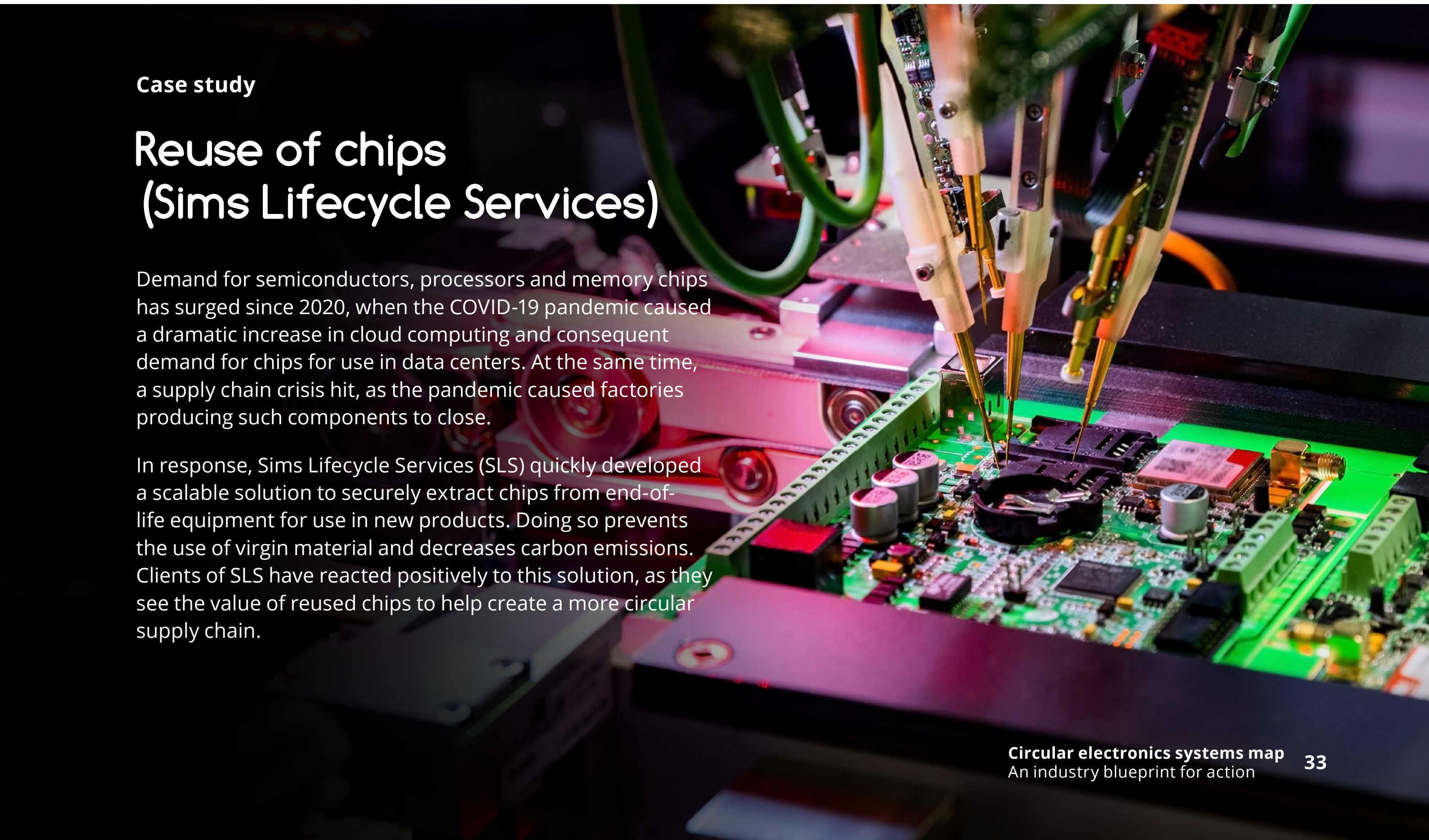
To ensure that consumers not only want to bring back their electronics but can actually do so, in a circular system, every consumer has easy and convenient access to a collection pathway. Companies offering circular products have transparency regarding the collection of their products at end of life and collection pathways. The most adequate pathways established for a product depend on factors such as existing local collection infrastructure, costs for downstream logistics, product properties and the customer segment (B2C, B2B or B2G), and need to be selected on a case-by-case basis. The excursus on the advantages and examples of various collection pathways on page 31 provides an overview of four common collection pathways.

