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Accenture Strategy



# Raising Ambitions: A new roadmap for the automotive circular economy

CIRCULAR CARS INITIATIVE  
BUSINESS MODELS CLUSTER  
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# Foreword



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The car has given us freedom. It has accelerated trade and made an indelible mark on modern culture and lifestyles. But cars are also responsible for ~10% of greenhouse gas emissions and a large share of global steel, aluminium, plastic, rubber, glass and increasingly battery material consumption. It is now time for a revolution in automotive sustainability.

The World Economic Forum and the World Business Council for Sustainable Development (WBCSD) jointly formed the Circular Cars Initiative to accelerate this transformation. The Initiative takes a systemic approach – accounting for the build phase as well as the use phase – to automotive sustainability. It looks at how technology and business levers can maximize the resource value of the car, minimize life-cycle emissions and unlock new opportunities.

Within the Circular Car Initiative, 40 companies from the automotive value chain, several research institutes, international organizations, governmental

bodies and think tanks are charting the course towards a zero-emission future through new technology, materials innovation, efficient vehicle usage and full life-cycle management.

We wish to thank Accenture under the leadership of Wolfgang Machur and Alexander Holst, and McKinsey under the direction of Fehmi Yüksel and Eric Hannon, for their in-depth analysis and thought partnership on these topics. We are also appreciative of EIT Climate-KIC's Sira Saccani and Kirsten Dunlop, and SYSTEMIQ's Matthias Ballweg, Tillmann Vahle and Martin Stuchtey, for joining early on and for their ongoing work on policy recommendations.

We also would not have come to this point at the end of 2020 without the leadership of Levi Tillemann at the World Economic Forum.

The “circular car” is now on its way to becoming a core component of the automotive future.



# Letter from Accenture Strategy and the World Economic Forum



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The automotive sector has integrated circular economics into its business practices for decades. But now is the time to raise ambitions on the sector's approach to circularity to effectively address climate change and resource depletion.

For the world to experience less than 1.5°C of global warming, the automotive industry needs to target around a 50% reduction in absolute carbon emissions by 2030. In the same period, we expect mobility demand to increase by 70% globally. Circularity and electrification will be the core strategies that enable the industry to decarbonize and prepare for this increased mobility demand. Circularity means using cars more efficiently, shifting to fleets and coordinating value ecosystems more effectively. All of these aspects of circularity can add value for the industry and for society, and enhance the broader ecosystem that humans inhabit.

Original equipment manufacturers (OEMs) have already set ambitious roadmaps towards carbon neutrality in the next two decades.

We expect circularity to become a major element of this transformation. Companies need to chart their individual paths and learn to optimize and orchestrate the full-value ecosystem and vehicle life cycle.

The Circular Cars Initiative (CCI) represents the first organized industry effort to systematically address the opportunities and challenges of circularity with an eye towards fundamentally remaking automotive value chains and business models. Accenture has been honoured to support the Forum and the participating companies on this journey towards a circular automotive economy.

This report proposes a taxonomy of five levels of circular cars and four major strategies for industry transformation before detailing a variety of necessary solutions for circular business models. Over the coming months and years, we expect multistakeholder pilot projects and public-private collaborations to move the vision of the Circular Car Initiative into reality.

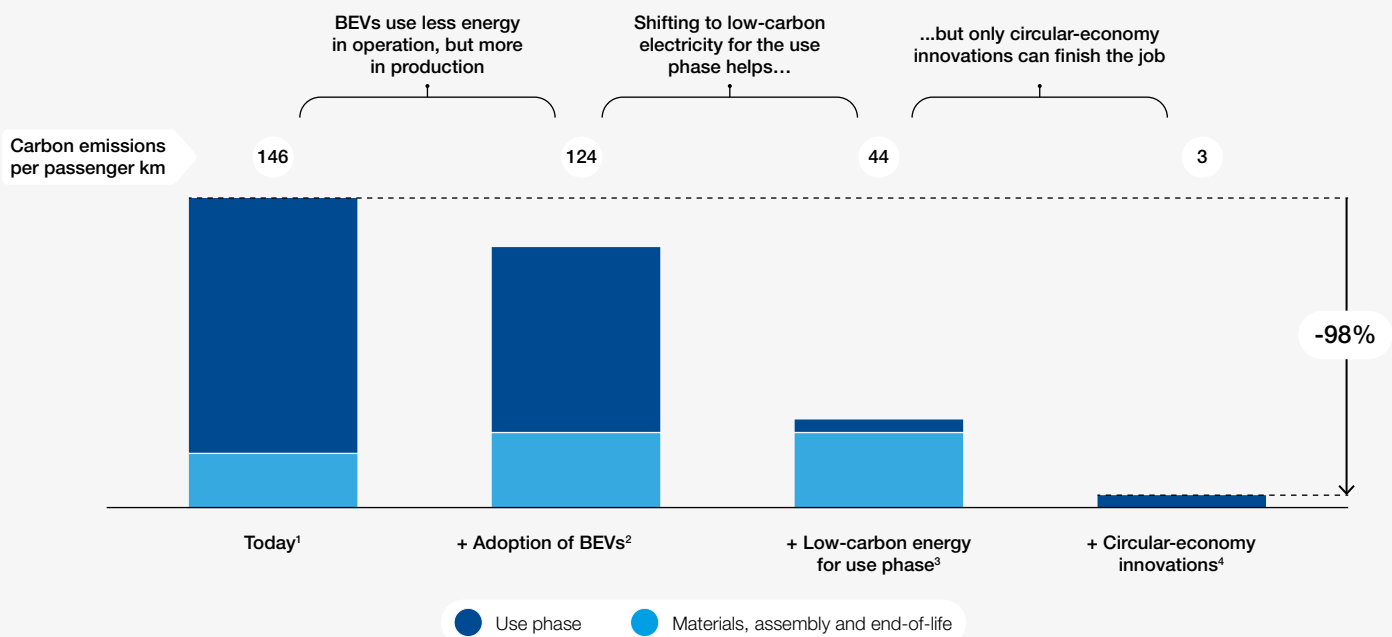
# Introduction

Sustainable cars must be powered by green electricity; circular economy principles need to govern both manufacture and use phase.

The term “circular car” refers to a theoretical vehicle that has maximized materials efficiency. This notional vehicle would produce zero materials waste and zero pollution during manufacture, usage and disposal – which differentiates it from today’s zero-emission vehicles. While cars may never be fully “circular”, the automotive industry can significantly increase its degree of circularity. Doing so has the potential to deliver economic, societal and ecological dividends.

Indeed, the convergence of technology, environmental and economic megatrends is propelling the modern automotive industry towards just such a transformation. The Circular Cars Initiative has assembled a broad coalition of participants from the automobility ecosystem committed to leading this transformation and increasing the environmental sustainability of global mobility by harnessing the power of new technologies, materials and business models.

FIGURE 1 Decarbonizing the car



1. ICEV hatchback (level 1) with 1.70t weight (incl. repair components), 0.90t steel, 0.15t aluminium, 0.29t plastics, 200,000 life-cycle km and average occupancy of 1.5  
 2. BEV hatchback (level 1) with 1.90t weight (incl. repair components), 0.70t steel, 0.19t aluminium, 0.32t plastics, 0.32t EV battery, 250,000 life-cycle km and average occupancy of 1.5  
 3. Requires decarbonization of electricity grid with additional renewable energy as per consumption requirement by BEVs  
 4. Circular-economy innovations consider level 4 circular BEV (fully circular)

Source: Accenture Strategy analysis

The Circular Cars Initiative (CCI) is comprised of three main workstreams:

- The **materials workstream**, led by McKinsey, is focused on the pressing need to decarbonize materials, institute closed-loop recycling and provide materials with a productive second life – capturing value that today is downcycled into other industries (see Figure 2).

- The **business models workstream** is led by Accenture Strategy. Its work lays out a series of strategies for achieving circularity. In collaboration with the World Economic Forum, Accenture Strategy has developed a taxonomy to guide the industry’s progress on carbon and resource efficiency. The goal is to maximize the mobility output achieved per unit of resources and emissions expended (see Figure 3). The

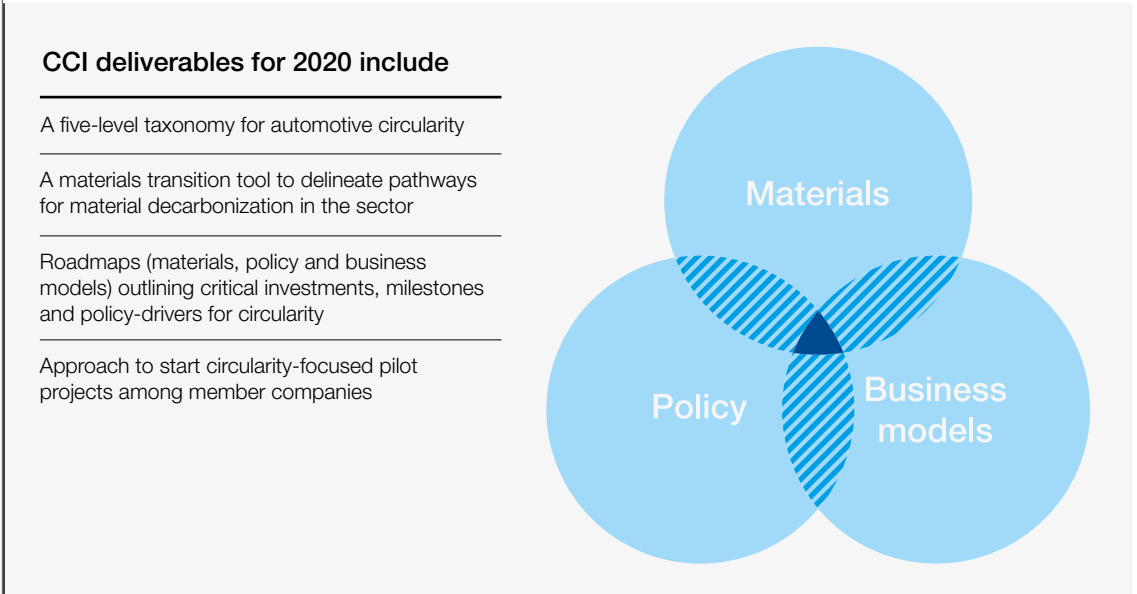
taxonomy addresses usage, vehicle lifetime, materials and energy-related aspects of circular business models.

