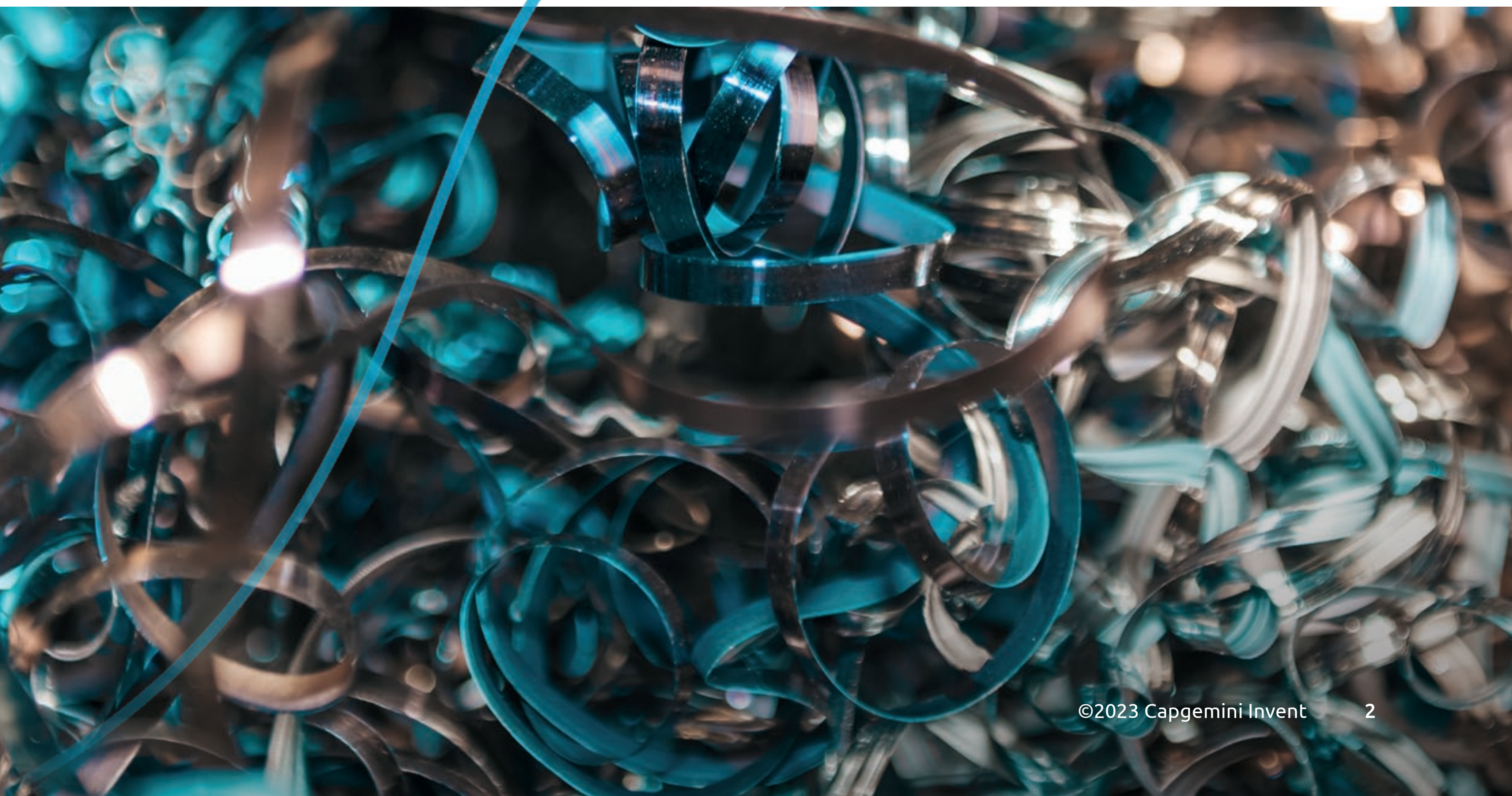
Capgemini invent

REMOVING THE FINISH LINE

How the Circular Economy will energize the automotive industry

Table of Contents



1. Executive summary

For more than 125 years, the Automotive industry has been one of the engines of the modern industrial era. Many of the central features of manufacturing have grown out of automotive: the assembly line, lean manufacturing, and too many trends to list in robotics, automation, and safety.

On the flip side, Mobility and Transport is one of four[1] global systems that cause the lion's share of greenhouse gas emissions and virgin material extraction. While the global population has doubled in the past 50 years, material extraction has tripled, leading to 100 billion tons of material consumed by today's global economy. Surprisingly, only 7.2% of that figure is circular.
Even more alarming, the share of circular material has fallen from 9.1% in 2018.[2] But just as 100 years ago, the automotive industry once again has the opportunity to define the value creation model of our times. The linear model of manufacturing has run its course. Now, with a new emphasis on sustainability and value, the 21st century will belong to the circular economy.

According to the European Commission, the circular economy refers to an economic model that aims to maintain the value of products, materials, and resources for as long as possible by reinserting them into the product cycle at the end of their use while minimizing the generation of waste. When applied to the automotive industry, circularity affects manufacturing along the entirety of the vehicle lifecycle. This paper considers the three phases of pre-use, use, and post-use in turn, demonstrating that circular economic principles add and preserve more value than traditional manufacturing models. Circularity requires broad changes throughout an organization, which must be carried out through new partnership models within and across industries. This overarching approach – detailed in our circularity framework – enables OEMs to deliver results at speed and scale, not only to decouple economic success from material extraction but also with the understanding that 70% of greenhouse gas emissions are tied to material handling and use.[3]

This paper begins by presenting a list of tectonic changes that push at the foundation of the automotive industry. This includes the demands of new regulations and a new generation of consumers, for whom sustainability is an increasingly dominant purchasing criterion. The growing trend towards electric vehicles provides another driving force through the increasing demands it puts on a range of materials, many of which are mined in just a few countries. These forces push in one direction – towards a manufacturing model that wastes less and preserves maximum value.

Our circularity framework presents six circular economy pillars that can lead automotive companies through the challenges of a fast-changing industry, maximizing value throughout product and service lifecycles while reducing waste to a bare minimum. This enables OEMs to create long-term value with actions that can be deployed and monitored in the short term, leveraging this alternative model that brings consumer desirability, resiliency, and competitiveness. This transformation will also include new sources of revenue spurred on by the evolution of transportation, away from a one-person-one-car model, towards increasingly innovative shared mobility options. Each part of an organization will have a part to play, with partnerships playing an increasing role.

What consumers value most is changing. One school of thought would aim to chill new trends and preserve the 20th century model for as long as possible. This paper takes a bolder approach. A shift in value provides a tremendous opportunity for the businesses that adapt first. In a world of increasing emissions and dwindling resources, pushed by increasing regulation, and pulled by consumer preference, the 21st century is gravitating towards the circular economy. For automotive leaders with vision, this is the time to lead.

[1] Circle Economy. (2023). The circularity gap report 2023 (p. 28). Retrieved from CGRi website
[2] Circle Economy. (2018). The circularity gap report 2018 (p. 20). Retrieved from CGRi website
[3] Circle Economy. (2021). The circularity gap report 2021 (p. 14). Retrieved from CGRi website

2. Introduction

The battle against climate change has moved into the action phase, as organizations around the world coordinate a strategic response. The transport sector has been under the spotlight as a high-emission industry (~9% of GHG emissions – corresponding to a carbon footprint of 4.8 Gt CO2e).[1] Increasing pressures from regulators and consumers are driving a massive transformation toward collective environmental targets. To achieve less than 1.5 ° C of global warming, the automotive industry will need to halve its carbon emissions by 2030. This goal is made all the more challenging in light of the transformation toward electric mobility. Different cost structures (the battery represents 30% of an EV's value) and the increased need for scarce materials are putting increased pressure on an already strained industry.

