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# Transforming the Automotive Industry with the Circular Economy Model

Xieshu Wang, Joël Ruet and Jean Grebert

## Abstract:

The circular economy model has gained unprecedented attention with increasing concerns of climate change and under recent major geopolitical crises. The automotive industry is now going through the electric transformation to become more environmentally and socially sustainable; but only the electrification of vehicles is not enough, the whole manufacturing process and the handling of end-of-life vehicles all need to be decarbonised. Moreover, the circular economy model provides an operational framework to deal with various problems including raw material crisis, material wastes, end-of-life vehicles treatment, battery reuse and recycling, and pollutions. This paper aims to (1) analyse the necessity for the automotive industry to urgently adopt the circular economy model, (2) propose a circular economy framework for the automotive industry, (3) make observations of existing or under-development practices of circular economy in the automotive industry and closely related manufacturing sectors, (4) examine the key drivers towards a favourable ecosystem for circular economy transformation. Our observations show that all the major OEMs are increasing adopting circular economy practices and some of them already have a dedicated strategy and business unit. In many cases, OEMs collaborate with suppliers, new technology startups and local public authorities to scale up projects and build closed-loop holistic solutions. Our study confirm that the circular economy model will become the new norm and fundamentally transform the automotive industry.

**Keywords:** circular economy, circularity, automotive, electrification, decarbonisation, carbon neutrality, reuse, recycling, end-of-life vehicle, EV battery, renewable energy, bio-based material, strategic materials, V2X, circular design

## Introduction

The circular economy model has gained unprecedented attention with increasing concerns of climate change and under recent major geopolitical issues including the explosion of raw material prices, the Chinese control of rare earth materials, the US-China trade and technology war, the COVID-19 crisis, the Russia-Ukraine War and the consequent global energy crisis. To accelerate and scale up the implications of circular economy, the EU has launched a New Circular Economy Action Plan in 2020 with a particular focus on high-impact sectors such as textiles, construction, and electronics.

The automotive industry has always been a key contributor to economic growth, job creation, technology advancement and modern life style. Yet, it is also largely responsible for air and industrial pollutions, material wastes and irrational consumerism. Even though the EU Directive on end-of-life vehicles (ELV) set targets for the reuse, recycling and recovery of

the ELV materials, more than 260,000 tonnes of automotive components were disposed and sent to landfills without any further processing (Mehlhart, Möck and Goldmann, 2018). For the automotive industry, the circular economy model provides an operational framework to deal with various problems including raw material crisis, material wastes, ELVs, battery reuse and recycling, and pollutions. More largely, it invites the whole automotive value chain and related mobility providers to rethink, redesign and rebuild their business models, based on local resources and know-hows, climate and social impact, higher economic, energetic and ecological efficiency.

This paper aims to (1) analyse the necessity for the automotive industry to urgently adopt the circular economy model, (2) make observations of existing or under-development practices of circular economy in the automotive industry, (3) examine the key factors contributing to a favourable ecosystem for transforming the automotive industry with the circular economy model.

### **1. The automotive industry must embrace the circular economy model**

Since the Paris Climate Accords, urgent challenges from the climate change and environmental sustainability have pushed global political entities and the business world to address multiple issues, in particular carbon emissions, durable energy, material circularity and water protection. According to a UNEP report, the extraction and primary processing of raw materials are responsible for 90% of biodiversity loss and global water stress, 50% of greenhouse gas emissions and 1/3 of air pollution and related health impacts (UNEP, 2019). Metals extraction and fossil fuel extraction have increased 3.5 times and 2.5 times between 1970 and 2017, contributing to 10% and 16% of global climate change impacts respectively (UNEP, 2019). The current economic system is highly wasteful and unsustainable because most production is based on virgin resources and over 90% of material and energy value is lost after one use cycle (SISTEMIQ, 2020).

The automotive industry is among the most criticised sectors when it comes to climate change and environmental issues. So far, transport has the highest reliance on fossil fuels of any sector and accounted for 37% of GHGs from end-use sectors in 2021<sup>1</sup>. According to the European Environment Agency (EEA), in 2012 the transportation sector accounted for 24.3% of total European greenhouse gas emissions. The core challenge is the waste embedded in the transport system. The European car is parked (often on expensive inner-city land) 92% of the time. When the car is used, only 1.5 of its 5 seats are occupied. The vehicle manufacturing process itself is all the same polluting and resource-consuming with the current business model. Even though the EU Directive on end-of-life vehicles (2020) set targets for the reuse, recycling and recovery of the ELV materials, more than 260,000 tonnes of automotive components were disposed and sent to landfills without any further processing (Mehlhart, Möck and Goldmann, 2018).

According to a study by Accenture (2021), by 2030, global demand for mobility is set to increase by 70%, while, at the same time, the automotive sector must reduce carbon

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<sup>1</sup> <https://www.iea.org/topics/transport>

emissions by at least 50% to help reach the goal of less than 1.5°C of temperature increase. Therefore, circularity and electrification will be the core strategies enabling the industry to decarbonise and satisfy the future demand. Circular economy approaches can help the automotive industry reduce the lifecycle carbon emissions per passenger km by up to 75% by 2030 (Accenture, 2021). There can be significant business value creation if companies focus on optimising performance and resource efficiency through the waste management model 4R - reduce, reuse, remanufacture and recycle, across the full life cycle of the vehicle.