- Finally, the **policy workstream** is under development. It will connect the dots of this ecosystem and address the relevant policy tools to be taken onboard by governments globally.

Each of these workstreams has been supported by our diverse community of stakeholder organizations, including carmakers, materials suppliers, national

research institutes, non-governmental organizations (NGOs) and academic institutions. They have contributed their insights through workshops and many dozens of interviews, as well as data and feedback on this multifaceted analytical process. In addition to our analytical partners McKinsey and Accenture, CCI would also like to recognize the valuable support and contributions of our CCI co-founders at the World Business Council for Sustainable Development (WBCSD), EIT Climate-KIC and SYSTEMIQ.

FIGURE 2 The Circular Cars Initiative (CCI): organizational structure and 2020 deliverables



# In a nutshell: driving industry transformation

To achieve a circular economy transformation, the industry requires a common language and roadmap.

The aim of this report is to lay a foundation for future discourse on automotive circularity by providing a framework for understanding circularity within the automobility ecosystem. Achieving circularity is a complex endeavour. In order to clarify the path forward, this study lays out a five-level taxonomy for circularity (0 = no circularity, 5 = net positive impact). This report also identifies business models that will generate more mobility and less waste in the future. Based on current technology, we see the opportunity to reduce carbon emissions by up to 75% and resource consumption by up to 80% per passenger kilometre by 2030.<sup>1</sup>

**Circular cars** will be a key building block for a **low-carbon mobility** system and are critical to achieving a **1.5°C scenario**. They can help to serve **growing mobility demand** while at the same time **reducing resource consumption** to a level that is truly sustainable.

**Business models** address a core aspect of this transformation. Simply improving vehicle use could yield dramatic reductions in carbon emissions per passenger kilometre. Combine this with optimized vehicle lifetime, increased materials recycling and clean energy, and automotive emissions could plummet in the years and decades to come.

A circular car should also be a good business case, as it maximizes resource and carbon efficiency, the two key performance indicators proposed by this report.

**There are four main transformation pathways** to increase circularity. These are centred on energy, materials, lifetime and use. This report examines

business models and strategies for achieving circularity through the lens of each of these transformation pathways.

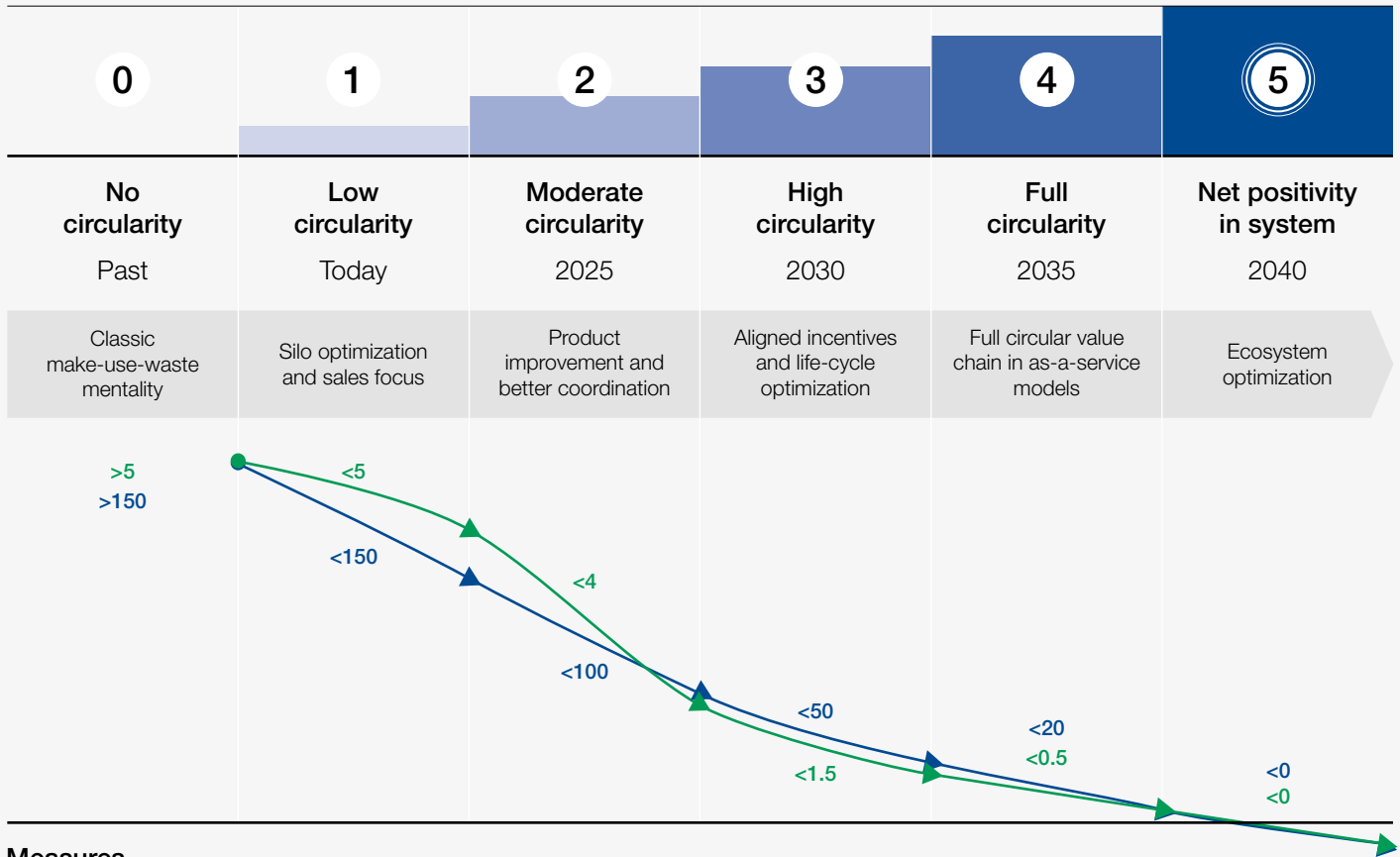
The industry has made carbon neutrality a core objective. Already most automotive materials are recyclable. Cars are built to last and to be repaired. These are all important aspects of circularity. But the industry must go further. The value chain needs to be fundamentally reimaged to minimize lifetime carbon emissions and resource consumption. This is a decadal transformation, which ecosystem players must address together.

Overall, the **key recommendations** for industry, the value-chain ecosystem and policy-makers are as follows:

- Create a common framework for guiding and measuring progress towards circularity. This framework should raise industry ambition from merely “do less harm” to building a sustainable global economy.
- Realign the profit motive for the automobility ecosystem away from selling products towards selling mobility and other services.
- Create data standards, reporting frameworks and transparency measures that allow for the rationalization of vehicle design development, life-cycle management and end-of-life processing.
- Secure policy support for systemic transformation.

“Circular cars will be a key building block for a low-carbon mobility system and are critical to achieving a 1.5°C scenario. They can help to serve growing mobility demand while at the same time reducing resource consumption to a level that is truly sustainable.”

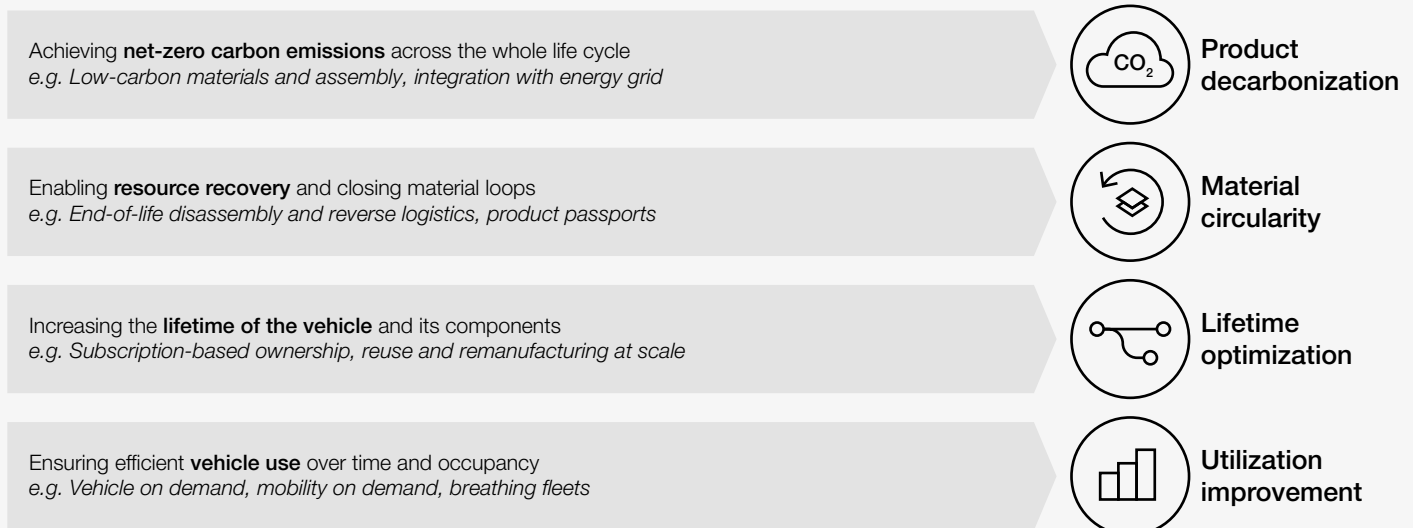
Levels of circularity



Measures



Transformation pathways



Source: Accenture Strategy



2

# There is an urgent need for circular business models

Business models are the key lever for rapid decarbonization of automobility.