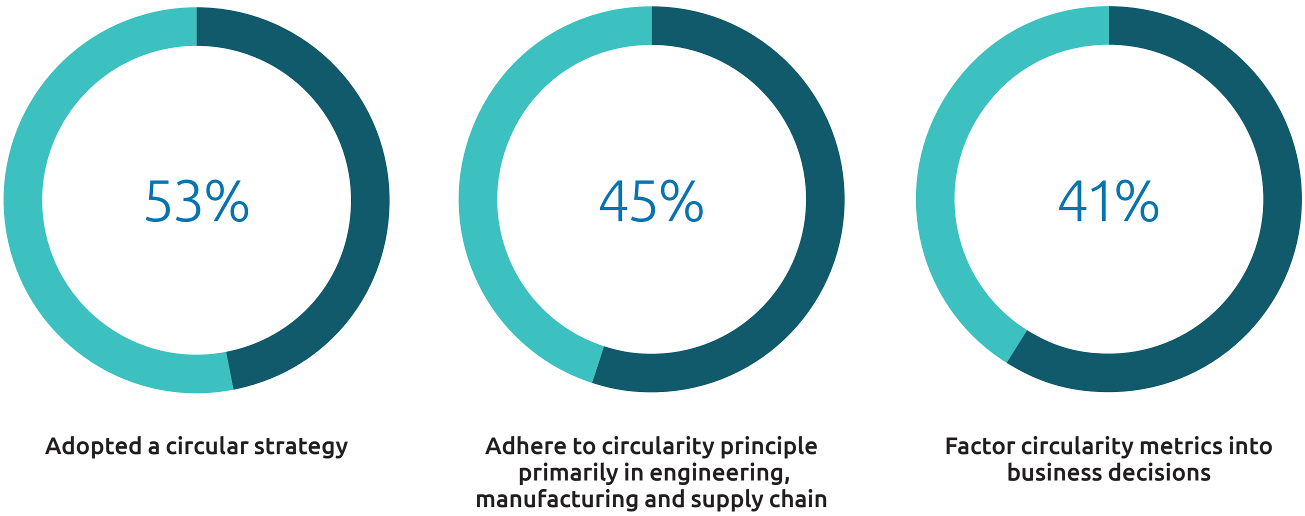
Ultimately, the industry is undergoing its most profound change in our lifetime, represented by six megashifts: platformization/ standardization, softwarization/ connectivity, autonomous driving, mobility and servitization, the trend to used cars or retrofitting, and electrification. These are further compounded by an energy crisis, disrupted supply chains, and a looming recession.

For too long have we been chasing short-term growth with a focus on optimizing linear value chains, a model characterized by large volumes of single unit sales, globalized value chains, product obsolescence, and in-house R&D driven by production cost. The global economy's circularity has stagnated at 8.6% meaning more than 90% of 100 billion tons of the raw materials consumed each year are never cycled back into the economy. While we have a long way to go, the recent succession of crises, such as sanitary and energy crises, supply chain disruptions (e.g., Suez Canal blockage, semiconductors shortage), and the war in Ukraine confirm that companies need to accelerate their transition.

For all these reasons, leaders in the automotive industry have begun to explore the benefits of a circular economy revolution.

According to the Capgemini Research Institute, while 73% of executives agree that a contribution to the circular economy is necessary to achieve long-term financial and competitive goals, only 53% attest to having a circular-economy strategy and only 41% of organizations have integrated circularity metrics into decisions.[2]

Level of integration of Circular Economy in the automotive's sustainability roadmap



Source: Capgemini Research Institute, Sustainability in Automotive Executive Survey, July-August 2022. N=1,080 executives.

[1] Stephan, B. et al (2019) Crashing the Climate
[2] Capgemini Research Institute (2022) Sustainability in Automotive

Multiple forces and one conclusion

Interest in circularity is growing, and it's beginning to translate into action. As more and more forces align, this trend can be expected to accelerate in the coming years.

We identified several forces driving the adoption of circular economy:

1. Growing intolerance to any pollution type,
2. Lack or absence of waste recovery,
3. Scarcity or difficulty in sourcing raw materials (mainly due to electrification),
4. CO2 emissions relating to the business activity in general.

While the first two have crystalized most of the initial and ongoing efforts and regulations for several years (targeted recycling, plastics management, management of unsold items), the current and forthcoming conditions give considerable prominence to the last two. Depending on their level of exposure to these threats, companies have a heterogeneous level of adoption and implementation. For instance, vehicle electrification is at the heart of the transformation with the legislation framework that has been increasingly intensified (e.g., latest legislation in Europe bans the sale of any combustion engine vehicle by 2035).

Mobility players pushed to adopt the circular economy have been implementing new business models that go far beyond recycling (e.g., Product-as-a-Service, Product Life Extension, Sharing Platforms, Sell and Buy-back, Repair and Maintenance services, Second-hand Platforms), representing new playfields that deliver proven economic value and consumer desirability (e.g., clients' acquisition and loyalty, turnover increase, brand image improvement). As a result, new industry players are pulled by these benefits and therefore either launch initiatives or make circularity one of their strategic pillars.

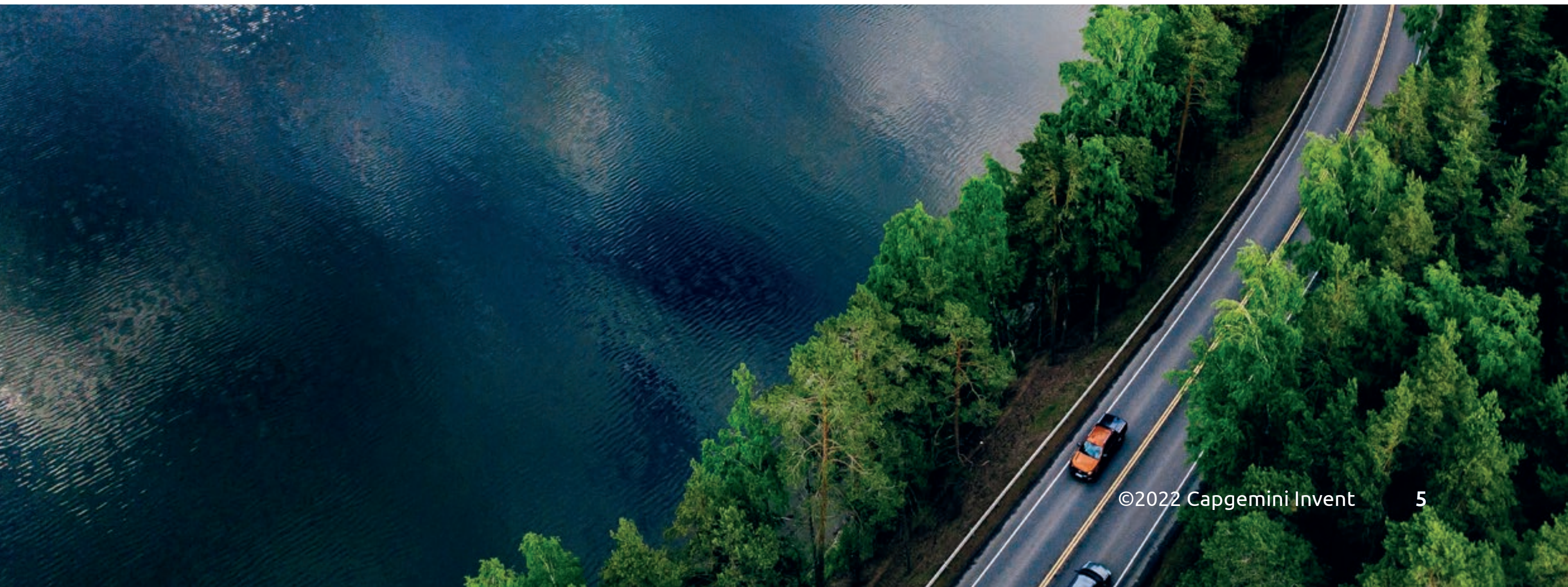
Key questions

Although circularity is not a new concept in the automotive industry, the increasing exposure to the abovementioned pushed and pulled factors make circular economy an inevitable paradigm shift for automakers. Large pools of value remain untapped between end-of-use and recycling which equates to countless opportunities in the form of reusing, repairing, and remanufacturing vehicles and their components that are widely unexplored. Therefore, the ultimate objective for automotive players is to leverage the circular economy and thus significantly reduce their raw material footprint, which is of primary importance when producing vehicles at scale in a world of limited resources.

Based on this shift, we address some of the key questions for OEMs and other automotive players on their path to circularity:

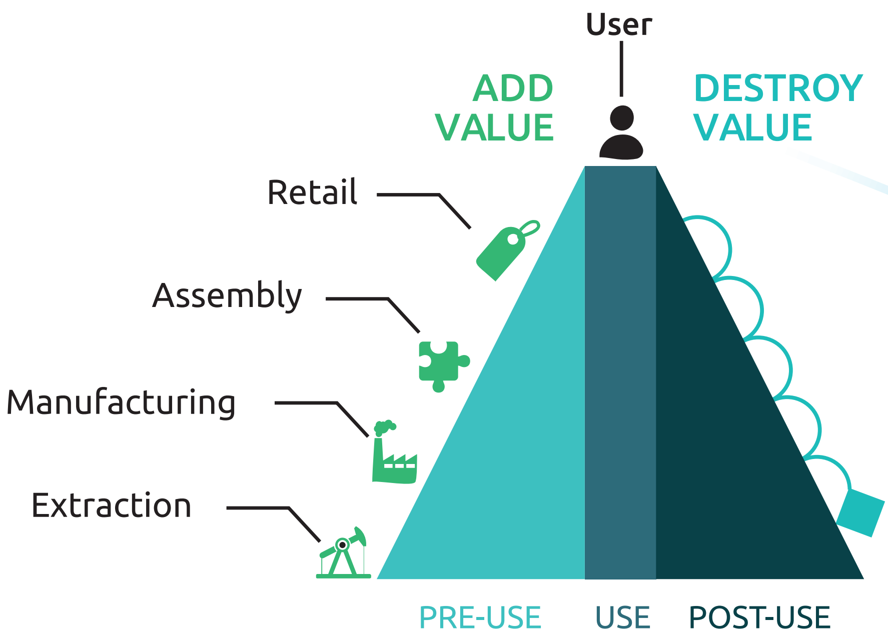
- What is needed to adapt current linear structures to a fully circular business model across structures, processes, and business domains?
- How does embracing the circular economy help OEMs sustain and even grow their businesses while reducing their environmental footprint?
- How well are OEMs equipped for the transition to circular business models and activities, and what do they need to do in order to accelerate and pioneer in the inevitable change?