All the major global original equipment manufacturers (OEMs) have already announced their roadmaps towards electrification and carbon neutrality in the coming decades (see Table 1). To reach these goals, OEMs have to redesign their production lines and reorganise their supply chain. The automotive sector has integrated circular economy into its business practices for decades. But now a systematic and full value chain approach is needed to transform the industry into carbon neutral and create new business models. As the MIT Center for Transportation & Logistics 2020 report on the State of Supply Chain Sustainability notes, “in 2022 and beyond, re-evaluations of supply chains - including sustainability - may gather steam as business models are redefined.”<sup>2</sup>

**Table 1. Major OEMs roadmaps for electrification and carbon neutrality**

	<b>Electrification</b>	<b>Carbon neutrality</b>
<b>General Motors</b>	100% in 2035	2040
<b>Hyundai</b>	36% in 2030	2045
<b>Volvo</b>	100% in 2030	2040
<b>Nissan</b>	50% by 2030	2050
<b>Toyota</b>	50% in 2030	2050
<b>Volkswagen</b>	50% in 2030	2050
<b>Ford</b>	40% in 2030	2050
<b>Renault</b>	100% in 2030 for Europe	2050
<b>Jaguar Land Rover</b>	100% in 2025	2039
<b>Mercedes-Benz</b>	100% in 2030	2039
<b>Stellantis</b>	100% in 2030 for Europe	2038
<b>BMW</b>	50% in 2030	2050

Source: authors’ elaboration based on company announcements

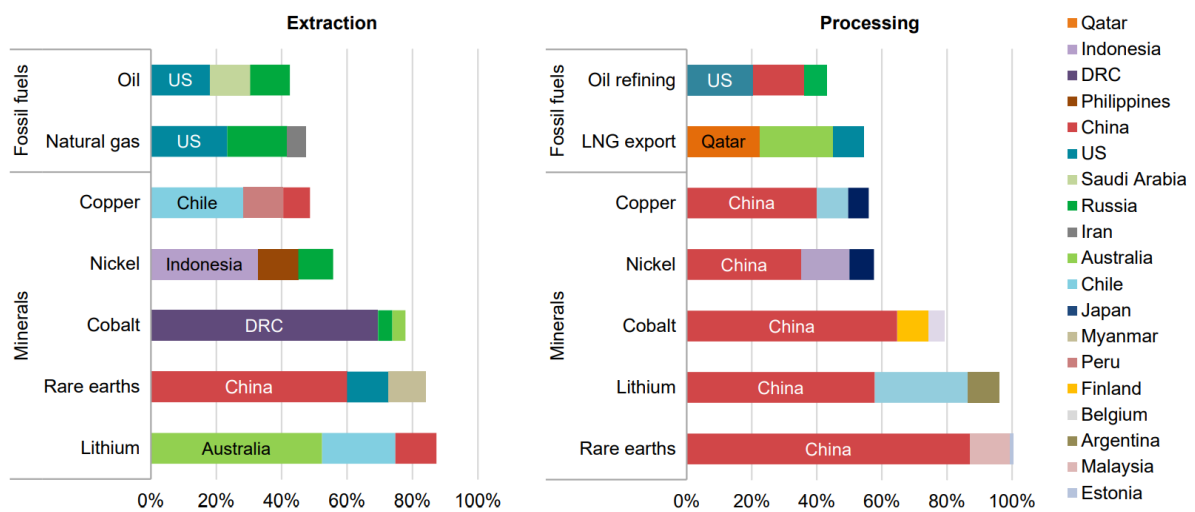
It is estimated that by 2030, one out of every two cars sold in the USA, the European Union and China could be electric (IEA, 2021). With the acceleration of the vehicle electrification, the on-the-wheel pollution might be largely reduced, but more challenges are emerging. As the International Energy Agency (IEA) notes, a battery electric vehicle (BEV) requires more than six times the mineral inputs of an ICEV; they also need a larger set of minerals compared to the combustion engine vehicle (Jetin, 2022). Considering the need to electrify the world’s existing stock of 1.3 billion ICEVs by 2050, with the total global vehicle stock projected to grow to 2.2 billion by 2050, such resource requirements are neither sustainable,

<sup>2</sup> Citation from “State of Supply Chain Sustainability 2020”, MIT Center for Transportation & Logistics Council of Supply Chain Management Professionals, page 5.

nor any longer bearable. The emissions are also higher during production due to the carbon intensity of mining battery metals.