The automotive industry is dramatically overshooting its estimated carbon and resource budgets. At the same time, car-based mobility is set to grow globally by around 70% by 2030 (passenger kilometres, as well as predicted vehicle stock in a business-as-usual use scenario).<sup>2</sup> This is happening at a time when the scientific consensus is that mobility emissions need to decrease by around 50% within 10 years (2030) to achieve a 1.5°C climate scenario.<sup>3</sup> Achieving Level 3 circularity for the full fleet by 2030 would align with achieving this important and ambitious goal (see Figure 4).<sup>4</sup>

But this will require a radical transformation of the car and the role it plays in the mobility ecosystem. Reducing reliance on cars is one approach, but that will get us only so far. Cars will remain a core provider of mobility for many decades to come. Because of this, it will also be critical to minimize the car's environmental impact. Some companies have already embraced both of these pathways to decarbonization. Original equipment manufacturers (OEMs) such as Volvo, Renault, Daimler, BMW and Volkswagen have set targets for carbon neutrality. They are investing heavily in electrification, closing material loops, new service offerings and new mobility solutions. Investors and regulators are pushing them to go further.













These trends and new technological possibilities have created a generational disruption in

the automotive sector. The confluence of electrification, autonomy and mobility business models has created a plastic moment during which OEMs can capture new revenue streams. Slowly but surely, we are witnessing a shift away from traditional business models focused on production and sales: Cars are increasingly bought online and flexibly “subscribed” to for shorter time periods; revenue streams are shifting towards the use phase; and the drive towards circularity is slowly picking up speed.

Business models represent an immediate opportunity to accelerate electrification, increase vehicle capacity factors and extend effective lifetime. Fleets can use capital more efficiently than individuals and provide a higher number of passenger kilometres with fewer cars. Combining fleet-based mobility with improved maintenance and advanced recycling systems has the potential to reduce both carbon emissions and resource extraction – the latter is especially relevant for the rare metals and rare earth elements in batteries.

The path ahead is not without peril for the industry. Sales might fluctuate as a “new normal” relying on higher utilization and extended lifetimes for vehicles takes hold. However, increased demand, shorter replacement cycles and service-based business models have the potential to fill that gap in revenues.

**FIGURE 4 Automotive passenger kilometres, non-circular resource consumption and carbon emissions per annum (currently and in 2030) in a business-as-usual and circular scenario**

KPI	Today	2030	
		Linear development	Circular scenario
Passenger km per year [tril. km]	 24	 40	 40
Global vehicle stock [bn]	 1.2	 2	 0.8
CO2 emissions per year [gt]	 3.4 Yearly CO2 budget for automotive industry (1.7gt)*	 5.7 Yearly CO2 budget for automotive industry (1.7gt)*	 1.6 Yearly CO2 budget for automotive industry (1.7gt)*
Non-circular resource consumption per year [mt]	 113	 188	 35

\*CO2 budget of automotive industry per year estimated at 1.7gt if net zero is reached in 2040 (66% probability)

Source: Accenture Strategy analysis, based on BloombergNEF (2020), OECD (2019), European Commission (2019), International Energy Agency (2019) and IPCC (2019). Note: In the circular scenario, all cars achieve Level 3 circularity

# Barriers holding back the transformation: paradigms and disincentives in the system

“ Over the past 100 years, the automotive value chain has been optimized for selling cars as a product, not providing mobility-as-a-service.

The primary barriers to circularity are related to: customers and use patterns; business models; production methods and technology; and regulatory hurdles.

**Customers and use patterns:** Buyers have long regarded cars as a status symbol. They are an **aspirational purchase** that provides freedom and independence. This leads to:

- **Inefficient allocation of capital:** Privately held cars are only effectively used at 1.5%<sup>5</sup> of their seat and time capacity. This leads to congested roads, unnecessary pollution, energy inefficiency and massive demand for parking.
- **Car lock-in:** Once a customer owns a car, they are inclined to use it. A customer accounts for only certain marginal costs (e.g. fuel), not the full cost of ownership, when weighing different mobility modes (e.g. public transport vs. car).
- **A “grey” fleet:** Due to their low usage, most cars are in use for 15–20 years. Thus old and inefficient cars remain on the road. They pollute excessively and are difficult to repair and recycle.

**Business models:** Over the past 100 years, the automotive value chain has been optimized for **selling cars as a product, not providing mobility-as-a-service**. This has a range of implications, including:

- **Focus on product costs:** The sales price is the prime concern for all players along the value chain – the customer, the OEM and suppliers. Total life-cycle cost optimization would enable more circularity.
- **Systems optimization that disincentivizes change:** The value chain and systemic incentives of the industry are optimized for today’s product sales-focused business model. As a result, alternative service-focused business models cannot compete. For them to be competitive, a new service-focused system will have to be optimized and achieve significant scale.
- **No incentive to invest:** The benefits from additional investments in circularity are often diffuse and they cannot be easily captured by any single entity through current business models (e.g. improved design for recyclability benefits end-of-life vehicle values, not sales margins).

Production methods and technology: Production methods and technology have focused on mass producing new cars. This results in:

- **Constant output:** Regardless of demand, new car production needs to remain constant to maximize economies of scale. This requires OEMs to push new cars onto the market and reduces economic interest in innovations for extending mileage and lifetime or optimizing capacity factors.
- **Overbuilt vehicles:** Most cars are designed to meet higher performance requirements than necessary (e.g. high speeds). This reduces the potential to design for circularity (e.g. material-efficient design, modularity or use of recycled materials).
- **Underdeveloped life-cycle technologies:** Technologies for repair, remanufacturing and recycling are underdeveloped. They lack scale and standardization.

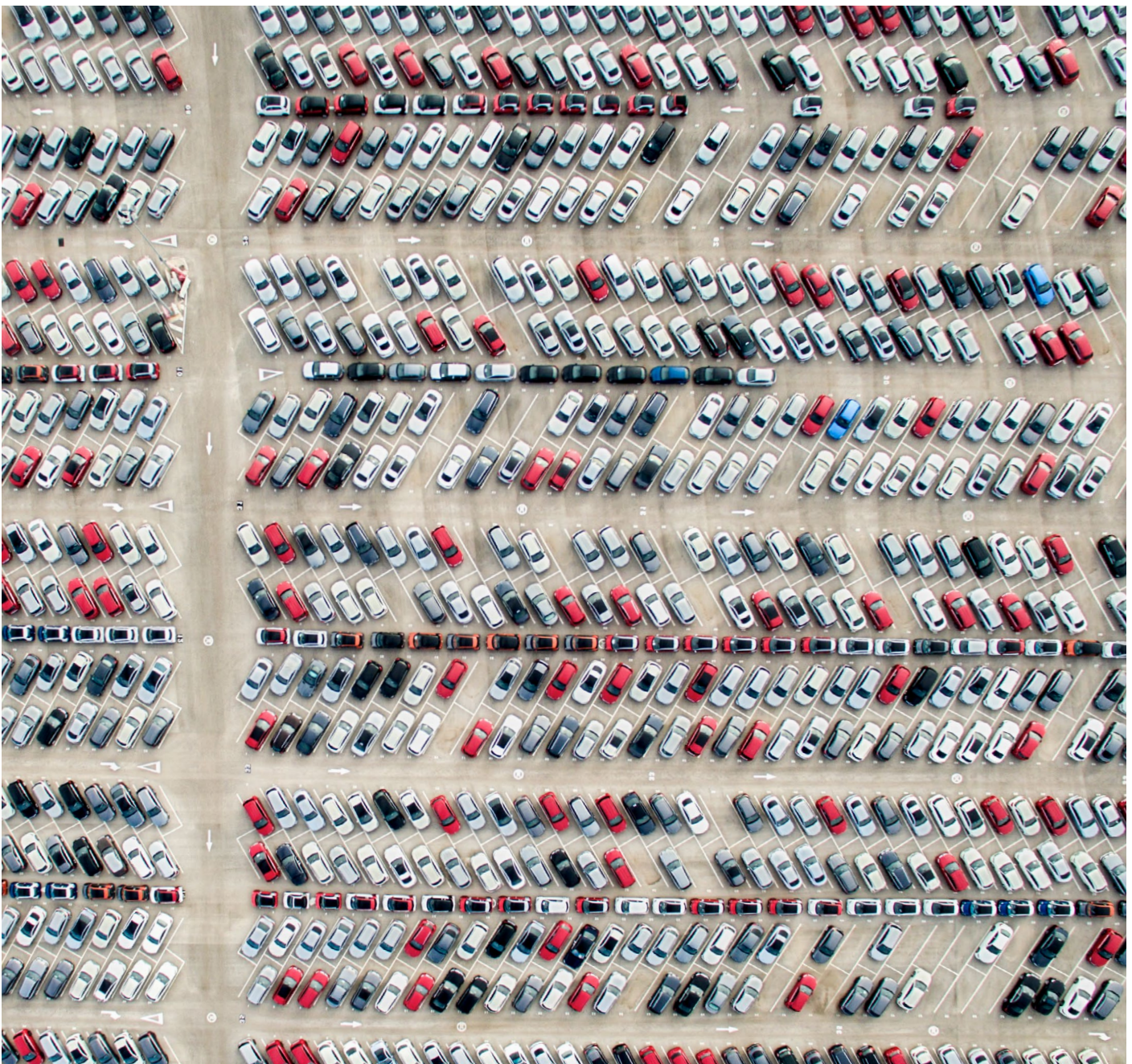
**Regulatory hurdles:** Up until now, car regulations have not directly accounted for life-cycle emissions and use of materials. Today’s regulations have led to:

- **Overload and unintended consequences:** OEMs and suppliers are forced to consider a multitude of regulations when designing and planning new models. Especially in the context of circularity, these well-intended regulations can pose an obstacle; for instance, by complicating the use of reused and remanufactured parts in the production of new vehicles.
- **Inconsistent or incomplete metrics for optimization:** Metrics used in regulation are often incomplete and neglect a variety of important considerations. For example, regulation ought to holistically regard life-cycle CO<sub>2</sub> per passenger km instead of just exhaust emissions to effectively incentivize the reduction of all CO<sub>2</sub> along a car’s life cycle.
- **Markets that discount externalities:** CO<sub>2</sub> emissions are not yet properly priced into the cost of mobility. Expanding schemes such as fleet emissions credit markets to include life-cycle carbon emissions, non-circular resource consumption and capacity factors could significantly benefit circular business models.

3

# Making sense of circularity: proposed definitions, measurements and levels of circularity

To build a circular ecosystem, the industry requires a common language.



To overcome the challenges to achieving circularity, it will be necessary for players along the automotive value chain to establish a common language related to the circular economy and relevant business models. This study proposes a taxonomy with five

levels of circularity based on two primary measures (carbon and resource efficiency) to evaluate and improve the circularity of cars. This framework is intended to serve as the basis for further discussion and refinement of ideas throughout the industry.

### 3.1 Definition of a circular car – value and efficiency

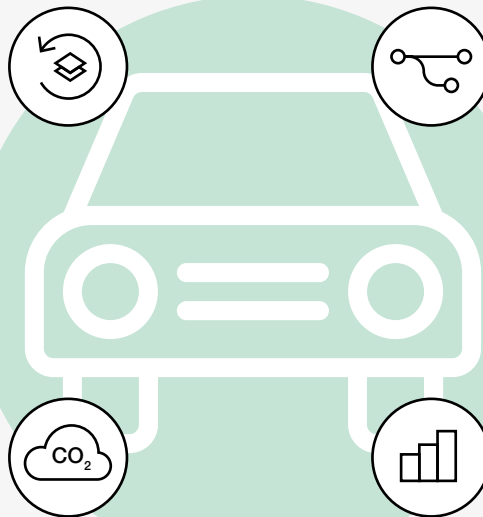
A circular car maximizes value to society, the environment and the economy while efficiently using resources and public goods. Its value is measured in terms of its ability to provide mobility, and its efficiency is measured in terms of carbon

emissions, non-circular resource consumption and use of public goods, such as space or clean air. Our definition focuses on four relevant variables: energy, materials, lifetime and use (see Figure 5).

FIGURE 5 Definition and elements of a circular car

#### A circular car maximizes the value from resource consumption

**Energy** (incl. fuel) is used efficiently (per km of movement) and renewable



**Lifetime** of the vehicle and components is optimized for resource efficiency (by emphasizing efficient design, modularity, purpose-built vehicles, reuse, repair, remanufacturing, etc.)

**Materials** are used without waste (reduced, reused, recycled and/or renewed)

**Use rates** are optimized (accounting for resiliency requirements)

Source: Accenture Strategy

To measure progress over the five levels of circularity, this study proposes carbon efficiency and resource efficiency as primary measures. Efficiency is increased by reducing carbon emissions and non-circular resource consumption, as well as by increasing the service delivered by a vehicle – mostly in the form of passenger kilometres.

**Carbon efficiency:** *life-cycle CO2 emissions per passenger kilometre*

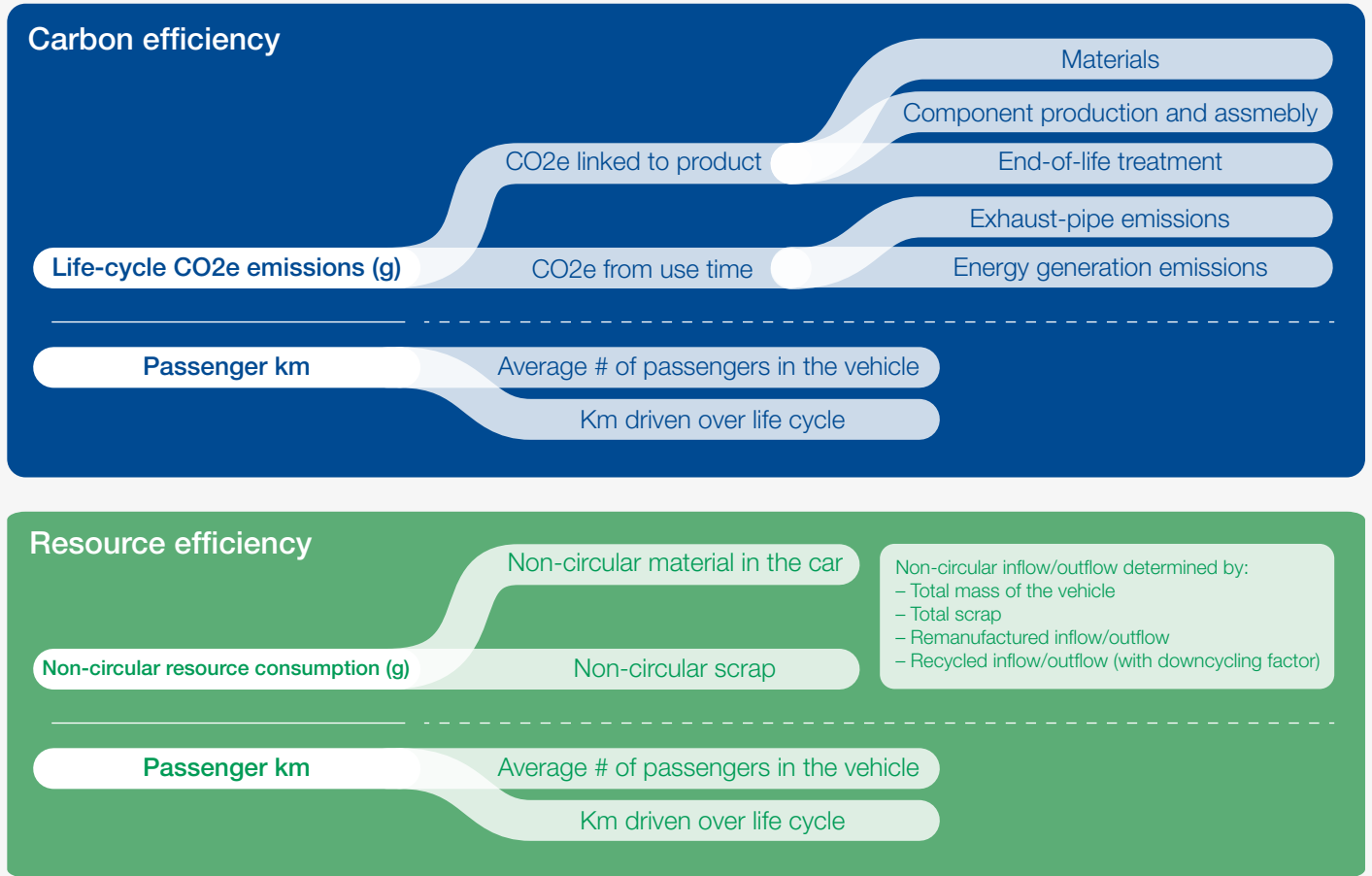
Carbon efficiency takes a holistic view of a vehicle's carbon footprint – not merely exhaust emissions or carbon intensity of materials. This methodology accounts for both: a) total life-cycle emissions, including materials, production, use phase and end of life; and b) service delivered (as opposed to kilometres driven). The entire automotive fleet's carbon efficiency should align with a 1.5°C climate scenario.

**Resource efficiency:** *non-circular resource consumption per passenger kilometre*

Resource efficiency considers the amount of non-circular resources consumed to deliver one unit of service. It takes into account the inflow of resources into a car (recycled, bio-based and renewable materials would be considered circular, while virgin materials are non-circular), as well as the outflow of resources. Circularity can be increased through strategies including reuse, remanufacturing and high-quality recycling. Improving resource efficiency often has an indirect impact on carbon efficiency as well.