There are different ways to establish and finance a widespread collection network in a circular system, such as through carbon credits or voluntary or mandatory extended producer responsibility (EPR) schemes. If EPR is a legal requirement, legislation should be simple and lean. In general, EPR obligations are harmonized across jurisdictions to reduce complexity for producers. In countries with large amounts of electronics, establishing producer responsibility organizations (PRO) might be reasonable. A PRO is a professional organization authorized or financed by producers that takes on the collective responsibilities for collecting end-of-life electronics, ensuring the recovery of products in an environmentally sound manner. In such cases, the targeted use of financial funds for the collection network is necessary, especially in countries where corruption is a major problem.

(11) Fast and cost-effective reverse logistics

In a circular electronics system, reverse logistics are fast and cost-effective. In such a system, both local and centralized recovery facilities have their place. While local recycling facilities minimize the cross-border transportation of materials, reducing time and carbon emissions related to reverse logistics, centralized recycling facilities are needed where sufficient scale is required to ensure cost-effective operations.

Due to the presence of substances classified as hazardous, the Basel Convention covers the cross-boundary movement of many end-of-life electronics globally, with varying degrees of implementation at the national level. The Basel Convention involves trade controls, financial guarantees and documentation requirements for the shipping of hazardous and other controlled materials. In a functioning circular economy, companies can obtain certified exemptions under the Basel Convention to ship and repurpose materials in an environmentally sound manner. High-frequency shipping sources and destinations can use expedited shipping permits through a fast-lane system, while for others, a standardized electronic PIC (prior informed consent) procedure and harmonized material classifications will allow for the well-documented yet fast processing of shipping permits. Fast permit applications and shipping routes are essential for feedstocks to reliably arrive at recovery facilities so that they can in turn plan their supply of recovered materials to their customers. Detailed information on what solutions related to reverse logistics need to be in place can be found in the World Economic Forum's *Facilitating Trade Along Circular Electronics Value Chains* white paper.[18]



Case study

Reuse of chips (Sims Lifecycle Services)

Demand for semiconductors, processors and memory chips has surged since 2020, when the COVID-19 pandemic caused a dramatic increase in cloud computing and consequent demand for chips for use in data centers. At the same time, a supply chain crisis hit, as the pandemic caused factories producing such components to close.

In response, Sims Lifecycle Services (SLS) quickly developed a scalable solution to securely extract chips from end-of-life equipment for use in new products. Doing so prevents the use of virgin material and decreases carbon emissions. Clients of SLS have reacted positively to this solution, as they see the value of reused chips to help create a more circular supply chain.

Case study

Collaboration between recyclers and material suppliers (ERI)

ERI works with strategic partners LS-Nikko Copper, Redwood Materials and Alcoa. In turn, these partners supply recycled materials to the circular economy. A smelter of precious metals, LS-Nikko Copper receives all ERI's printed circuit boards and precious metals such as copper and gold for electronics. Redwood Materials receives all ERI's batteries and solar shred materials for beneficial reuse. Alcoa receives ERI's aluminum for a wide array of reuse applications. All three are both downstream partners and investors, and sit on ERI's board. This establishes a radically transparent, end-to-end closed loop where companies keep elements – including cobalt, nickel, copper and lithium – out of landfills and responsibly recycle them for beneficial use in new products.

(12) Efficient and effective product sorting, disassembly and recovery

Once electronic products reach recovery facilities at the end of their lives, recyclers sort, disassemble and recover products and their components. Efficient and effective processing makes recovered materials economically viable and ensures that they are high-quality alternatives to virgin materials.