The reality is that the production of many energy transition minerals today is more geographically concentrated than that of oil or natural gas (See Figure 1). At the global level, China produces over 80% of graphite used in batteries and about 2/3 of rare earth elements, critical to many clean technologies including wind turbines and electric vehicle (EV) motors; China also has a dominant position in the processing and refining of many other minerals and metals including cobalt, lithium, nickel and aluminium (IEA, 2021). The Democratic Republic of Congo (DRG) owns 70% of the world’s cobalt, but it lacks a local refining industry and value chain development. Russia is a major producer of battery-grade nickel and platinum. Recently, with the EV boom, Chinese companies have made substantial investment in mines in Australia, Chile, Indonesia and Africa. Geographical concentration reduces global resilience and raises major security concerns as physical disruptions, trade restrictions, technical failures, or other geopolitical events in one major country producer can quickly affect global supply (Birol and Canfin, 2023). Moreover, these crucial minerals are often located in geographic zones under climate change stress, making the global supply even more vulnerable and at increasing risks (IEA, 2021).

**Figure 1. Geographical concentration of materials and minerals for energy and mobility**



Source: IEA (2021)

Therefore, the choice of circularity is unavoidable for any auto maker and supplier, given their stake of social responsibility and climate change obligations, but also in order to increase resilience to resource and supply shock, create new business values and reduce total costs over full life-cycle. According to a recent estimate by Bain & Company, the use of recycled materials by the European automobile industry has potential to more than double by 2040, from 23% to 59%, resulting in a 60% reduction in production carbon emissions compared to using “virgin materials” (Peccoud et al, 2022). Although European automakers already have a relatively good practice of recycling, driven in part by strong regulation, there are still high inefficiencies and losses; recycling rates for crucial materials such as nickel,

cobalt, manganese and lithium as low. The fast growth of EVs creates an urgent need to improve recovery levels of these materials. The report stresses that a circularity revolution in the industry will combine recycling, better material utilisation, reuse and remanufacturing of components, and scaling up new mobility business models (Peccoud et al, 2022).

A special attention is paid to the EV batteries. Driven by the electrification of transport, demand for batteries is increasing rapidly and is set to increase 14-fold by 2030, and the EU could account for 17% of that demand (European Commission, 2022b). As part of the European Green Deal, sustainability requirements on carbon footprint, recycled content and performance and durability will be introduced gradually from 2024 onwards. Used-car batteries must be tested first for second-life potential before considering recycling. When recycled, high recovery rates must be reached: 70% of lithium and 95% of cobalt, copper and nickel already by 2030 and even higher in 2035 (Bain, 2022). Combining the circular economy framework and EU's climate neutrality objective, the new law will foster the development of a competitive sustainable local battery industry and support Europe's energy independency and clean transition. Stricter material recovery targets will be introduced over time; for lithium, the targets will be 50% by 2027 and 80% by 2031 (European Commission, 2022b). While EU policy initially focused on end-of-life vehicles (ELVs) and battery recycling, it now extends to the design phase with recycled content mandates and considers the recyclability of the full vehicle. These policies will continue to evolve over the coming decade.

## **2. Circular economy framework for automotive industry and observations of how OEMs and key suppliers are adopting the model**

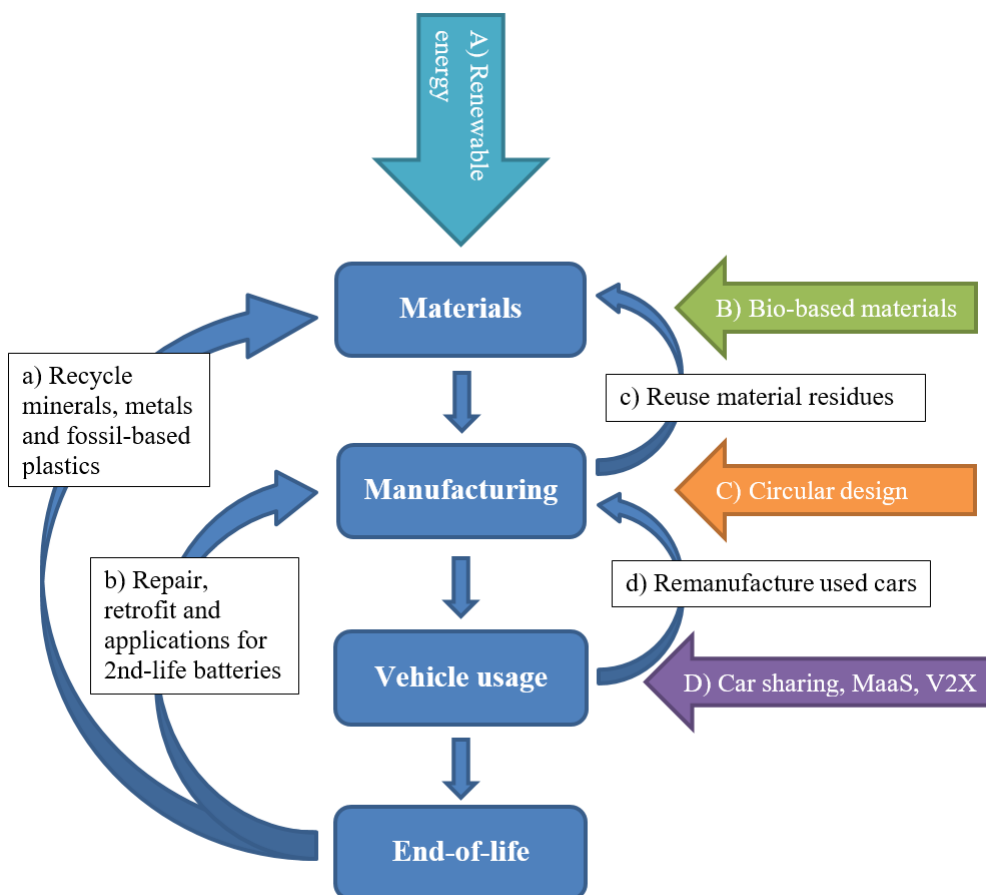
The circular economy is a model of production and consumption, which involves sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible (European Parliament, 2015). A circular economy is based on a looped economy in which products at the end of their intended purpose are recollected and recycled back into the economy or disposed of in a way to store carbon as opposed to simply landfilling (Geissdoerfer et al., 2017). This model brings multiple benefits, in particular: less consumption and lower dependence of raw materials; less waste, fewer emissions, thus less environmental pressure; lower costs with second-life materials; green job creations. Its origin not traceable, the concept has been popularised and largely diffused by The Ellen MacArthur Foundation. Their famous butterfly diagram illustrates the elements and flows embedded in the circular economy model. There are two main cycles, the technical cycle and the biological cycle: in the technical cycle, products and materials are kept in circulation through processes such as reuse, repair, remanufacture and recycling; in the biological cycle, the nutrients from biodegradable materials are returned to the Earth to regenerate nature (Ellen MacArthur Foundation, 2013).