There are still several open questions with regards to how to measure circularity. For instance, the difference between reuse, remanufacturing, high-quality recycling and downcycling options needs to be quantified. Resources consumed for streets, parking or fuel/energy creation could also be taken into account – though they are not addressed in this study.

Making sense of circularity







Source: Accenture Strategy. Notes: 1) including replacement components; 2) calculation analogous to non-circular material in the car

## 3.2 The five levels of circularity – a proposed taxonomy to gauge and guide progress

The five-level taxonomy proposed here for automotive circularity ranges from single-owner use and disposal (Level 0) to an aspirational goal of an automobility ecosystem that has net positive impacts (Level 5).

The levels describe vehicles that are part of an increasingly circular automobility system. Each level can be determined based on characteristics of both the product and its use. Thus both the producer and the owner of the car are responsible for achieving circularity.

FIGURE 7 Five levels of circularity in cars – overview

Levels of circularity	0	1	2	3	4	5
	<b>No circularity</b> Past	<b>Low circularity</b> Today	<b>Moderate circularity</b> 2025	<b>High circularity</b> 2030	<b>Full circularity</b> 2035	<b>Net positivity in system</b> 2040
	Classic make-use-waste mentality	Silo optimization and sales focus	Product improvement and better coordination	Aligned incentives and life-cycle optimization	Full circular value chain in as-a-service models	Ecosystem optimization
 <b>Energy</b>	Carbon-intensive fuels	Renewable energy in component production and assembly	Alternative drivetrains; low-carbon production	Carbon-neutral use phase; low-carbon materials	Carbon-neutral production and materials	Full energy grid integration of vehicles
 <b>Materials</b>	Linear value chain	Production scrap looping	Recycled content increased	High-quality recycling loops	Full “at level” recycling and transparency	Upcycling of waste
 <b>Lifetime</b>	Sales-driven model	Repair networks and used car markets	Increased reman in aftermarket	Modular design for upgradability and reman	Purpose-built vehicles	Second-life applications
 <b>Use</b>	Private ownership	Private ownership and leasing	On-demand services (cities); subscriptions	Fleets dominate: vehicles and mobility on demand	Mobility on demand in breathing fleets	Optimized mobility system

Source: Accenture Strategy – developed during project

## Level 1 circularity – today's reality

1

The value chain is mostly optimized for sales, focused on reducing product costs. Optimization is transactional and in isolation (e.g. reducing material scrap in production). Players along the value chain are not coordinated, and incentives are narrow and misaligned.



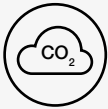
**Materials without waste**

Production scrap is recycled.



**Lifetime of components and vehicle**

A network of repair shops and second-hand markets support lifetime extension. Repairs are conducted on a per-event basis and cost case.



**Energy use**

Assembly processes are shifted to renewable energy, reducing Scope 1 carbon emissions.



**Capacity use**

Private car ownership with typical low levels of use.

Carbon efficiency < 150g CO<sub>2</sub> / pkm

Resource efficiency < 5g resources / pkm

Today's automotive system generally operates at this level of circularity. As a result, the automobility value chain is still characterized by high levels of waste and unnecessary carbon emissions.

## Level 2 circularity – the next step

2

Use-phase emissions are improved, especially through alternative drivetrains. Carbon emissions and to some extent resource consumption are reduced. Lifetime and use are enhanced through increased cross-value chain coordination.



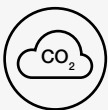
**Materials without waste**

Recycled content in materials is selectively increased. Cross-value chain collaboration to improve recycling and high-quality recyclability. End-of-life processing is also more carefully considered during the design phase.



**Lifetime of components and vehicle**

Remanufactured components are used more in the aftermarket, and reparability of vehicles is improved through design.



**Energy use**

Alternative drivetrains reduce use-phase carbon emissions with some decarbonization of materials and production.



**Capacity use**

Cars in cities are increasingly used via mobility-on-demand services, boosting use. Subscription-based solutions begin to reach rural areas.

Carbon efficiency < 100g CO<sub>2</sub> / pkm

Resource efficiency < 4g resources / pkm

The seeds for a Level 2 circularity ecosystem have already been planted. Significant portions of our automobility system will probably reach Level 2 circularity by 2025.



## Level 3 circularity – transformational shift

3

Full vehicle life cycle is optimized, driven by a significant shift towards cars-as-a-service and fleet solutions. Incentives are aligned across the value chain.



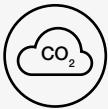
**Materials without waste**

High-quality end-of-life recycling is broadly implemented, enabled by product passports and network collaboration. Materials-as-a-service solutions align ecosystem incentives.



**Lifetime of components and vehicle**

Modular design facilitates upgradability, disassembly and remanufacturing. Remanufactured components are, as far as possible, used in new vehicle production.



**Energy use**

Use phase is mostly carbon-neutral (as a result of alternative drivetrains and renewable energy), and low-carbon materials and production technology are ubiquitous.



**Capacity use**

Subscription and on-demand services dominate, and a significant share of vehicles are operated as part of a “true fleet”. Fleet ownership increases incentives for circularity.

**Carbon efficiency < 50g CO<sub>2</sub> / pkm**

**Resource efficiency < 1.5g resources / pkm**

Level 3 represents a transformational shift away from the current automobility ownership and use model. It could start to characterize large portions of the mobility system by 2030. Individual cars and fleets could achieve this level sooner, through a shift to mobility-as-a-service (MaaS) and substantial cross-value chain alignment.

## Level 4 circularity – end-to-end revolutionary change

4

The value chain is fully circular, with no waste – meaning zero carbon emissions and zero non-circular resources consumption. Car design is closely coordinated with mobility providers and efficiency of use is optimized through fleet management. The full value chain, from design to recycling, is highly optimized.



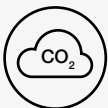
**Materials without waste**

100% of end-of-life materials are reprocessed or recycled within “same-quality”-level loops. Transparency and traceability are ensured, with standardized, global product passports.



**Lifetime of components and vehicle**

Design is highly optimized to application. A significant proportion of vehicle content consists of remanufactured components and recycled materials.



**Energy use**

Material processing and production are fully carbon-neutral, as is the use phase.



**Capacity use**

In cities, cars are part of multimodal platforms and all cars are fleet-based. Use is optimized. Cars are no longer a consumer product, but a service.

**Carbon efficiency < 20 CO<sub>2</sub> / pkm**

**Resource efficiency < 0.5g resources / pkm**

To achieve Level 4 circularity, the value chain, market structure and vehicle are transformed – indeed they are hardly recognizable. This kind of revolution could characterize automobility by 2035–2040. Some elements of Level 4 circularity are already being pioneered by certain companies and research institutes. One challenge is achieving scale and building a new value chain to support Level 4 circularity. But with proper policy support, Level 4 circular cars could start to appear within the next few years.

5

Cars help to optimize their surrounding ecosystem – improving system-level use of different transportation modes, upgrading materials and improving energy grids. This means close integration and alignment with adjacent ecosystems and convergence of business models and services. The overall system is highly integrated, optimized and sustainable.



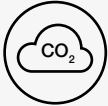
**Materials without waste**

Lower-value materials or waste streams from other industries (e.g. end-of-life wind turbines) are upcycled. Their utility is improved at end of life.



**Lifetime of components and vehicle**

Suitable components of vehicles, such as electronics, motors or batteries, are enabled for external second-life applications at scale. Improving resource efficiency for other systems (beyond passenger km).



**Energy use**

Car batteries are an integral element of the energy grid and balance loads from renewable energy generation at scale.



**Capacity use**

Cars improve use of other modes of transport, through tight integration with other mobility business models and aligned customer incentives.

**Carbon efficiency** < 0g CO<sub>2</sub> / pkm

**Resource efficiency** < 0g resources / pkm

Level 5 is an aspirational vision. Nevertheless, elements of it are already being tested and even in use today. Level 5 may be developed in parallel with Levels 2–4 – and lower levels of circularity should not be considered as necessary intermediary steps. Some electric vehicles are already used to balance the grid and soak up renewable power that would otherwise go to waste. Through inspired industry leadership and supportive policy, clever business models and the ingenuity of automotive engineers, it is possible to achieve Level 5 circularity on a shorter time horizon than many would imagine.

4

## Next stop, a mobility revolution: pathways, solutions and business models

There are four distinct but complementary strategies for increasing automotive circularity.



## 4.1 Transformation pathways – key strategies towards circularity

“Circularity requires the implementation of a set of solutions across the value chain to achieve environmental impact or to create business value.”

This report defines a number of concrete pathways for increasing circularity. These strategies have the potential to reduce carbon emissions by up to 75% and non-circular resource consumption by up to 80% per passenger kilometre for a battery electric vehicle (BEV) (hatchback) by 2030 (achieving Level 3 circularity, compared to a 2020 internal combustion engine vehicle/ICEV) (see Figure 8).<sup>6</sup>

Operationalizing a circular economy is challenging because its elements are so closely intertwined. Often it is not worth pursuing individual solutions. Circularity requires the implementation of a set of solutions across the value chain to achieve environmental impact or to create business value.