The recovery infrastructure is optimized to obtain the most efficient and effective processing in a circular system. Recyclers leverage advanced technologies to sort products and identify the most suitable recovery pathway. Due to the diversity of the countless products available and the associated difficulty of product identification, artificial intelligence helps to recognize and sort products, potentially via unique product identifiers. Once they have identified the product, these technologies instantly analyze its material composition using product passports, which include data regarding, for example, its valuable materials or batteries requiring special treatment. Further, as the product passport contains data on the condition and remaining life expectancy of certain components, sorting and triage can happen based on product age and outer appearance as well as on actual recovery potential.

Once the system has sorted the product and identified a suitable recovery path, where appropriate and beneficial, recyclers in a circular system deploy robotics to disassemble products effectively and cost-effectively. Robots fed with model-specific disassembly instructions stored in the product passport can optimize automatic disassembly for each product. Higher effectiveness in disassembly can reduce contamination and, in the end, contribute to high-quality secondary material feedstock.

Recycling technologies are capable of processing the materials included in circular electronic products, as these technologies are developed in conjunction with the introduction of new materials. Sufficient investment is available to enable the development and use of the latest recycling technologies. Investors have increased interest in recycling and secondary markets due to higher and more reliable demand for secondary materials. Further, pricing in externalities, such as carbon emissions, will generally change profit margins in global commodity markets to the benefit of secondary markets, attracting further investments. While the technologies keep up with new and innovative materials, infrastructure is also in place that can process legacy materials included in products years ago – especially against the backdrop of the long life cycles of products such as washing machines.

To close the loop, recyclers also collaborate and align with material suppliers to prepare secondary materials with properties as requested on secondary material markets. This ensures that products and materials are recycled for use in new products (see the Collaboration between recyclers and material suppliers case study to the left).

4. Moving forward

The success of a circular electronic product and the system in which such a product can circulate rely on companies understanding that, for their products to be considered circular, they do not only develop and manufacture a product based on circular principles. They also consider and enable the product's collection and recovery at the end of its life cycle.

If a product ends up in a landfill, regardless of its circular design, it's not any better than a linear product after all. Based on this, companies that wish to offer circular products can no longer assume responsibility only up to the point of sale. Instead, they must work with partners to develop a holistic strategy to keep products in the loop.

So where do we go from here? This report is a vision for the Circular Electronics Partnership – an agreed understanding of what the initiative and its members are working to achieve in the coming years. However, this vision of a circular product and system is in no way set in stone. It is intended to be a dynamic construct that may change and adapt over time. The system will not, however, put itself in place. All electronics industry stakeholders and those in the broader circular economy landscape, as well as members of the scientific community and public sector, are invited to contribute and sharpen this vision in the coming years and, of course, to jointly make this vision a reality.