### **2.1 Circular economy framework for automotive industry**

Automotive industry has an intensive use of resources. The three resources OEMs are mostly fundamentally relied on are: materials, energy and water. A mobility provider needs to

increase efficiency in terms of carbon emissions and non-circular resource consumption, as well as use of public goods. In this paper, we consider that the circularity that the automotive industry must embrace should include a fourth dimension: efficient use of public goods, such as space and clean air (Accenture, 2021). Therefore, for the automotive industry’s circular economy model, we propose the four phases of analysis: materials, manufacturing, vehicle use and end-of-life. The following framework is based on the principles of circular economy according to the butterfly diagram (Ellen MacArthur Foundation, 2013), taking into account the key elements and flows during the vehicle’s life cycle. It also learns from the study of Aguilar Esteva (2020) and their circular economy framework for automobiles.

**Figure 2. Automotive industry’s circular economy framework**



Source: by authors

Our framework covers all the four major phases and states of the vehicle life: the raw materials, the manufacturing process, the usage of vehicle, and the end-of-life vehicle treatment. What make it a circular economy model come from the loops that link different phases (the four curve flashes from a to d) and the new inputs (the four coloured flashes from A to D; A applies to all four phases) that increase the circularity and resource efficiency. In this circular economy model, the resource consumption is not linear, each phase can draw resources (through reuse, repair, remanufacture and recycle) from other phases or obtain new inputs to amplify the circularity. (1) The first phase of materials production includes the

mining, refining, transportation and processing of substances into materials of a desired quality. Under the circular economy model, a) non-renewable resources as minerals, metals and fossil-based plastics should be recycled at maximum. For example, steel, aluminium and plastics are the three major groups of materials used in car production, which are non-renewable but could be largely recycled. c) Material residues from the manufacturing process can be reused or recycled. B) Renewable resources such as bio-based materials can be valuable new inputs to substitute certain non-renewable and non-sustainable resources. Incorporating greater shares of bio-based alternatives like cellulose, kenaf and soy could also retain light-weighting benefits (Aguilar Esteva, 2020). (A) Using renewable energy or clean energy as much as possible for extraction, refinery and production. An essential aspect for material in a circular economy is eliminating, substituting, or reducing the use of scarce/finite, non-renewable and toxic elements (Ellen MacArthur Foundation, 2013).

(2) In the second phase of vehicle manufacturing, most GHGs come from the consumption of energy generated by fossil fuels and around 30% of GHGs from the manufacturing process come from the painting phase. The circular economy model implies switching to cleaner-burning fuels or lower-waste additive manufacturing techniques, increasing energy and material efficiency, reducing water-use through on-site treatment or recycling. Instead of producing vehicles from virgin materials, the d) remanufacturing of used vehicles or b) the treatment of ELVs are considered. When remanufactured, car parts can also be used in different ways from its origin design, especially for the electric batteries loaded on the EVs, as they don't lose all of the charging capacity, there are multiple applications using EV batteries as energy storage (mobile energy storage, microgrids, marine electrification, etc.). It is also very important to bring in C) circular design as new inputs. In order to be able to disassemble the vehicle and its components quickly and cost-efficiently, the manufacturing of the vehicle must be done with the circular purpose already in mind. Aguilar Esteva (2020) find that currently BEVs have lower shares of recycled materials than ICEVs in the US, which indicates a gap to close up. A) Remanufacturing vehicles or repurposing its parts by using on-site generated or procured renewable energy.