Potential transformation pathways consist of clusters of interdependent solutions. Their implementation requires alignment across the value chain. This orchestration can be driven by automotive OEMs, as well as by other players with an interest in making the full value chain circular.

Each pathway directly addresses one distinct variable related to circularity.

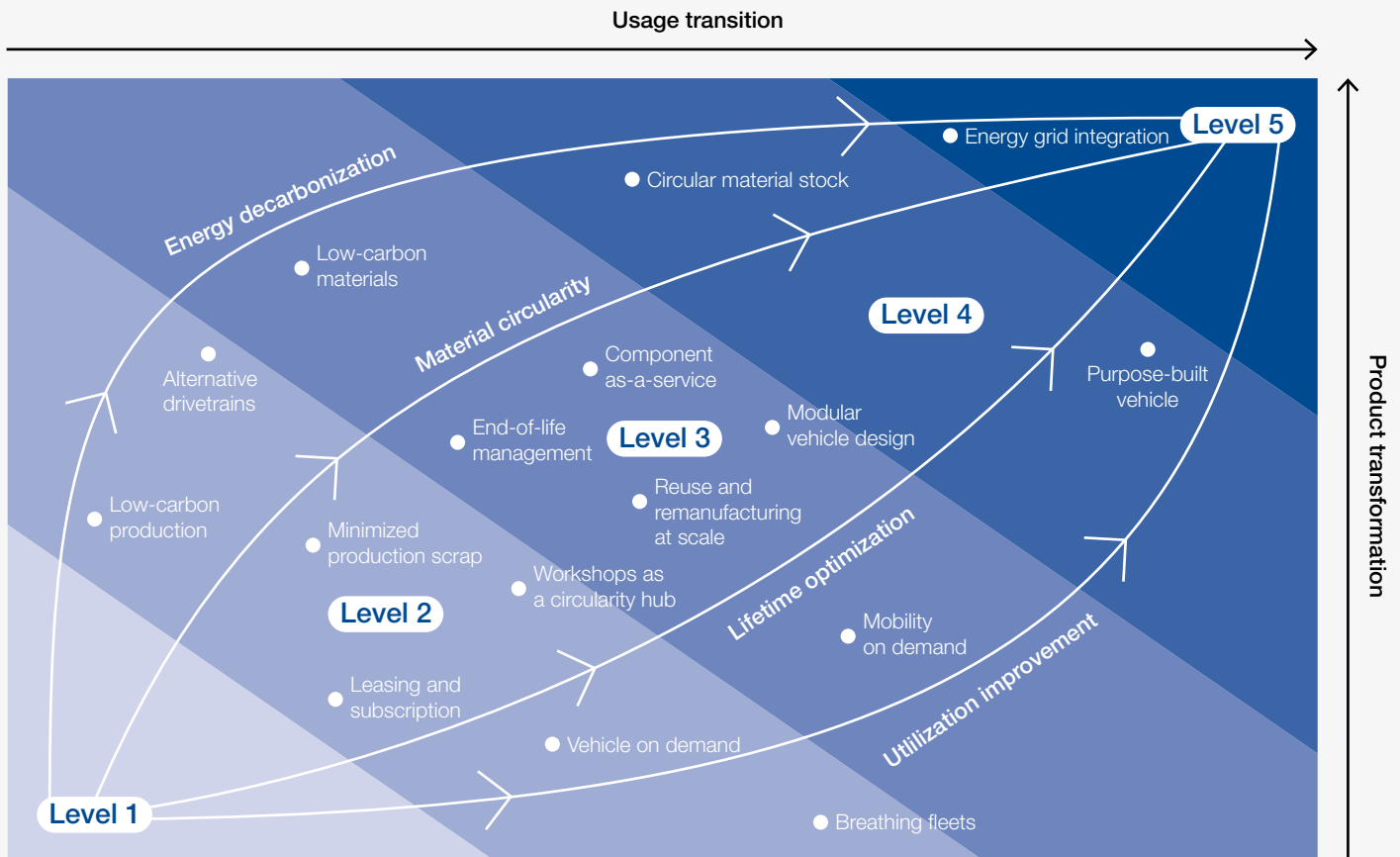
- Energy decarbonization – A complete shift to renewable energy sources in the production and use phase. This pathway is led by the OEM, enabled by suppliers (through investments in low-carbon technologies) and supported by the transformation of the energy system. Decarbonization relies on significant investments in renewable energy sources, alternative drivetrains, low-carbon production processes and the integration of vehicles with the grid. This pathway drives down carbon emissions.
- Materials circularity – Achieving 100% circular material content (recycled or renewable materials) and end-of-life processing (“same level” recycling). This process is led by OEMs and enabled by partners along the value chain (suppliers and end-of-life recyclers). It requires adapting design for recyclability, investing in materials and scrap recovery (in production and at end of life), extensive reverse logistics and advanced recycling technologies, shifting to as-a-service models for materials and components, and creating markets for and adequate stocks of all kinds of recycled materials. This pathway drives down non-circular resource consumption. It can also positively affect carbon emissions.

- Lifetime optimization – Extending vehicle and component lifetimes. This pathway can be led by OEMs as well as by aftermarket service providers. It requires close coordination and information exchange between producers and aftermarket servicers. Necessary interventions on this path include modularizing vehicle design, strengthening workshops as circularity hubs, scaling reuse and remanufacturing, and shifting to fleet-based and on-demand mobility solutions. This pathway increases per-vehicle passenger kilometres. It also helps to reduce non-circular resource consumption and carbon emissions.
- Utilization improvement – Drastically improving use of available capacity. This pathway is led by fleet operators and supported by OEMs and use-phase service partners. Purpose-built vehicles, fleets and vehicle/mobility on demand solutions enable this pathway. This pathway drives up per-vehicle passenger kilometres through improved use of seat capacity and increased operation, leading to dramatic increases in passenger kilometres delivered per vehicle per annum.

The improvements along these pathways are not always straightforward. For instance, the move away from combustion engines towards electrification has the potential to significantly reduce carbon emissions per passenger kilometre, by up to 60%.<sup>7</sup> This is dependent on decarbonization of electricity supply (with current average carbon intensity, the improvement is only 9%).<sup>8</sup> At the same time, non-circular resources consumption increases with the shift to BEV by 20%. But if we account for the expected longer lifetime of BEVs, non-circular resources consumption per passenger kilometre will decrease by 4% (BEV baseline vs. ICEV baseline – for both baselines see Figure 8).<sup>9</sup>

A balanced approach to all four pathways is important. Investing heavily in only one pathway, such as energy decarbonization, misses out on the “low hanging fruits” of other pathways and might make improvements more costly. Also, the double benefit, of improving both carbon and resources efficiency, should be appropriately considered – making utilization improvement, lifetime extension and materials circularity ultimately complementary to energy decarbonization.

FIGURE 8 | Transformation pathways and potential solutions



○ Example solutions      Positioning of circles represents high application level of solution

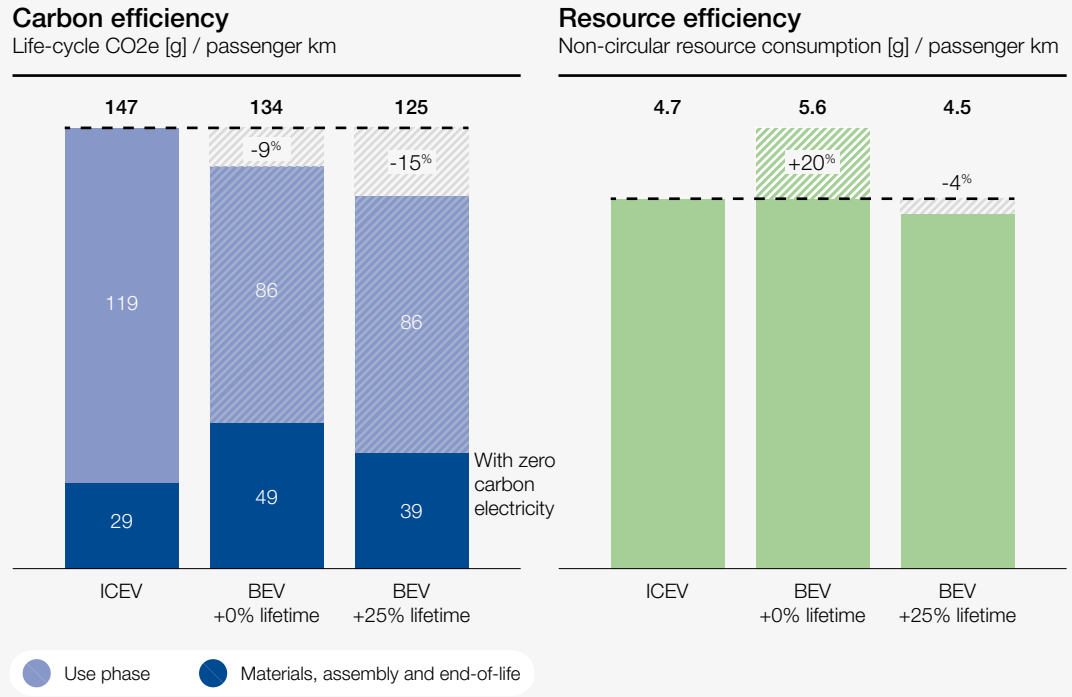
Source: Accenture Strategy analysis

FIGURE 9 | Impact of transformation pathways on carbon and resources efficiency – for a Level 3 BEV hatchback by 2030 (baseline: Level 1 ICEV hatchback in 2020)