This paper aims to explore the opportunity of circular economy for the automotive industry to accelerate its sustainability transformation. Through Capgemini's 6-pillar framework, business leaders can embark on this journey by laying the foundation for circularity with a holistic approach – embedding business models, product design, operations, and partnership ecosystem in order to embrace the six megashifts that are disrupting the entire sector to an unprecedented extent.



3. The circular economy value chain for automakers

The linear model is a sales-oriented business model, where value is mainly created during the production process, and then consumed during the value optimization phase. Once quality and utilization levels are no longer optimal, product value continues to decline until it becomes non-functional, and the product is disposed. Reinforced by the drive for economic growth, this leads to an increasing destruction of limited resources while polluting land, water, and air, destabilizing the climate.



Source: Circle Economy, 2016

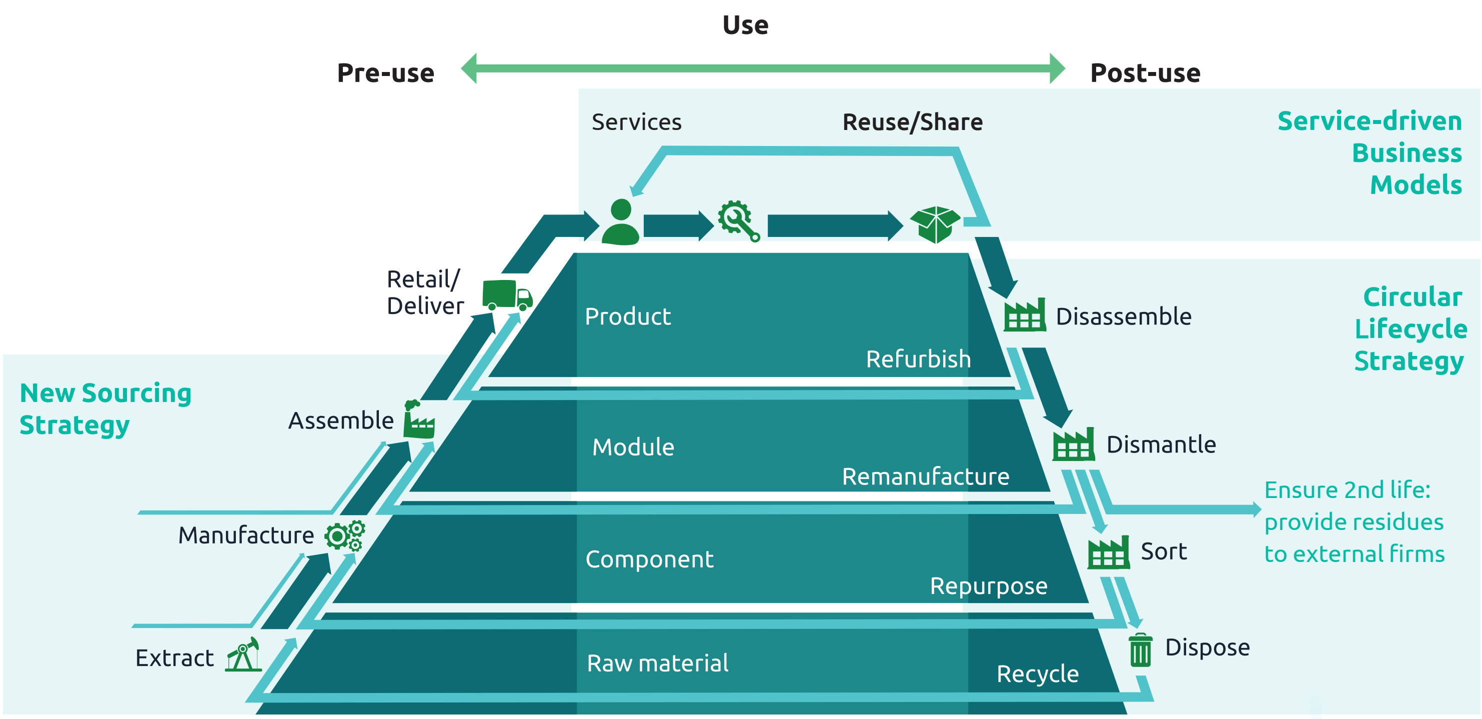
The circular economy incorporates value recovery mechanisms to ensure that the value of products and materials is maintained after their use. Value recovery activities include resale/second-hand sale, repair, refurbishing, remanufacturing, and recycling. Thus, moving to a more circular economy aims to increase resource efficiency and reduce primary resource inputs by design, maintain products and materials at their highest possible value for as long as possible, and eliminate waste at the end of life. In the **PRE-USE** phase, value is added naturally as the products get assembled,

1. In the **USE** phase, value is optimized by extending the usability of firsthand products (mainly through sharing and repair),

2. In the **POST-USE** phase, value is retained via revalorization processes (life extension, new lives, end-of-life).

In principle, the model can be applied in any industry. The focus in this work though is the transformation of the linear lifecycle to the circular lifecycle in the automotive industry. Its applicability requires a holistic approach across product design, business models, operations, and partnerships, as no company implements circular economy in isolation. Due to the number of stakeholders involved within the organization and across all the third parties, data is a key enabler to the implementation of circular economy strategies through greater traceability and transparency.

Value hill target picture - circularity and service-driven business model for automotive



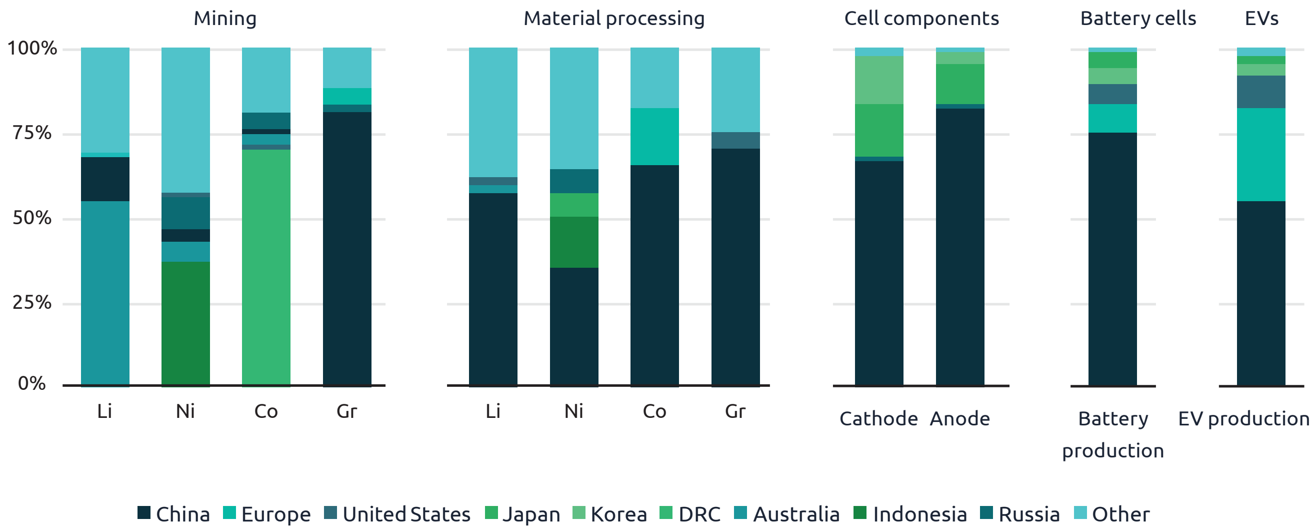
3.1 The pre-use phase

In the pre-use phase, value is added to the product by assembling the slowly evolving product piece by piece. This includes all value-adding processes from product strategy and design towards the delivery of the final product. During this phase, automotive players face many issues in their race toward sustainability, such as:

- There is a high dependency on very few countries (notably China) that are responsible for the extraction and transformation of critical raw materials (such as lithium, cobalt, nickel) as well as the production of batteries and their components.
- The increased level of disruptions has put global supply chains at risks, making it increasingly difficult to source components and materials as illustrated during the semiconductor's crisis. Beyond geopolitical issues, the high concentration of the EV market on resources can lead to similar effects if global production chains are maintained.