(3) During the use phase, a vehicle's powertrain and its associated fuel type significantly influence its sustainability performance. Hybrid EVs and plug-in hybrid EVs have improved fuel economies relative to ICEVs; BEVs are powered solely by electric powertrains and do not produce tailpipe GHGs; yet, even BEVs are not complete "clean" as they do have associated GHGs from electricity generation. Only by using A) renewable energy produced electricity or hydrogen as fuel, the vehicle's carbon emissions during usage can become zero. Besides the materials that compose it, the vehicle also occupies space and impacts on the air condition. In order to realise circular economy's objective to maximise resource utility and reduce to the least any waste, it is essential to increase the use rate of the vehicle, by putting it to d) car sharing or through Mobility-as-a-Service (MaaS) usages. Driven by multiple factors, including the fight against climate change, rapid urbanisation, and consumer preferences changing from owning a good to using a service, there is already a trend towards a rebalancing from individual car mobility to more efficient and sustainable collective or shared mobility (Tinnilä and Kallio, 2015; Alochet et al., 2021). Furthermore, EVs can be



used as a smart charger for the grid and the energy systems; from this capacity, circular solutions such as vehicle-to-grid (V2G), vehicle-to-home (V2H), vehicle-to-building (V2B) or in general vehicle-to-everything (V2X). For the moment, there are only pilot projects in test, such as the European FLOW project<sup>3</sup>, but once regulated and standardised, vehicles can become much more than just transportation tools.

(4) At its end of life, the vehicle should go through obligatory diagnoses to determine whether they can be repaired and reused, or they need to be remanufactured, or finally recycled. OEMs are now gradually working with their suppliers to recycle major materials from the ELVs, such as steel, aluminum and plastics. There are small quantities of critical materials in internal combustion engines, motors and generators, exhaust control systems, EV batteries and other vehicle components. The EV batteries use several critical and rare earth elements like cobalt, neodymium and platinum, as well as other precious metals such as lithium and nickel which exist in limited reserves. To be more sustainable, it is crucial to reduce the consumption of critical materials through material substitution and promote end-of-life recovery for closed-loop recycling. OEMs and battery makers are increasing collaborating on end-of-life EV battery reuse and recycling.

Based on this framework, we collected information and data about important projects and practices of circular economy that major OEMs and their suppliers have been carrying out recently. While a larger part of the data come from internet, a small part of them are also from interviews made with a few OEMs. We first present key circular economy projects and developments by leading OEMs, since they are the central actors in the automotive value chain organisation and in its transition towards circularity and carbon neutrality. We will highlight some initiatives focused on EV battery's reuse and recycling, as this component has significant impact on resources sustainability, carbon emissions and a durable development of the EV industry itself. Finally, we will map the circular economy practices based on our collected data and our analytical framework.

## **2.2 Mapping circular economy plans and practices by major OEMs**

Audi has launched different pilot projects to build its circular economy business ground. Since 2017, a closed aluminum cycle has been implemented at the Audi sites Ingolstadt, Neckarsulm, and Győr (Hungary) and at the Volkswagen Group's plant in Bratislava (Slovakia): aluminum offcuts generated from production are returned directly to the supplier, who uses them to create new aluminum sheets to be fed back into the production process. Audi is also committed to recycling synthetic components, PlasticLoop, which is carried out together with LyondellBasell and through which a process was defined, that for the first time uses chemical recycling to reuse mixed automotive plastic waste from cars in the production of the Audi Q8 e-tron. In the spring of 2022 Audi launched a pilot project for glass recycling: damaged windows that cannot be repaired are shattered into small pieces and sorted; the resulting glass granulate is melted down and turned into a new plate of glass. This process is already used in the production of Q4 e-tron. Most recently, a new initiative called MaterialLoop was created, as the circular economy project for end-of-life cars.

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<sup>3</sup> <https://cordis.europa.eu/project/id/101056730>

BMW has unveiled its fully-recyclable concept BEV, the i Vision Circular, in September 2021, and plans to realise its production by 2040. The design, described as ‘disruptive’, relies on 100% recyclable materials, including the battery pack; the surface is made from recycled aluminium while the tyres are created from certified natural rubber; the interior is 100% sustainable, with the dashboard being 3D-printed and produced from recycled plastic (Autovista24, 2022). BMW is also trying to use more secondary materials in the supply chain. A pilot project the company has initiated with chemicals company BASF and recycling firm Alba Group aims to reduce the use of primary plastics. Alba Group analyses end-of-life BMW Group vehicles to establish whether physical recycling and a car-to-car reuse of the plastic is possible; in a second step, BASF assesses whether chemical recycling of the pre-sorted waste can be used in order to obtain pyrolysis oil. In a further effort to substantially reduce GHGs in the supplier network, BMW recently also signed a deal with one of Europe’s largest steel producers, Salzgitter AG, to increase the use of low-carbon steel at its European plants.