Level 3 impacts of pathways (2030) shift from ICE hatchback (Level 1, 2020) to BEV hatchback (Level 3, 2030)	Carbon efficiency Life-cycle CO <sub>2</sub> e emissions [g] / passenger km	Resource efficiency Non-circular resource consumption [g] / pkm
Energy decarbonization	up to -60%	around 0%
Material circularity	up to -35%	up to -75%
Lifetime optimization	up to -35%	up to -70%
Utilization improvement	up to -30%	up to -50%
<b>All four pathways combined</b>	<b>up to -75%</b>	<b>up to -80%</b>

Source: Accenture Strategy analysis. Notes: ICEV hatchback (Level 1) with 1.70t weight (incl. repair components), 0.90t steel, 0.15t aluminium, 0.29t plastics, 200,000 life-cycle km and average occupancy of 1.5; BEV hatchback (Level 1) with 1.90t weight (including repair components), 0.70t steel, 0.19t aluminium, 0.32t plastics, 0.32t EV battery, 250,000 life-cycle km and average occupancy of 1.5

FIGURE 10 | Level 1 baseline carbon and resources efficiency for ICEV and BEV, both hatchback, in 2020



**Source:** Accenture Strategy analysis. Notes: ICEV hatchback (Level 1) with 1.70t weight (including repair components), 0.90t steel, 0.15t aluminium, 0.29t plastics, 200,000 life-cycle km and average occupancy of 1.5; BEV hatchback (Level 1) with 1.90t weight (including repair components), 0.70t steel, 0.19t aluminium, 0.32t plastics, 0.32t EV battery, 200,000/250,000 life-cycle km and average occupancy of 1.5; carbon intensity of electricity based on current German energy mix



## 4.2 Identified solutions and enablers – concrete actions for circularity

This report highlights 16 of the most promising solutions for circularity. The following table provides an overview of these solutions and how they fit into the overarching levels of circularity framework. Potential ranges for the carbon and resource efficiency improvements are also integrated. These ranges are, for the moment, indicative and intended to serve as a basis for

future discussion and exploration. (Table 1 provides a description of the 16 highlighted solutions.)

Our research also identified some required enablers for these solutions to achieve their full impact. Together with the aforementioned solutions, they help drive higher levels of circularity. An overview of these enablers can be found in Table 5 in the

TABLE 1 Overview of the most promising solutions for circularity

	Solution	Description
1	<b>Low-carbon materials</b>	Recyclers and material suppliers deploy energy-efficiency measures and scale the use of renewable energy in the recycling of automotive materials. Where virgin materials cannot be replaced by recycled materials, new technologies are deployed to decarbonize energy-intensive processes in virgin material production.
2	<b>Low-carbon production</b>	OEMs and component suppliers deploy energy-efficiency measures and scale the use of renewable energy in component production and vehicle assembly.
3	<b>Minimized production scrap</b>	OEMs and component suppliers collaborate with material suppliers to reduce material scrap in production. Processes to optimize recycling rates and quality of unavoidable production scrap are established.
4	<b>Modular vehicle design</b>	OEMs and component suppliers integrate knowledge from repair and recycling experts in the product development process. Cars are designed based on a modular concept that simplifies repair, disassembly and remanufacturing, and allows for refurbishment, component upgrades and purpose adjustments.
5	<b>End-of-life management</b>	OEMs, suppliers and recyclers work together to increase efficiency of disassembly, sorting and reverse logistics processes and enable recovery at the highest possible value. Components and materials are channelled towards specialized facilities (e.g. remanufacturing plant, recycling facility).
6	<b>Circular material stock</b>	A stock of material with fixed size is used and reused for cars. All materials are 100% recyclable (“same level recycling”). Waste (including downcycling) is reduced and materials are recycled at the highest level by specialized recyclers. A starting point is to establish circular stocks for selected materials (e.g. aluminium). Material-as-a-service enables closed-loop recycling of selected materials.
7	<b>Component-as-a-service</b>	Critical components – generally those with higher value – are sold as a service, rather than as a product by OEMs. Batteries are an example of a high-value component with the potential for an extended life in automotive and non-automotive applications and closed-loop recycling at end of life. Probably, the focus will be on business to business (B2B) models with the battery manufacturer providing the battery to the OEM in a full-service model. The OEM sells the car including battery to the consumer and provides the guarantee for the service. Alternatively, OEMs could sell cars without batteries, allowing for aftermarket providers to provide and manage battery stocks.

Table 1 continues on the next page

	<b>Solution</b>	<b>Description</b>
8	<b>Reuse and remanufacturing at scale</b>	OEMs, component suppliers (original equipment and independent aftermarket) and workshops push for a vivid reuse and remanufacturing market. Necessary technologies are improved, processes automated and large-scale facilities established to increase cost-competitiveness. Reused, remanufactured or retreaded components are the default option in the aftermarket. Remanufactured components are introduced in new car production.
9	<b>Workshops as a circularity hub</b>	Workshops take a central role in optimizing the life cycle of cars and components. Workshops increase cost efficiency, optimize maintenance services based on predictive analytics and use remanufactured parts as the default option.
10	<b>Purpose-built vehicle</b>	OEMs provide purpose-built/purpose-adjusted vehicles to mobility providers that enable improved capacity use and optimized vehicle lifetime. OEMs assess use phase requirements and employ the insights from this to provide vehicle variations that better align vehicles with their purpose, especially in terms of size, repairability and durability.
11	<b>Alternative drivetrain</b>	OEMs scale alternative drivetrain solutions with substantially lower – ultimately zero – exhaust emissions to reduce use phase emissions. Drivetrain optimization considers the full market picture – i.e. energy use of the full vehicle portfolio on the streets and available supply of green energy (e.g. renewable electricity, green hydrogen).
12	<b>Energy grid integration</b>	OEMs scale smart charging and vehicle-to-grid (V2G) technology for battery-electric vehicles, plug-in hybrids and fuel cell-electric vehicles. Emissions from electricity generation in electric mobility (well-to-tank) are reduced and cars help to balance loads in the energy grid. Fleet management companies (mobility services, financial services) make use of this integration for their fleets.
13	<b>Leasing and subscription</b>	OEMs and fleet management companies (mobility services, financial services) increase their offerings for fleet-based private mobility. New forms of ownership align incentives for value chain players to the principles of a circular economy. The most prominent models in this area to date are (lifetime-) leasing and subscription-based ownership, which have the potential to transform the automotive market at scale to as-a-service models.
14	<b>Vehicle on demand</b>	Mobility service providers increase capacity use of vehicles by offering vehicles on demand to customers. A variety of on-demand solutions are already on the market, including car rental, car sharing, P2P sharing and micro mobility. The consolidation of these business models into holistic vehicle on-demand offerings that integrate different rental durations or vehicle types enables scaling of these models.
15	<b>Mobility on demand</b>	Mobility service providers increase capacity use through mobility-on-demand solutions. To date, these business models include ride hailing, ride sharing and demand-responsive transport/ride pooling. Ride pooling in particular has the potential to optimize capacity use of the vehicle by increasing the life-cycle kilometre per vehicle as well as the number of average passengers.
16	<b>Breathing fleets</b>	Fleet management companies increase capacity use of their fleets by sharing the fleet across multiple service offerings. Depending on demand cycles (e.g. weekends vs. workdays) and age/quality requirements, cars are shifted from one service offering to another, thereby achieving higher-capacity use for each car over its life cycle.

Source: Accenture Strategy analysis, based on interviews and research



## 4.3 Case studies

### CASE STUDY

#### Swapping platform and battery-as-a-service – Ample and NIO

Batteries enable the entire low-carbon energy system, including electric cars. At the same time, they are expensive and carbon-intensive to produce. Accordingly, the trend of ever-increasing electric vehicle (EV) ranges is not necessarily environmentally desirable and increases EV cost unnecessarily. Viewing batteries through a component-as-a-service lens and managing them via fleets allows for a more economically rational, inclusive and environmentally friendly approach to electrification.

A major enabler of this system is battery swapping: where consumers no longer own their battery, but pay for electricity and battery use by subscription or the mile. This approach is being widely adopted in China by companies including NIO, which has just completed its 1 millionth battery swap in a consumer vehicle.