China dominates the entire downstream EV battery supply chain

Geographical distribution of the global EV battery supply chain

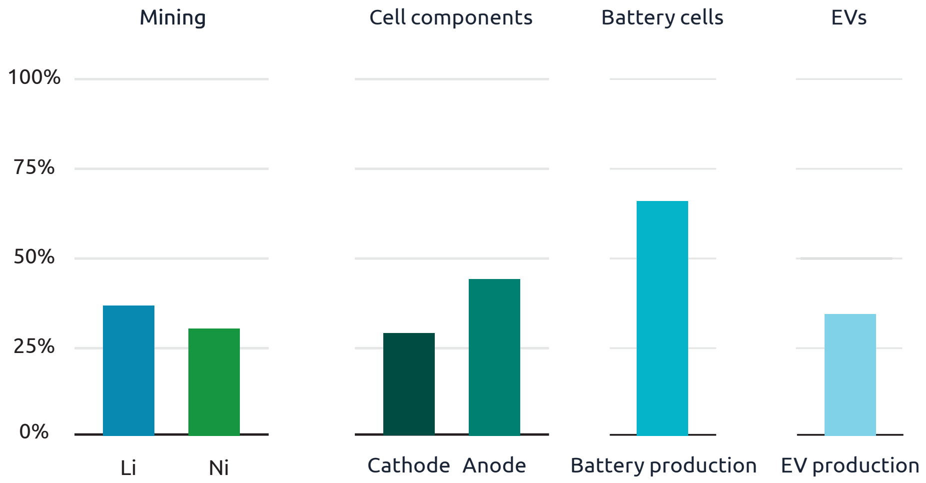


Notes:Li = lithium; Ni = nickel; Co = cobalt; Gr = graphite., DRC = Democratic Republic of Congo. Geographical breakdown refers to the country where the production occurs. Mining is based on production data. Material processing is based on refining production capacity data. Cell component production is based on cathode and anode production capacity data. Battery cell production is based on battery cell production capacity data. EV production is based on EV production data. Although Indonesia produces around 40% of total nickel, little of this is currently used in the EV battery supply chain. The largest Class1 battery-grade nickel producers are Russia, Canada and Autralia.

Sources: IEA analysis based on: EV Volumes; US Geological Survey (2022); Benchmark Mineral Intelligence; Bloomberg NEF.

Production in all stages of the EV battery supply chain is concentrated in few companies

Share of total production of top-three companies at each stage of the EV battery supply



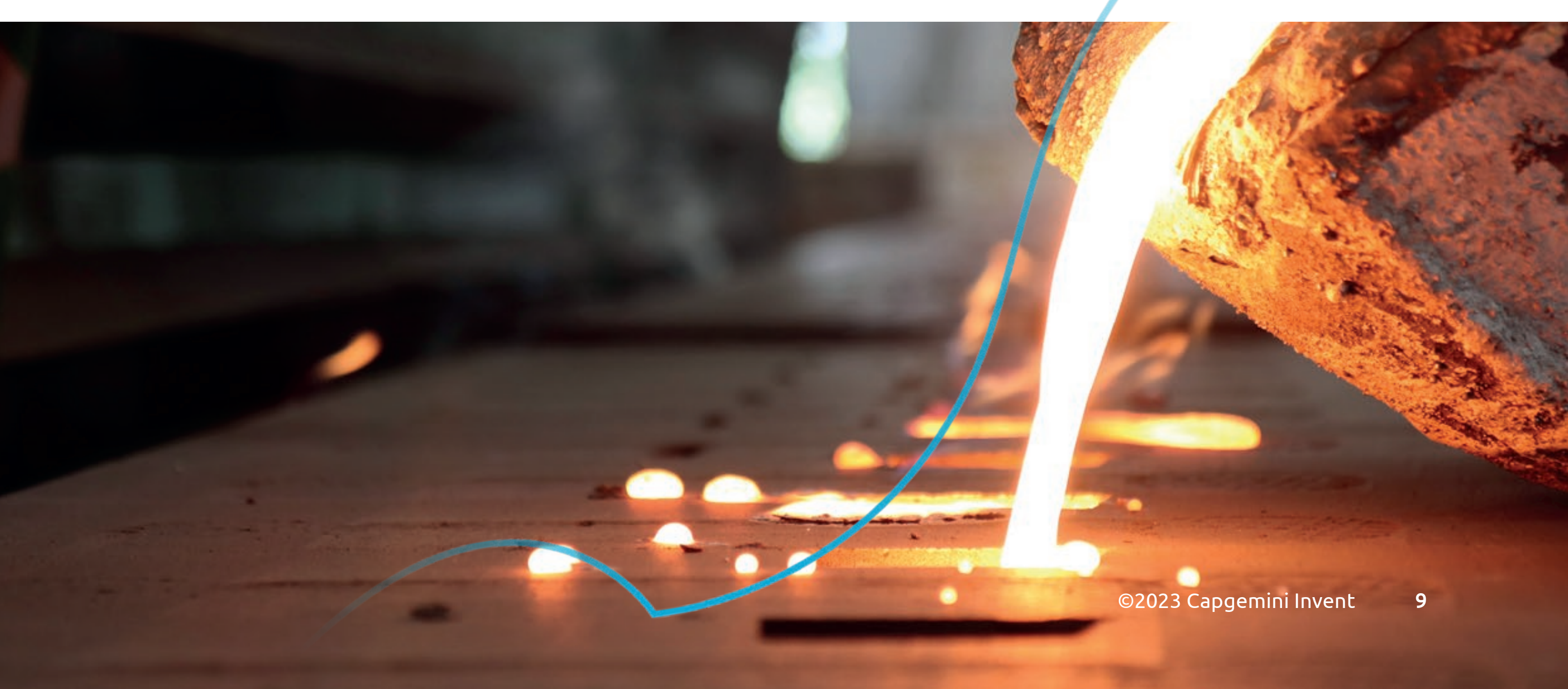
Notes: The figure shows production percentages of top-three companies for 2021: EV production by sales, battery production by MWh produced; cathode and anode by production capacity, mining by production capacity. Top-three companies by production (countru where headquatered): lithium - Sociedad Qyunuca t Nubera Cguke (Chile); Pilbara Minerals (Australia), Allkem (Australia); nickel - Jinchuan Group (China); BHP Group (Australia); Vale SA (Brazil); cathode - Sumitomo (Japan); Tianjin B&M Science and Technology (China), Shenen Dynanonic (China), anode - Ningbo Shanshan (China), BTR New Energy Materials (China); Shanghai Putailai New Energy Technology (China); battery production - CATLK (China), LG Energy Solution (Korea), Panasonic (Japan); EV production - Tesla (United States) VW Group (Germany): and BYD (China)

Sources: IEA analysis based on Benchmark Mineral Intelligence, Bloomberg NEF, S&P Global.

Vehicle design principles don't always include the revalorization requirements throughout the lifecycle. This is often due to the information access of the entire vehicle lifecycle management, which is fragmented across organizational functions. This is particularly relevant considering that lithium prices increased more than seven times and cobalt prices more than two between the start of 2021 and May 2022.[1]

Circular economy principles during the pre-use phase do more than save money and reduce waste – they set the ball in motion for the entirety of a vehicle's lifecycle.

[1] IEA – Global Supply Chains of EV Batteries, 2022



3.2 The use phase

At the start of usage, the finished car passes from the pre-use phase to the use and value-optimization phase. The value-optimization phase is the moment where a vehicle's value is at its peak. There are two objectives at this stage:

1. To avoid value depletion by leveraging life extension operations with minimal effort,
2. To use the opportunities brought by circularity to optimize vehicles' use rate. The circular business model calls for vehicles that are of greater value over a longer lifespan.

This is especially relevant given two realities of the status quo:

- Over the entire lifespan of a traditional car (20 years on average), the use rate is remarkably low – on average, just 1.5% for privately used cars.[1]
- The energy crisis that is hitting the global economy has structural impacts at all levels of the value chain, and there's a strong likelihood that this trend will continue. According to the World Bank, crude oil prices have increased by 350% from April 2020 to April 2022. Global coal, natural gas and crude oil prices have undergone an additional estimated increase this year of 81%, 74%, and 42% respectively.[2] Renewable energy capabilities have accelerated dramatically (with a record increase of 6% in 2021) but that rise does little to compensate for the supply issue for fossil fuels.[3]

Given the energy required to operate vehicles of all kinds, it is incumbent to rethink the ways in which we move people and goods. Increasing vehicles' usage and lifespan take us closer to that goal.