For Daimler Group, all Mercedes-Benz car models are 85% recyclable and 95% of the material in vehicles can be reused or recovered according to the European ELV Directive. For passenger cars, Mercedes-Benz has set itself the target of by 2030 increasing the share of secondary raw materials by 40%, reducing water and energy consumption per vehicle by 33% and 43%, compared to 2013/2014; and decreasing waste disposal per vehicle by 82% compared to 2018. Its subsidiary Mercedes-Benz Energy is responsible for the development of innovative energy storage solutions using retired EV batteries. Mercedes-Benz is also building a battery recycling plant in Germany. The pilot plant will have an annual capacity of 2500 tonnes and will contribute to the production of more than 50,000 battery modules for new electric Mercedes-Benz vehicles.

Ford has set an interim target of using 20% recycled and renewable plastics in new vehicle designs by 2025 at its factories in North America and Europe and a 10% target for its factories in China and Turkey. Ford uses a closed-loop system to manufacture its F-series trucks and is the largest closed-loop aluminium recycling automaker in the world, according to its 2022 sustainability report (EIU, 2023). In recent years, Ford has also increased its use of recycled non-metal and bio-based materials. For example, Ford has teamed up with Kraft Heinz since 2014 for developing new component parts based on food waste: tomato skins. Dried tomato skins become the wiring brackets in a Ford vehicle or the storage bin a Ford customer uses to hold coins and other small objects. Other examples include cellulose fiber-reinforced console components, rice hull-filled electrical cowl brackets, coconut-based composite materials, recycled cotton material for carpeting and seat fabrics, and soy foam seat cushions and head restraints (Ford, 2014).

In 2022, General Motors (GM) has announced accelerated energy goals, including sourcing 100% renewable energy to power its facilities in the U.S. by 2030 and globally by 2035. The group also aims to divert more than 90% of its total operational waste from landfills, incinerators and energy recovery facilities by 2025. Besides, GM has joined the First Movers Coalition through commitments to low-carbon concrete, cement, aluminum and steel. To build a more resilient and sustainable supply chain for its EV growth plan, the group has also

signed a number of agreements with suppliers, including with Lithium Americas for lithium from the United States and POSCO for cathode-active material from Québec. In 2021, its mobility brand Cruise launched the first paid zero-emission driverless ride-hailing service in San Francisco; at the same time, last-mile delivery solutions were also offered through BrightDrop. Based on its EV brand Ultium and through its energy business unit GM Energy, the group has also developed Ultium Home and Ultium Commercial, offering V2H and V2G solutions to home and business.

Nissan aims to reach 70% non-new materials resources (recycled materials and biomaterials) for new vehicle production by 2050. Nissan Intelligent Factory (launched in 2021) has been using a new water-based paint technology, enabling the simultaneous painting of the body and bumpers, reducing GHGs by 25%; the adopting of dry booths allows to collect 100% of the residual airborne paint, which is reused as an alternative to auxiliary agents to remove impurities in the iron casting process. Nissan EV36 Zero Electric Vehicle Hub was unveiled in July 2021, in Sunderland, UK, Europe's biggest auto plant. The project brings together EVs, renewable energy and battery production. Envision AESC, a Chinese battery firm, will build a new 9GWh-capacity giga-factory near the Nissan Sunderland Plant. Renewable energy and microgrid will be used to deliver 100% clean electricity for Nissan and its suppliers on the site, and second-life EV batteries will be used as energy storage for ultimate sustainability (Nissan, 2021). On the experiments of diversifying the EV's usage, Nissan partners with electric power companies and charging service providers from different countries to test how EV charge and discharge control can help stabilise the supply and demand of electricity for economic and environmental benefits. Nissan has built the Blue Switch program to use EVs as emergency power source during natural disasters in Japan. Back in 2010, Nissan already joined force with Sumitomo Corp. to establish 4R Energy Corp., which specialises in the reuse, resell, refabricate and recycle of lithium-ion batteries, with the aim of building an efficient battery life cycle (Nissan, 2021). In September 2019, Nissan and 4R Energy started using fixed storage batteries built with used batteries from the Nissan LEAF for producing electric power from renewable energy. Nissan and 4R Energy are also doing trial operations of safety devices for railroad crossings powered by recycled EV batteries.