Glossary

Term	Description	Source
as-a-service model	The ownership of the product remains with the OEM, retailer, telecommunications company or other corporate operator. Consumers pay a recurring fee to access the product. There are different forms of as-a-service models, such as a fixed monthly fee or pay-per-use.	No source
business model	How a company creates, delivers and captures value. It is described through the value proposition, resource requirements, cost structure, revenue streams, activities, customer segments, communication channels and partners.	CEP Roadmap
circular economy	An economic model that is restorative and regenerative by design and aims to keep products, components and materials at their highest utility and value while minimizing the raw materials input into the value chain and reducing waste streams.	CEP Roadmap
Circular Electronics Partnership	A pre-competitive platform for the electronics value chain to collaborate, coordinate, co-create and cross-fertilize initiatives and projects toward a shared CEP vision for a circular electronics industry following a co-created CEP Roadmap.	CEP
closed value chain loop	Materials remain within the value chain of one party (and its partners).	No source
collection	The act of collecting something from a place or people. We group both formal and informal collections in this report. This is separate from take-back services conducted by businesses whose operation is to supply, purchase, sell or lease electrical and electronic equipment (EEE).	CEP Roadmap
component	Part of a product that cannot be taken apart without destruction or impairment of its intended use.	Existing standard ETSI TR 103 679
consumable	Product content foreseen to be frequently replaced or refilled during the lifetime of the product.	Existing standard CEN/CLC/TC 10
disassembly	Process whereby a product is taken apart so that it can subsequently be reassembled and made operational.	Existing standard ITU-T L.1022
downcycling	Recycling something in such a way that the resulting product is of lower (economic) value than the original item.	Circular Transition Indicators V2.0
durability	The ability of a part of a product to function as required, under defined conditions of use, maintenance and repair, until a final limiting state is reached.	Existing standard ITU-T L.1022
electronic products	All types of electronic and electrical equipment as defined by the EU's Waste from Electrical and Electronic Equipment (WEEE) Directive 2012/19/EU. This includes devices and equipment from six product categories: temperature exchange equipment, screens and monitors, lamps, large equipment, small equipment and small IT.	EU directive WEEE Directive 2012/19/EU
electronics manufacturer	A business manufacturing electronic products, including original equipment manufacturers. Manufacturers can also be producers if they sell or lease directly to consumers.	CEP Roadmap
e-waste	Waste generated from discarded electronics that can no longer be repaired for reuse. Products and components that are labeled as WEEE but destined for reuse are not at the end of their life and hence not considered e-waste.	CEP Roadmap
extended producer responsibility (EPR)	Policy principle to promote total life cycle environmental improvements of product systems by extending the responsibility of the manufacturers of the product to various parts of the entire life cycle of the product and especially to the take-back, recycling and final disposal of the product.	CEP Roadmap
informal economy	Informal system that operates without clear regulation or quality control and outside the guidelines of governmental authority, labor standards or taxation.	CEP Roadmap

Term	Description	Source
maintenance	Action carried out to retain a product in a condition where it can function as required.	Existing standard ITU-T L.1022
open value chain loop	Materials moving in and out of the value chain of one party (e.g., via a public collection program).	No source
post-consumer recycled material	Materials from end-of-life products generated by households or by commercial, industrial and institutional facilities in their role as consumers of the product.	European Commission – Circular Plastics Alliance
post-industrial recycled material	Material that has never reached the consumer, having been diverted to the waste stream during a manufacturing process.	Existing standard UL
producer	Anyone who places electrical and electronic equipment (EEE) on the national market of a country. This includes legal entities that manufacture EEE or have EEE manufactured and sell it within the country, resell EEE within the country or import EEE into the country.	CEP Roadmap
recovery	The principal result of any operation is waste serving a useful purpose by replacing other materials that would otherwise have been used to fulfill a particular function in the plant or the wider economy. This does not include energy recovery through the incineration of materials.	Eurostat
recycled content	Percentage of recycled materials within a raw material, component or product.	CEP Roadmap
recycling	To reduce a product back to its material level, thereby allowing the use of those materials in new products.	Circular Transition Indicators V2.0
refurbishment	Returning by industrial process a used product to a satisfactory working condition without making any important changes to the product.	Existing standard ITU-T L.1022
remanufacturing	Industrial process of inspecting, disassembling, cleaning, reprocessing, storing, reassembling and testing an energy-related product in such a manner that the product is in a condition equal to a newly manufactured product or component.	Existing standard CEN/CLC/TC 10
sales-focused models	Companies transfer the ownership of a product to the consumer in return for a one-time payment independent of the intensity of use.	No source
stakeholder	Any actor, institution, group or individual – public or private – with an interest or a role to play in a societal, economic or environmental decision-making process.	CEP Roadmap
take-back	The return of electronic products that have reached the end of their primary life cycle in their original form and are incapable of performing their original intended function or that their purchaser or consumers no longer need (B2C, B2B and B2G). Its purpose is to maintain the life-cycle value of EEE through reuse, repair, reprocessing, remanufacturing or refurbishment or, as a last resort, through safe and efficient environmental management.	CEP Roadmap
traceability	The ability to identify, track and trace elements of a product or substance as it moves along the life cycle, from raw materials to finished products and applications and back.	CEP Roadmap
upgrade	Process of enhancing the functionality, performance, capacity or aesthetics of a product.	Existing standard EN 45554

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Endnotes

1 Belkhir, L. & Elmeligi, A. (2018). Assessing ICT global emissions footprint: Trends to 2040 & recommendations. *Journal of Cleaner Production.* Volume 177, 10 March 2018, Pages 448–463. https://www.sciencedirect.com/science/article/abs/pii/S095965261733233X?via%3Dihub.