3.3 The post-use phase

In the traditional linear lifecycle, a vehicle's value decreases rapidly as old vehicles are handed over to scrap facilities, including all their parts and components. Firms following circular economy principles put a lot of effort into retaining this value. The objective in this phase for OEMs and their partners is to loop a maximum of parts back into the production process for new and used vehicles. The most relevant revalorization option depends on the actual conditions of the vehicle and its residual value leading to multiple levels of disassembly (e.g., for refurbishment, remanufacturing, repurposing, and recycling). However, implementing these steps in practice requires OEMs to overcome a broad set of challenges.

- The move to electric mobility is increasing the value of a car (by a rough average of $10,000 compared to an ICE vehicle). However, the second-hand market today is largely outsourced, meaning that OEMs don't always have access to vehicles at the end of use. Therefore, they need to develop the right capabilities to increase used vehicle collection, sorting, diagnosis and dismantling as an entry point to any revalorization process. This is a mandatory step to achieve greater resource sovereignty and profitability in the long-term.
- Many recovery activities in automotive have already been developed, demonstrating great economic and environmental value. However, there have been difficulties in scaling such initiatives. Doing so will be an essential part of extending the lifespan of vehicles. To look at two examples:
  1. Remanufacturing vehicle components for the same quality level as original ones can reduce cost by 30 to 50%
  2. Remanufacturing engines leads to a 73% to 87% reduction in CO_2 emissions compared to constructing new ones through traditional manufacturing processes
- Although recycling rates in the automotive sector are already high (~80% in the EU and US), the arrival of batteries is changing the rules of the game for vehicle end-of-life management to support critical metal procurement and sourcing. As such, with the surge in the amount of batteries in the market, recycling can provide up to 22% of the metals needed to produce lithium-based batteries, thus reducing the overall demand for nickel, lithium, and cobalt for EVs by up to 30% by 2050. [4]

[1] Davis, S. C. and Boundy, R. G. (2022) Transportation Energy Data Book
[2] IEA (2022) Renewable Electricity
[3] Kelley Blue Book (2021) Eight Straight
[4] Circular (2022) How the Circular Economy is Solving the Problem of Spent Batteries

4. Six pillars for a circular economy

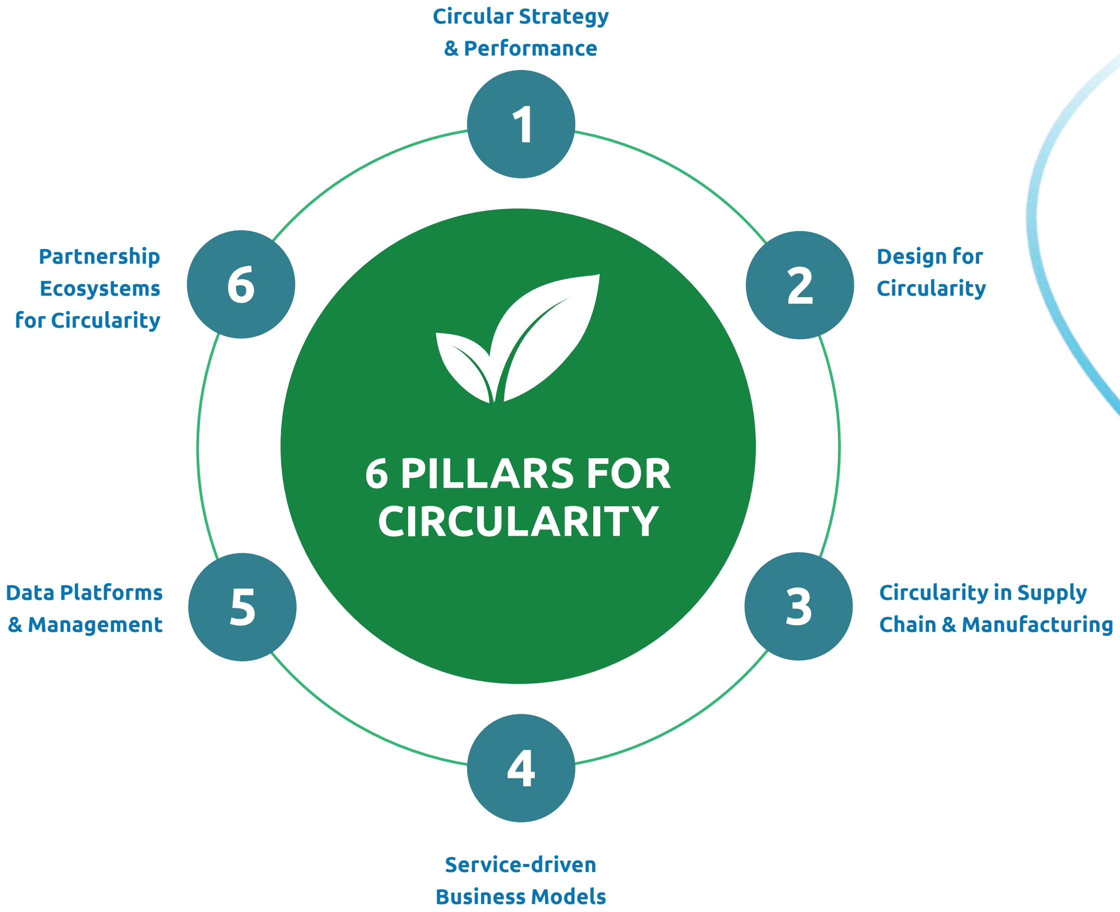
From a revenue perspective, how does it benefit OEMs to produce longer-lasting cars that more drivers use? The answer lies in another fundamental shift. Organizations are transitioning toward a Product-as-a-Service business model, where they own the products they market and are responsible for optimizing their first life and for identifying and facilitating their next lives. Technology is the key to making this concept applicable at scale, namely through automation, process virtualization, and optimized energy consumption.

Building and implementing a circularity strategy for businesses entails the consideration of multiple factors throughout the product lifecycle:

- The product conditions (e.g., energy supply, component, and material)
- The business capabilities (e.g., supply chain and distribution)
- The market situation (e.g., customer demand and regulations).

Considering the whole product lifecycle additionally requires OEMs to think in terms of overarching systems instead of standalone products. For example, carmakers must collaborate with telecommunications and energy providers to design end-to-end circular vehicles and services. We highlight six circular economy pillars that can bring automotive organizations flexibility, robustness, and scalable solutions to meet the challenges of a fast-changing, increasingly sustainability-led industry and transition towards circular product and services lifecycles.

Our Circularity Framework



4.1 Circular strategy and performance

Strategy and performance form the foundation of a successful transition to circular products, services, processes, and operations, and are thus the first pillar. Key questions for automotive OEMs in this context are:

1. Is the circular economy ambition aligned with the corporate strategy?
2. What are the empirical changes that need to be implemented from the top to secure long-term business resiliency on resources?
3. How to ensure that my long-term vision is transcended to, and applied on a daily basis?

The increasing difficulty in accessing raw materials in the automotive industry, especially in advanced economies, is putting industry players in an economy of scarcity. Now is the time to consider the elements that may jeopardize business operations within the next 30 years and build a resilient strategy against them. Failing to establish a prospective strategy could have severe operational consequences.

Sustainable procurement is foundational to business resiliency, requiring us to change the way we understand quality, costs, and availability. To align procurement with our planetary boundaries and sustainable supply chain practices, four steps are required:

- Encourage sourcing a maximum from recyclates, bio-based, and alternative materials that are less environmentally harmful from internal and external sources – such as bioplastics, synthetic leather (SofTex), Acella Hylite, or natural fibers (e.g., soy foam, wheat straw, cellulose or kenaf fibers).
- Monitor suppliers' practices against international standards, especially regarding soils, mines, and sites regeneration, as well as fair production processes. This involves complying with human rights as well as environmentally friendly extractions of raw materials.
- Encourage production as close as possible to the sourcing firms' production facilities, which also helps achieve better traceability. This is possible through partnerships with qualified suppliers.
- In the near future, it will also become increasingly important to implement smart, flexible, and forecast-driven sourcing processes. Automotive OEMs can, for instance, increase the sourcing of in-house recycled batteries by relying on forecasts that are transmitted from intelligent component tracking systems during the use phases of electric vehicles.

Furthermore, steering the transformation to deliver the **long-term strategy** via short-term objectives will require changes in the financial models and governance structure. The definition of new KPIs is key to measuring the success of circular initiatives, building new relations with investors and shareholders, and valuing long-term investments alongside long-term ROI.