Renault Group is one of the pioneers in embracing the circular economy strategy. In November 2022, Renault created a business unit dedicated to the circular economy, called "The Future is NEUTRAL", which aims to achieve closed-loop circularity across the vehicle life-cycle, from procuring raw materials, production, use to ELVs; the group targets €1 billion revenue from circular economy business by 2030 (Renault, 2022). Currently, only about 30% of vehicle materials are recycled for new vehicles mainly through metal scrapping and battery repairs for ELV, and Renault wants to raise the rate to about 85%. "The Future is NEUTRAL" relies on three subsidiaries - Gaia (specialised in reuse and recycling of parts and materials), Indra (leader in ELV treatment in France) and Boone Comenor (expert in metal scraps recycling) - which form part of Renault's circular economy factory, Refactory, located in Flins, France. Launched in 2020, Refactory is the first European circular economy factory, along with an Open Innovation Hub and a future University campus. In November

2021, Renault launched another circular economy factory in Spain with a targeted roll-out between 2022 and 2024; it is planning to launch similar projects in Turkey, South America and Portugal (EIU, 2023). In 2021, Renault has also launched a new vehicle brand Mobilize, offering on-demand flexible service using modular electric vehicles, aimed for car sharing and last-mile delivery (Renault, 2022). For EV batteries, Renault has partnered with Betteries to produce mobile and modular energy storage solutions based on second-life batteries. It has also partnered with Veolia and Solvay for closed-loop recycling of battery-used strategic materials to produce new batteries. The group targets 80% of material recycled back into new battery production in Europe by 2030.

Stellantis has also announced the launch of its circular economy business unit to become carbon neutral by 2038. The company is aiming to generate about €2bn in revenue from the unit mainly through its “Circular Economy Hub” in Italy, at FCA Group’s historical plant in Mirafiori Sud, planned to be operational in 2023. In September 2022, the company unveiled its concept electric vehicle, Citroën oli, made from recycled material and with end-of-life recyclability. The Cassino plant, where the luxury brands Alfa Romeo and Maserati are produced and EVs lines are newly planned, has been “zero waste” since 2000: not a single gram of industrial waste is sent to landfill, 100% of the electricity used by the plant comes from renewable sources and 100% of the emissions related to the use of thermal energy are offset. Before its merger into Stellantis, FCA has been pursuing a circular process design strategy by focusing on numerous elements, such as the choice of materials for some bio-based vehicles, easily recyclable, natural fibers such as kenaf and jute, or renewed materials such as recycled nylon, or the reduction of waste and water consumption in the supply chain. Besides, Stellantis’ car sharing mobility unit Free2Move has acquired Share Now, the former mobility unit of BMW, in 2022.

Volvo Group has fixed the goal to become a circular business by 2040, largely by increasing the share of sustainable recycled and bio-based materials used in cars. For 2025, 40% aluminum, 25% steel and 25% plastics used for new car production will be recycled or bio-based; and its 55 sites will be transformed to landfill-free (Volvo, 2022). In 2021, 96% of Volvo’s global production waste was recycled. In 2022, 48% of the total energy sourced by the group’s operations (production, technology centers, warehouses and dealership sites) was from renewable sources. For the reuse of EV batteries, Volvo is developing energy storage systems both inhouse and in collaboration, for example with the UK-based second-life battery energy storage specialist Connected Energy.

In particular regarding EV battery recycling, the Swedish battery developer Northvolt, 20% owned by Volkswagen, has produced in 2021 its first battery cell with 100% recycled nickel, manganese and cobalt. Northvolt is now building its new recycling facilities in Sweden to recycle 125,000 tons of batteries per year, amounting to approximately 30 GWh of battery production per year. The company has more than \$55 billion in contracts with customers that include Volkswagen, BMW, Scania, Volvo and Polestar. There are also consortiums of OEMs in battery recycling. For example, Ford Motor and Volvo Cars have partnered with battery recycling startup Redwood Materials in developing processes, starting in California,

to collect end-of-life batteries from electric and hybrid vehicles and recover the materials for use in new batteries.

The following table maps the development of circular economy practices by major OEMs to obtain a general picture of how the automotive industry is embracing the circular economy model.

**Table 2. Mapping of the deployment of circular economy by OEMs (in alphabet order)**

<i>a) Recycle minerals and metals</i>	Audi, BMW, Daimler, Ford, GM, Jaguar Land Rover, Nissan, Renault, Skoda, Stellantis, Volvo
<i>a) Recycle fossil-based plastics</i>	Audi, BMW, Ford, Nissan, Renault, Skoda, Volvo
<i>a) Recycle battery-used strategic materials (cobalt, nickel, lithium)</i>	Daimler, Ford, GM, Renault, Volkswagen, Volvo
<i>b) Repair and retrofit</i>	Renault, Stellantis
<i>b) Applications for 2nd-life batteries</i>	Daimler, GM, Nissan, Renault, Stellantis, Volvo
<i>c) Reuse material residues</i>	GM, Nissan, Renault, Skoda, Volvo
<i>d) Remanufacture used cars</i>	Daimler, Renault, Stellantis
<i>A) Renewable energy for manufacturing</i>	GM, Nissan, Renault, Skoda, Stellantis, Volvo
<i>B) Bio-based materials</i>	Ford, Nissan, Stellantis, Volvo
<i>C) Circular design</i>	BMW, Renault, Stellantis, Volvo
<i>D) Car sharing, MaaS</i>	Daimler (Car2go), GM (Cruise), Nissan (e-Share Mobi), Renault (Mobilize), Stellantis (Free2Move), Volvo (Sunfleet)
<i>D) V2X</i>	Renault, Nissan, Hyundai, Ford, GM, Stellantis, Volvo