2 Forti, V., Baldé, C.P., Kuehr, R., Bel, G. (2020). *The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential.* United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme, International Telecommunication Union (ITU) & International Solid Waste Association (ISWA). Bonn/Geneva/Rotterdam. https://ewastemonitor.info/wp-content/uploads/2020/11/GEM_2020_def_july1_low.pdf.

3 UN Environment. (2019). *UN report: Time to seize opportunity, tackle challenge of e-waste* [Press release]. https://www.unep.org/news-and-stories/press-release/un-report-time-seize-opportunity-tackle-challenge-e-waste.

4 Forti, V., Baldé, C.P., Kuehr, R., Bel, G. (2020). *The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential*. United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme, International Telecommunication Union (ITU) & International Solid Waste Association (ISWA). Bonn/Geneva/Rotterdam. https://ewastemonitor.info/wp-content/uploads/2020/11/GEM_2020_def_july1_low.pdf.

5 Trading Economics. (n.d.). *Lithium*. https://tradingeconomics.com/commodity/lithium.

6 European Commission. (n.d.). *Critical raw materials*. https://ec.europa.eu/growth/sectors/raw-materials/areas-specific-interest/critical-raw-materials_en.

7 Forti, V., Baldé, C.P., Kuehr, R., Bel, G. (2020). *The Global E-waste Monitor 2020: Quantities, flows and the circular economy potential*. United Nations University (UNU)/United Nations Institute for Training and Research (UNITAR) – co-hosted SCYCLE Programme, International Telecommunication Union (ITU) & International Solid Waste Association (ISWA). Bonn/Geneva/Rotterdam. https://ewastemonitor.info/wp-content/uploads/2020/11/GEM_2020_def_july1_low.pdf.

8 WBCSD. (n.d.). *Circular Transition Indicators (CTI).* https://www.wbcsd.org/Programs/Circular-Economy/Metrics-Measurement/Circular-transition-indicators.

9 Ellen MacArthur Foundation. (n.d.). *Measure business circularity: Circulytics*. https://ellenmacarthurfoundation.org/resources/circulytics/overview.

10 Cradle to Cradle Products Innovation Institute. (n.d.). *What is Cradle to Cradle Certified®?* https://www.c2ccertified.org/get-certified/product-certification.

11 As part of this report, the term "recycled materials" refers exclusively to post-consumer recycled materials and not post-industrial recycled materials.

12 We acknowledge that the carbon-reduction potential of circular resources depends on the setup of the system. Under unfavorable conditions, the recovery process and related logistics could even cause circular resources to have higher carbon footprints than virgin materials. However, we believe that with the right setup and system, circular resources can generally contribute to carbon reductions.

13 Organisation for Economic Co-operation and Development (OECD). (2012). *Case study on critical metals in mobile phones: Final report*. https://www.oecd.org/environment/waste/Case%20Study%20on%20Critical%20Metals%20in%20Mobile%20Phones.pdf.

14 Not including energy recovery through the incineration of materials.

15 World Economic Forum. (2022). *Driving ambitions: The business case for circular economy in the car industry*. https://www3.weforum.org/docs/WEF_Driving_Ambitions-2022.pdf.

16 World Economic Forum. (2019). *Harnessing the fourth industrial revolution for the circular economy: Consumer electronics and plastics packaging*. https://www.weforum.org/whitepapers/harnessing-the-fourth-industrial-revolution-for-the-circular-economy-consumer-electronics-and-plastics-packaging/.

17 Waste Management World. (2021). *Dubai e-Waste Collection and Management System*. https://waste-management-world.com/artikel/dubai-e-waste-collection-and-management-system/.

18 World Economic Forum. (2020). *Facilitating trade along circular electronics value chains*. https://www.weforum.org/whitepapers/facilitating-trade-along-circular-electronics-value-chains.

circular electronics partnership

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