An assessment of the long-term risks and the level of exposure against them needs to be conducted to anticipate the biggest challenges that businesses will face, and at which timescale. This is particularly notable for raw material sourcing and alternative processes and solutions. Executives will then be able to use the findings of this assessment to fuel far-reaching changes:

- Define a new mode of governance with indicators that make it possible to monitor the transformation advancement and facilitate decision-making (e.g., through the creation of a separate entity, cross-functional teams, new reporting mechanisms…)
- Steer the company's trajectory relating to this long-term strategy by setting financial and environmental objectives evaluated on a longer timescale

Finally, automakers are urged to embrace electrification and softwarization as part of the megashifts that are impacting their activities. Adapting their **talent model** will be instrumental in this new era. This includes:

- Shift organizational mindset and culture. Workforces must be prepared to embrace and implement the coming changes. This should foster a culture around the need to adopt circular ways of working. Responsibilities must be shared with a governance structure that make leaders and investors accountable for this transition by evaluating the company's performance against longer term objectives that go beyond financial criteria.

- **Hiring, upskilling, and reskilling:** Educating people through dedicated communication and training programs need to be supported by the top management. Critical skills to face this new paradigm include:

  » Scientists and Engineers: software engineers, mechanical engineers, electro-chemists, battery experts

  » IT talents: developers, tech experts, data scientists

  » Additional expertise: telecom, mobility, energy, sustainability

- **Stimulate innovation through multidisciplinary teams:** The creation of capabilities composed of multidisciplinary teams is paramount to ensure product design, product management, or service management. For instance, designing circular products entails connecting design, procurement, marketing, engineering, and manufacturing experts.

We already see significant commitments and investments from automotive players in their strategy for circular economy. Strategies and ambition are embedded in the overall sustainability strategy with different levels of focus and independence of circularity, requiring long-term vision over sourcing risks.

Industry examples

- Renault: TheFutureIsNEUTRAL: ties the circularity objective directly to P&L and hence the business objective by committing to annual revenues of $2.3 billion with an operating profit commitment of more than 10% by 2030.

- Stellantis: 'Unit to Power New Era of Sustainable Manufacturing and Consumption': another great example of company and management commitment with creation of a dedicated unit with dedicated management support and ambitious goals towards real carbon net-zero and cradle-to-cradle business models with revenues above €2 billion.

- BMW: RE:BMW Circular Lab is a new communication and experience platform focusing on circular thinking and awareness of new, sustainable activities in collaboration with all the brands of the group. It relies on four guiding principles: RE:THINK, RE:DUCE, RE:USE and RE:CYCLE. The RE:BMW Circular Lab is a paradigm shift to make the most of circular design with major impact throughout the lifecycle.

4.2 Design for circularity

The second pillar focuses on the topic of product design. At this stage, multiple core values and attributes of the end product have already been defined, hence the high relevance of this pillar for subsequent stages of the product lifecycle. Key questions for automotive OEMs in this context are:

1. Which parts and processes must be considered during product design to get to circular products and services?

2. Is the current design process and approach supporting circular design?

3. What is the impact of the design on subsequent stages of the lifecycle? Are life extension, recycling and other subsequent product stages considered?

Sustainable product design is the cornerstone for a circular economy strategy that is viable economically and environmentally. Products must be designed to enable the implementation of end-to-end circular strategies through vehicles that are fit-for-purpose through sobriety, dematerialization, durability, modularity, recoverability, or recyclability. In addition, the energy consumption and polluting aspects of the vehicles in use need to be minimized during the design phase. Examples for this are electric or fuel cell vehicles instead of combustion engine vehicles, but also single features, such as brake energy recovery.

Modularity and integration of vehicle revalorization systems from the design phase is critical: the less a vehicle has to be disassembled and separated mechanically or chemically, the more value is preserved. In other words, the product, component, or material at hand retains a high value. This aspect highlights the importance of the vehicle design to be able do loop back into production with minimal effort later in the lifecycle.

Considering the inherent long-lasting characteristics of vehicles, their components need to be designed so that they can be easily...

1. Assembled consuming less energy,

2. Repaired or replaced,

3. Retrofitted and repurposed across different vehicle models by relying on modular units or interchangeable component structures.

At the same time, components need to be durable to guarantee a maximal lifetime, given the limited number of times they can be repurposed.

The digitalization of vehicles from the design phase has amplified the amount of data that is created, collected, processed, and transferred. Leveraging connectivity and the power of data, smart products and systems help harness the full potential of servitization to deliver superior value, in the form of:

1. Enhanced customer experience thanks to augmented infotainment services

2. Vehicle and components life extension through predictive maintenance, and software upgrades

3. Continuous product enhancement via greater traceability and transparency throughout the value chain.

Embedding circularity into design requires a broad approach, including the trial and approach of new material and sourcing methods, to holistic vehicle design strategies for circularity. Players are looking at new approaches and methods on their own or in dedicated partnership and virtualization solutions with expert companies.

Industry examples

- Selected new city cars (focus seems to be on small vehicles for now): For example, Zoe, Citroen Ami with fit for purpose design through sobriety, dematerialization, durability, modularity, recoverability, or recyclability

- Acceleron: Li-Ion battery designed to facilitate easy replacement of components (extending battery life) coupled with advanced analytics that can detect which components need servicing

- BMW: in September 2021 at the Munich Motor Show, BMW exhibited the i Vision Circular, a four-seat electric concept car made 100% out of recycled materials that can be recycled again and again.

4.3 Circular supply chain & manufacturing (upstream and downstream)

Most materials are used, and the majority of waste is generated in the third phase, making it an essential focus for circularity. Key questions for automotive OEMs in this context are:

1. What is the current impact of manufacturing & supply chain processes on circularity?
2. How can waste be minimized, and circular materials be embedded in my processes?
3. What is needed to build up processes that extend the product lifetime and include already built products in production and supply chain?

For **production and provisioning** processes, the circular economy will entail a number of changes:

- During manufacturing, manufacturers should focus on minimizing waste, which can be achieved through greater scrap reuse/co-product or defective product reworking. This also involves leveraging industry 4.0 technologies (e.g., advanced supply chain data analytics, factory automation with robotics, virtualization and modelling with digital twins). Furthermore, production lines need to be calibrated to ensure the smooth integration of new, as well as recycled, components. Any residues that arise during the manufacturing process, e.g., from plastic or metal punching, are to be minimized and collected to serve as input into the same or different PLCs.

- In supply chains and logistics, many processes need to be transformed entirely to guarantee a fair and environmentally friendly distribution of the assembled products. This means, for example, minimizing the distances from production facilities to the point of sales, as well as sustainable means of transport. Mutualization of flows via partnerships and/or the construction of eco-parks can also support industrial waste revalorization activities.

- Finally, a key aspect to transition efficiently towards circular processes is accurate data management. Implementing a high amount of repurposed and recycled vehicles and parts into production is only feasible if costly components have already been tracked during the use-phase, enabling manufacturers to forecast when components that are currently in use will be retired, and thus available at the production facility. Circular processes will also increase the need for accurate supply-chain data – not only to undertake regulatory ESG reporting but also for determining the exact amount of repurposed and recycled items in different input materials. This is further detailed in the 5th pillar, data platforms and data management.

At this stage of the lifecycle, automakers need to develop the right capabilities and processes to revalorize vehicles and parts through life extension (refurbishment, remanufacturing), new life (repurposing), and end-of-life services (recycling). To achieve tangible results, this may require the integration of partners from their horizontal and/or vertical value chains, direct competitors, or even players outside their initial industry borders.

- **Refurbishing** refers to the collection of disposed vehicles and the renovation and reparation thereof to recover the vehicles' value and thus their originally intended purpose. In fact, this process implies that OEMs themselves or certified partners return used cars back to nearly original condition.
  In comparison to remanufacturing, however, this process is typically less costly and often rather aesthetic in nature while resulting in vehicles being in good conditions but not comparable to new or remanufactured cars.

- **Remanufacturing** implies all necessary steps to transform a used vehicle into the condition of a new one. This process usually requires that the vehicle has to be disassembled into individual parts in order to repair, replace, or upgrade single components. Since the remanufactured vehicle reaches the same quality level as a new one, remanufacturers – as of OEMs or certified partners that undertake the remanufacturing – provide official warranties as they do for new vehicles.

- **Repurposing** products is an already common practice in automotive, unlike in other industries, due to the high value of a vehicle. However, the true potential sits in repurposing components and parts to use them across the value chain such as in the procurement, production, and revalorization processes of both first- and second-hand vehicles.
  This ultimately needs to be looped back applying the right processes to support the OEMs' circular ambition throughout their reverse operations.