Source: authors' elaboration, based on company announcements and interviews with several OEMs

Through the mapping we see that major OEMs are all gradually integrating the circular economy model in their corporate strategy. Some OEMs also have established a dedicated circular economy business unit. As shown by the table, most OEMs are actively involved in more “traditional” practices of parts and material reuse and recycling; many of them have announced targets to achieve lower resource consumption and high circularity. Since energy presents a big trunk of a vehicle’s life-cycle GHGs, we observe significant efforts by OEMs to source more renewable and clean energy for production and related operations. There are pilot projects of material substitution by renewable and bio-based materials, but not yet as a standardised practice. In general, OEMs rely on their components suppliers and material providers to amplify their reuse and recycling practices; in particular, for EV battery recycling, partners specialised in battery material treatment are indispensable. Some OEMs

are supporting the incubation of startups in the domain of circular economy, and gradually integrating them in the automotive industry ecosystem. To increase vehicle's use rate, a good number of OEMs have launched car sharing service through their dedicated branch; yet, the new mobility business is not always profitable and OEMs are still learning by doing. Regarding EV batteries, OEMs are developing different applications for second-life batteries, building related business models such as energy storage systems and V2X solutions, which expand EV's life-cycle value and optimise the strategic materials used in batteries. We also notice a trend: with an increasing demand for traceable materials, especially those used in batteries, there are increasing initiatives and startups specialised in tracing materials throughout the global supply chain from mining to end-of-life using new technologies (e.g. the Dutch startup Circularise, which collaborates already with several OEMs).

### **3. Conclusions: building a favourable ecosystem of transformation**

Until recently, most circular economy practices and efforts are driven largely by regulations. European automakers are required to adhere to the European Commission's directive on ELVs, which sets targets for the recyclability, reusability and recoverability of vehicles and their components. The current directive requires up to 95% reuse, recycling and recoverability by weight per vehicle. Japan and South Korea have similar vehicle recycling laws. The Japanese government has adopted the End-of-Life Vehicle Recycling Law in 2005, requiring OEMs to reach 95% recyclability rate through dismantling and shredding. India also launched a similar framework for scrapping ELVs in August 2021. In the US, there is no federal law for ELVs, but several state governments have legislation and requirements for vehicle recycling (EIU, 2023). For end-of-life EVs, battery reuse and recycling have been particularly stressed by recent and upcoming regulations.

Despite these initiatives, companies are far from attaining a closed-loop recycling system for their vehicle production. Most of their initiatives are limited to Europe, where both national and regional governments have strict targets. However, to achieve a full shift to circularity carmakers need to be driven not only by regulation but also by the potential to develop more efficient and profit-making business models for recycling (EIU, 2023). In the meanwhile, there is increasing pressure from consumers, investors, the society and environmental projection institutions on automakers and the whole industry to assume climate responsibility and tackle sustainability challenge.

The World Economic Forum and the World Business Council for Sustainable Development jointly formed the Circular Cars Initiative to accelerate the transformation of automotive industry towards circularity and a zero-emission future, through new technology, materials innovation, efficient vehicle usage and full life-cycle management (Accenture, 2021). Besides, the security benefits of recycling can be far greater in regions, like the EU, with high levels of clean energy deployment and limited resource endowment. Putting in place better collection systems, harmonised waste regulations, and a sound investment framework for recycling facilities are vital to position the EU as a leader in the space (Birol and Canfin, 2023).

During our observations, we have further identified some drivers that can accelerate the adaptation of circular economy. First, regarding the background, we find that local industrial tissues play a crucial role in anchoring certain type of circular economy projects. Second, regarding the content, we underline that there is an increasing co-development of local policy and projects tackling energy transition, mobility transition and circular economy at the same time. Synergy is created through collaborations of actors from different sectors united by these “cross-border” projects. Third, regarding the financing, we argue that public funding for pilot projects, such as Horizon 2020, serves as a starting point to incubate tech startups providing innovative solutions, which later relies on local funding, venture capital or other strategical investors to further support the maturation and the scale up of the project.

Looking forward, there are great challenges and opportunities. In April 2022, 100 EU cities have been selected by the European Commission to participate in the Cities Mission, with the goal to become climate-neutral and smart cities by 2030 (European Commission, 2022a). The actions will focus on clean mobility, energy efficiency and green urban planning, offering possibilities of joint initiatives and ramp up collaborations. Urban areas consume over 65% of the world’s energy, accounting for over 70% of the global GHGs; it is therefore important that cities act as experimentation and innovation ecosystems to help accelerate transitions to climate-neutral by 2050 (European Commission, 2022a). Under this context, automotive industry, as an important contributor of urban development, has a crucial role to play in the cities’ transformation; vice versa, cities offer the industry a fertilised ground for experimentations and adaptations of best practices of circular economy.

Through our observations and analyses, we confirm that the circular economy model will become the new norm and totally transform the automotive industry. It is crucial to create the right ecosystem, by combining policy, regional initiatives, city climate missions, industrial supply chain collaborations, partnerships with local startups, research and design centers.

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