- **Recycling** is the moment when vehicles attain the end of their lifecycle, meaning that all the other recovery strategies that may have been applied before are ineffective or not viable.
  It already has a long tradition in the automotive industry, with scrap yards providing spare parts and acting as collecting and sorting points for different recyclable materials. Many metallic materials, for example, are melted down and then reused as inputs for the same, similar, or completely different parts. Another famous example in the context of recycling is the extraction of rubber powder from worn tires, which serves as input for either new tires or even for entirely different PLCs, such as input for construction materials. However, recycling activities remain highly technical, with a range of associated dynamics that mean they are not always profitable nor environmentally friendly, depending on the volume and the type of materials to treat. As raw materials become more expensive, demand for recycled materials is likely to increase which will push them to commodity status. It means that OEMs should invest in such capabilities (either or both mechanical and chemical recycling) to increase the access to recycled materials at greater cost, quality, and quantity. Finally, recyclates are often less emitting than their virgin counterparts (e.g., aluminum produced from recycled content emits 95% less carbon than the traditional production from virgin bauxite (World Economic Forum, 2020)).

With the broad array of supply chain and manufacturing processes that affect the circular economy, we also see a broad array of industry activities, ranging from the optimization of production and manufacturing processes to the inclusion of used materials and products in the same processes.

Industry Examples

- Northvolt / Hydro partnership: Hydrovolt is Europe's largest electric vehicle battery recycling plant, with a capacity to process 12,000 tons of batteries per year (i.e., the entire Norwegian market) via a fully automated process that recovers up to 95% of battery materials. The estimated target by 2030 is to be able to put 50% recycled materials back in battery production.

- Renault: Circular economy factory dedicated to mobility (Re-Factory). Re-FACTORY is structured around four interconnected and complementary activities (re-trofit, re-energy, re-cycle, re-start)

- Volkswagen: Volkswagen's 118 production facilities generated 2.4 million tons of waste in 2020 and recycled 96% of it for car interior and battery recycling. Rigorous testing is made to ensure that only high-quality recycled materials are used.[1]

[1] Surbhi, S. (2021) Volkswagen's Production Facilities

4.4 Service-driven business models

Once the vehicle is produced, the circularity focus shifts from pre-use to the actual customer usage of the products. Classical usage and business models are being extended or shifted to optimize the lifetime of a vehicle. Key questions for automotive OEMs in this context are:

1. Are service models in place maximizing the value of the vehicle?
2. Which models can maximize both usage and business?
3. Is the mobility platform foundation ready and suitable for the refined circular business and service model?

Sustain vehicles and components to make sure they keep their highest value for the longest period of time once they reach driving conditions, which can occur via many different measures, such as:

- **Repair and maintenance** (e.g., by offering cheaper repair services, ensuring by design the possibility of reparation for a maximum of parts, engaging in building up an online marketplace for second-hand spare parts)
- **Software updates** (e.g., through assembling flexible modules in the interior space of a car which allow for effortless upgrades of multimedia technologies and design parts)
- **Reduction of wear and tear** (e.g., through higher quality by design, through smart technologies that enforce gentle driving and impede wearing via controlling driving features in a better manner than users do)

Servitization of circular business models helps to provide access to vehicles. This is because there is an influx of users engaging with such services as car reselling, leasing, renting, sharing, and X-as-a-service. The use of such platforms positions OEMs as asset managers of the vehicles they put on the market, which helps increase the overall utilization rate and passenger seat per vehicle. But it also improves client relationships through multiple physical and digital touchpoints. The objective is to provide the best mobility solution for each user's particular circumstances, such as distance, location (rural vs. urban area), number of passengers, while maintaining control of vehicle fleets to keep them in operation for as long as possible.

All the above activities of the value optimization phase contribute to driver and passenger education on consumption patterns and how to use vehicles.

Service-driven business models and new customer solutions have been on the market for a while (e.g., car sharing) but only in a few cases have they been with the particular edge of creating circular solutions. However, we do see some players actively pushing circularity in the space of service-driven business models and embedding it in their mobility (platform) strategy.

Industry Examples

- Stellantis: Stellantis' mobility services company, Free2move, is strengthening its positioning as a mobility service provider with the acquisition of Share Now, which offers a fleet of more than 450,000 rental, car-sharing and subscription vehicles, 500,000 parking spaces, and a network of 250,000 charging stations. Free2move will add more than 3.4 million customers to its 2 million users, continuously expanding users and portfolio services that expand the usage and availability of vehicles, charging stations and more.
- Renault: In October 2021, Renault launched Mobilize, a car-sharing service where individuals can rent Renault or Dacia electric vehicles that can be 100% retrofitted or recycled in the Re-FACTORY. The fleet is adapted to all users' needs, as vehicles exist in different sizes and can be booked for periods ranging from a few hours to one month. Home charging costs will be optimized, leveraging smart charging from artificial intelligence solutions.
- Nio: In August 2020, NIO, a Chinese EV company officially launched a Battery-as-a-Service (BaaS) offering. Through monthly subscription, customers can charge, swap, and upgrade batteries in NIO's dedicated stations.

4.5 Data platforms and data management

In this pillar, one of the core enablers of circularity is discussed: data platforms and data management. Data is one of the main foundations when creating transparency, measuring the impact of the OEM approach on circularity measures, and effectively steering products and services towards circularity. Key questions for automotive OEMs in this context are:

1. Is the right data collected and analysed so that products and services circularity impact can be measured throught the lifecycle?

2. How is a consistent data management approach created that is suitable for circularity?

3. Are the right platform and systems used to successfully implement the (data) strategy? Where are adaptations and changes required?

The more cars connected, the more data they create, capture, and compute. By 2023, there will be 745,000 self-driving cars in operation, and each of them will generate 5 to 50 terabytes of data per day. The benefits delivered by 5G connectivity (e.g., low latency, speed, large volume of connected devices, etc.) will be instrumental for organizations looking to harness the potential of data. However, more data doesn't mean high quality data. Consequently, car manufacturers are urged to implement strong data management practices across all business functions and to invest in solid technology foundations if they want to gain a competitive edge: think of advanced cloud-native solutions and analytics, track-and-trace platforms for goods and materials, process automation, etc. In a circular economy context, data-driven decision-making will help address supply chain needs, new vehicle paradigms, and personalized customer services. Hence, the value in the automotive industry – at least where data use is concerned – will be based on trust and the ability to enable all the services the mobility industry can offer.[1]

Data sharing and platforms:
The extension of the value chain and the increased interaction with partners calls for the deployment of intelligent support and services that can connect the players in a new ecosystem. The ultimate objective is to encourage cross-fertilization, traceability, and transparency across the entire range. This will facilitate the delivery of a richer customer experience and drive new revenue streams for organizations.
By leveraging data platforms and systems, transparent communication can be orchestrated between actors to achieve the following:

1	2	3	4	5
Facilitate the integration of market intermediaries	Manage the collection, repair, and/or resale of products, components and materials	Monitor primary and secondary material supply needs, and adjust supply and demand in real time	Anticipate volumes per material to be produced, stored, and redistributed	Collect data that can be leveraged for the creation of business cases to obtain additional financial support

Enhanced customer experience:
While hardware defines the original customer experience in terms of design and feel, continuous software development creates more features over time. It also continuously improves the product's performance, extending the customers' experience and matching their expectations. In recent years, the automotive sector has undergone a profound change, one driven by digital transformation to improve the global driving experience. This shift in preferences, from mechanical capabilities to driving experience, has led manufacturers to adapt their business models. They now put the sentimental connection with customers at the center of their value proposition. A wide range of recent car features are designed, implemented, and updated by software applications. Like smartphones, embedded software in cars, combined with data, enable OEMs to continuously improve their customers' ride experience and respond to current market needs.

Continuous product enhancement:
Access to data in the value optimization phase and leveraging connected products present a unique opportunity to foster innovation and new business models. For instance, detecting patterns of product use or defection with Product Lifecycle Management (PLM) tools can drive

[1] Gartner (2019) Newsroom

continuous product improvement. This progress is based on real-world information that the design team can integrate into the process and its virtualization tools. Access to such insights is essential to apply maintenance, upgrades, and recovery processes at the best time in the best manner. This will ensure value preservation of vehicles and parts.

Traceability and digital continuity: As circular products are designed to last longer and to be reused and recycled over time, it is vital that organizations leverage traceability capabilities (such as RFID, IoT, tinyML, Blockchain). They are key to operationalizing circular business models by preserving all the necessary information throughout the lifecycle. Deploying reliable digital continuity for products is a prerequisite for delivering end-to-end business value, as it enables the scaling up of collection processes for closed-loop supply chains, improved performance tracking (that can also help address scope 3 emission targets), improved customer services, or even help predict future consumer demand. However, in practice, around 60% of manufacturers are struggling to ensure "digital continuity" throughout product lifecycles.[1] This explains why the European Commission plans to introduce a "digital product passport" to boost the circular economy as part of its new Circular Economy Action Plan. The sectors in which this will initially be applied are consumer electronics, batteries, ICT, fashion, furniture, and also "high-impact intermediate products," such as steel, cement, and chemicals.

Creating a consistent data sharing and management approach powered by a performant platform is one of the core priorities of OEMs to help monitor products, processes, and systems, but also orchestrate circular activities between internal and external stakeholders. Anchoring both together is amplified by only a few players, including (technology) partnerships or developing proprietary solutions.

Industry Examples

- Volvo: implements global traceability of cobalt used in its batteries by applying blockchain technology. Technology firms Circulor and Oracle operate the blockchain technology across CATL's supply chain, following a successful pilot earlier this summer, while the Responsible Sourcing Blockchain Network (RSBN), together with responsible sourcing specialists RCS Global and IBM, is rolling out the technology in LG Chem's supply chain.

[1] Final Report Converstations for Tomorrow 3

CASE STUDY: Catena-X – The first open and collaborative data ecosystem[1]

The vision of Catena-X is to be the first collaborative, open-data ecosystem for the automotive industry of the future, linking global players in end-to-end value chains.

At the same time, Catena-X is a consortium funded by the German Federal Ministry for Economic Affairs and Energy until mid-2024. It is organized as an association of providers and users in the automotive value chain, covering a wide range of company sizes.

The shared goal of Catena-X members is to establish a standardized global data exchange based on European values and key principles, such as openness, trustworthiness, data sovereignty, above-average resilience, innovative strength, and earnings opportunities. It is based on and compliant with GAIA-X and the International Data Space Association (IDSA).

The ecosystem will allow the implementation of a variety of so-called use cases that are enabled by specific software development "KITs." Three of the first 10 use cases that have been identified to kickstart the network support the ambition of transforming the automotive industry towards the idea of a circular economy. The respective "Sustainability KIT" is planned to provide solutions regarding material passports, a material marketplace, Dismantling-as-a-Service, a Product Carbon Footprint (PCF) calculator, and the respective CCF rulebook. Other use cases cover Mobility-as-a-Service (also a driver for a Circular Economy with respect to product lifecycle extension and optimized product utilization), as well as demand and capacity management, zero defects, digital twins, or traceability.

For further information, refer to Catena-X website https://catena-x.net/en/

[1] https://catena-x.net/en/

4.6 Partnership ecosystems for circularity

True circularity can hardly be achieved without OEMs opening their doors to customers, partners, and technology pioneers. Creating a true ecosystem to access state-of-the-art technology, platforms, and customer-facing solutions is crucial in this respect. Key questions for automotive OEMs in this context are:

1. What is my current partner landscape looking like? Are my partners aligned with my circularity strategy? What are gaps and white spots?

2. Which partner can I collaborate with, and in which form to access the best and most suitable solutions?

3. Is there any additional value I can create for my customers by extending my ecosystem?

Closing loops and rethinking ways of generating both environmental and economic value is pushing industries to widen their vision and to secure a new position within the business community. The central idea of collaboration is to share the effort and pools of individual competences to develop general standards and new practices that accelerate the cycling of material and energy flows. Partnerships act as enablers that make better use of resources, accelerators for innovation, and optimizers for supply chains. There are a variety of collaboration forms that can be leveraged to accelerate the circular transition.

Industry coalitions and consortiums:
These are essential when establishing a common, industry-wide approach to address the challenges involved in the transition to a circular economy. This can involve collaborating with direct competitors to propose circular alternatives and foster innovation at scale. In addition to alliances on innovation projects, major companies within a dedicated sector can partner up to set industry standards that encourage the development and application of sustainable practices for the majority.

Collaborative project development:
In the linear model, contract awarding, and operations tend to be segmented along the timeline between clients and suppliers. The circular economy offers the opportunity to design technical requirements hand-in-hand with all stakeholders in the value chain for better incorporation of environmental considerations involving suppliers, brands, retailers, and consumers. This leads to the creation of an open innovation ecosystem that can respond to the challenges of the next-gen value chains.

Institutional project involvement:
Much like the importance of public participation in the governmental decision-making process, the business community has a huge role to play. By becoming decision-makers and participating in national and regional initiatives, organizations can better anticipate and steer future regulations to ensure they get adapted to the industrial reality. They also provide accurate data from their operations to give decision-makers a clear picture while indirectly accelerating the adoption of circular practices.

Local cross-industry initiatives:
As explained in the previous section on the new responsibilities for producers, the circular economy promotes the creation of systems that are beneficial for the majority of actors in the value chains. This includes those that are from a different sector (e.g., shared take-back schemes, collection systems, repair facilities, and waste revalorization). One of the most popular approaches of this model, named "industrial symbiosis," brings together companies from different sectors located in similar industrial parks. The purpose is to promote the valorization of waste, improvement of resource efficiency, and reduction of environmental impact through the mutualization of operations. The collaborative support that emerges from industrial symbiosis stimulates the development of a circular economy with a closed-loop industry chain.

Collaboration with startups and academics:
Generating disruptive innovation and out-of-the-box thinking often requires new skills or external vision. Academics and entrepreneurs are both drivers for effective R&D and offer great adaptability. They also make it possible to explore innovative possibilities while conducting feasibility studies at a reasonable price. Finally, organizations should look at partnering with academics or startups to cover value proposition and expertise gaps within their circular value chain.

Looking beyond their own company spectrum and creating a dedicated ecosystem of partners and collaborators are key factors across the industry. We see examples ranging from partnerships dedicated to specific areas of circularity (e g., battery management) to cross-industry partnerships to improve the circular ecosystem and circular performance of products.

Industry Examples

- BMW: Launched more than 2,800 return points in 30 countries to step up the recycling and return of end-of-life vehicles to keep control of existing resources.
- Renault, Veolia, and Solvay have joined forces with the ambition of creating a secure and sustainable source of strategic metals for batteries, such as cobalt, nickel, and lithium. Through the combination of advanced technologies developed by Solvay and Veolia, strategic metals will be extracted and purified into exceptionally pure materials ready to be reused in the manufacture of new batteries. This new closed-loop process will contribute to reducing the environmental footprint of future electric vehicle batteries.
- Stellantis is launching a new partnership with Roda in a circular economy initiative in fashion. This project will use wastes from the automotive sector for the creation of unique and original new products, such as backpacks, bags, and sandals that are produced with leather, rubber, safety belts, and even airbags as raw materials. The parts are available for marketing throughout the country through e-commerce: https://www.roda.eco.br

5. Conclusions

Automotive leaders now stand at a crossroads. Down one road, organizations will attempt to stretch existing models to their limits, buying time in a race against the inevitable. Those who choose the other road recognize the immense opportunity that comes with engraining sustainable practices into the entire mobility value chain. These leaders look for ways to unlock long-term growth, opening the doors to new innovative initiatives. And clearly, the time to act is now. If not pressured by regulations or fluctuations in raw material and energy prices, we see substantial circularity commitments in the auto industry. For example, Renault and Stellantis have dedicated units and several billions of revenue commitments for the coming years. The real question is not being addressed: do OEMs only want to keep pace or pioneer and lead the race?

Circularity is not one-size-fits-all, but rather a complex and long-lasting transformation that needs to start now. In this long journey, early circular economy adopters will earn a competitive edge by creating and or ripping off market shares. However, after aligning C-suite members on a common vision, organizations can already start building the transversal enablers that will help accelerate the implementation of the circular economy, such as:

- **Circular strategy:** Set the baseline and monitor progress
- **Circular strategy and performance:** Shift organizational mindset and culture
- **Design for circularity:** Stimulate innovation through multidisciplinary teams
- **Partnership ecosystems for circularity:** Create new collaboration ecosystems
- **Service-driven business models:** Build long-term consumer relationships
- **Data platforms and management:** Leverage technology and data

Our framework on how to implement circularity implies that all six dimensions need to be developed – simultaneously and holistically – for results at speed and scale. Circularity has evolved in the priority order of the automotive decision-makers, from tactic to strategic, due to the acceleration of unprecedented trends putting greater stress on raw materials. Innovation powered by data from the merging of physical, digital, and biological technologies will be at the heart of the transformation. This will facilitate the creation of new materials and processes for circular products and services, each one delivering end-to-end value and making way for the emergence of regenerative business models.

The circular economy is a long journey. Those that will start now will gain a profound competitive advantage, fending off new entrants while capturing a new market share. The market forces are aligned – the future of automotive will be circular.

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