Another example is Ample, a San Francisco-based start-up that has invented a rapidly deployable

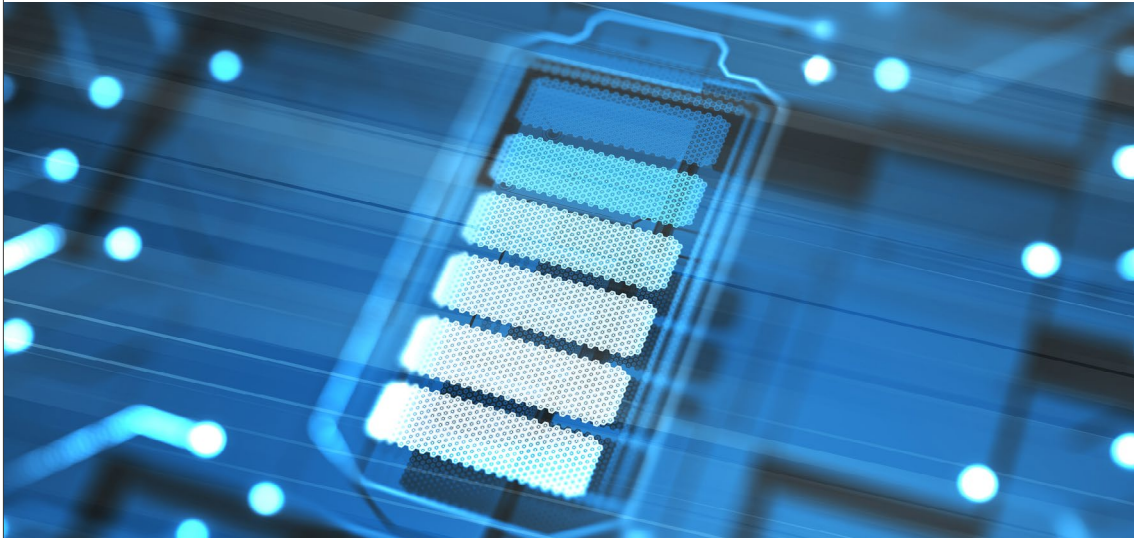
platform that delivers a full charge to any electric car in minutes through battery swapping. Ample uses autonomous robotics and smart-battery technology to swap batteries. Its “pods” filled with batteries can absorb energy from the grid when it is cheap or particularly low-carbon, and dispense it faster than much more costly fast-charge systems. The approach also reduces consumer risk by eliminating battery ownership and potentially enables the consumer to use shorter-range batteries for urban commuting while accessing long-range batteries for extended trips – thus significantly reducing the total number of kilowatt hours required to run a fleet. Uber recently revealed that it is closely collaborating with Ample, using Ample’s battery-swapping stations as part of Uber’s 2040 zero-emission fleet strategy. Ample is collaborating with asset financiers and fleets to optimize its battery-as-a-service model. The company emphasizes the importance of designing batteries for second-life use and high recyclability.



**Green workshop: use extension and recycling one-stop shop – Nexus**

Nexus Automotive International is an international alliance of car and truck parts suppliers and distributors in the automotive aftermarket. Nexus functions as a platform for its members to organize bulk purchases of aftermarket components and supports projects in the areas of industry innovation and training. It is developing a concept it calls the “green workshop” – a new, eco-responsible way to approach car maintenance and support sustainable development for entrepreneurs in the aftermarket.

The green workshop could play a central role in a circular automotive industry by optimizing the life cycle of cars, components and materials. Nexus is planning to develop a digital ecosystem to connect vehicle owners with green workshop members and suppliers, in order to support innovative approaches to predictive maintenance, to provide special offers and services for remanufactured parts and to support collaboration and knowledge exchange in the areas of renewable energy procurement or end-of-life collection.



**Factory transformation – Renault**

As part of a major restructuring programme, Renault has announced that it plans to phase out new vehicle production at its oldest manufacturing plant in Flins near Paris. Instead, the factory will be transformed into a “circularity ecosystem”. It will focus on manufacturing prototypes, reconditioning old vehicles and remanufacturing used parts – including EV batteries.

In 2020, about 2,600 employees worked in Flins. The transformation strategy for the plant will enable Renault to protect the majority of jobs while reducing capacity, costs and pivoting towards increased circularity of its products and services.



5

# Raising ambitions for a circular cars agenda

It is time for automotive players to embrace a systemic approach to circularity.



The five-level circularity taxonomy is explicitly directed at addressing the exigencies of climate change and economic inequality. This will require a reimagining of the system that is both profound and should be inspiring. Members of the automobility ecosystem need to raise their ambition and, with the support of policy-makers, build a new automobility ecosystem that seeks not merely to do less harm but rather to enable a bright new world of possibilities.

**Some of the main actions required to do this include:**

- Developing and aligning common measures regarding circularity in the automotive value chain
- Testing and developing potential solutions in cross-industry initiatives and at scale

- Developing data-sharing standards across the value chain

**Part of realizing this vision also includes:**

- Agreeing on concrete thresholds for levels of circularity
- Providing data basis and methodology to evaluate the degree of recovery of different circular loops such as reuse, repair, remanufacture and recycle
- Developing a life-cycle “car governance framework” that helps to orchestrate the actions taken by players and enables optimal application levels of different solutions across the life cycle

**Key recommendations of this report:**

**For industry and value-chain ecosystem:**

- Develop strategies to enable increased data transparency and information-sharing with other players along the automobility supply chain up to, and perhaps including, joint standards
- Carefully examine which aspects of your business can be transitioned to “as-a-service” business models and what regulatory/systemic enablers are necessary
- Design vehicles with full life-cycle value optimization in mind (including end-of-life disposal). Consider especially what role modularity can play
- Explore coordinated investments in breakthrough technologies: materials and energy decarbonization; advanced recycling technology; flexible production technology (e.g. 3D printing); alternative drivetrains; product passports; and mobility platforms
- Consider the impacts of autonomous driving post 2030

**For policy-makers:**

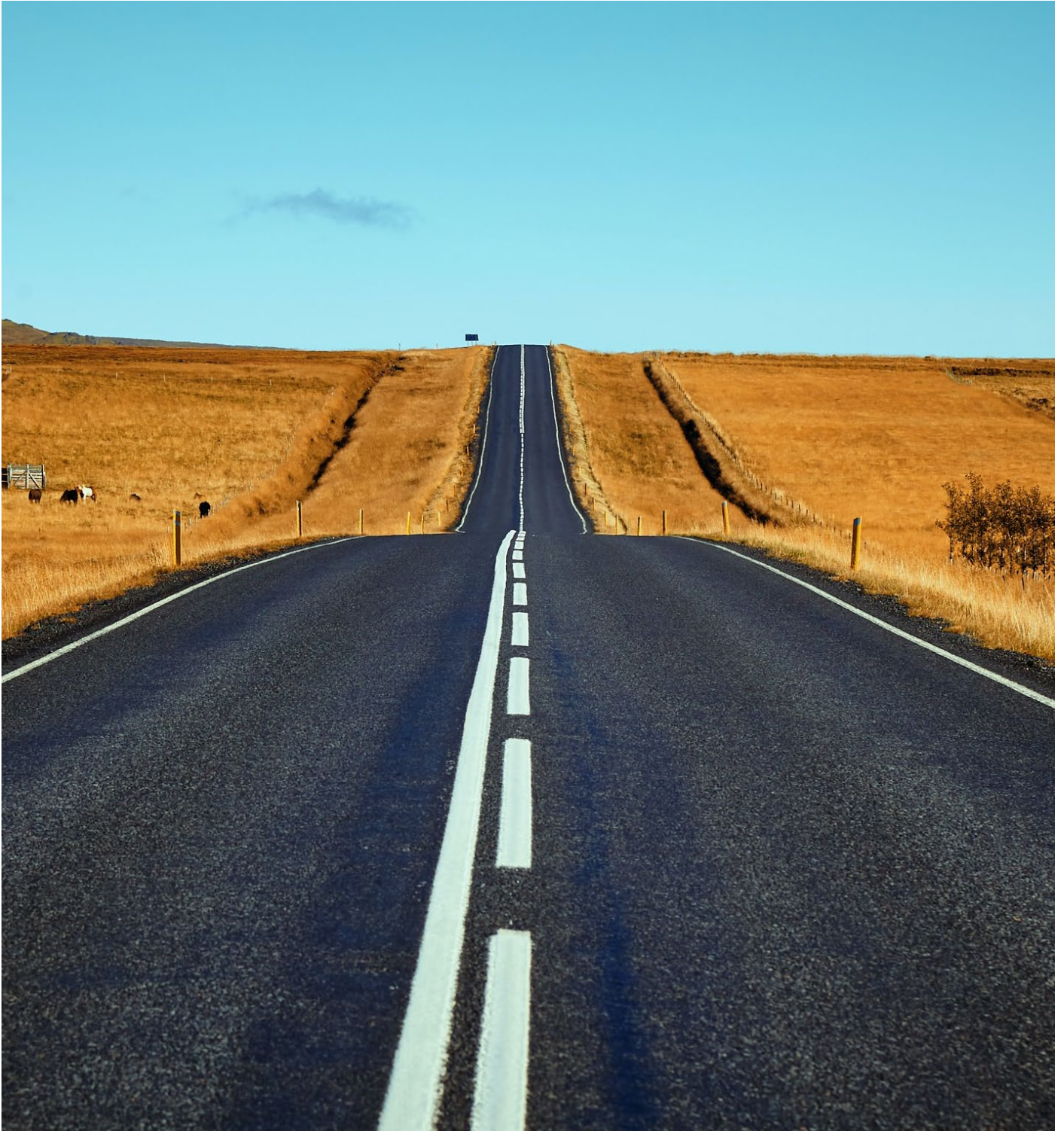
- Prioritize the greatest opportunities for decarbonization first while considering economic, social and other environmental trade-offs
- Proactively enable data transparency and sharing efforts throughout the automobility value-chain actors, as well as among vehicles and fleets

- Consider two pathways for material recovery (in reuse, remanufacturing, recycling):
  - An ICE pathway aimed at efficiently decommissioning vehicles
  - An EV pathway aimed at life-extension, second-life battery use and finally recycling
- In order to accelerate technological development and achieve scale, enable industry consortium efforts to invest in: materials and energy decarbonization; advanced recycling technology; flexible production technology (e.g. 3D printing); alternative drivetrains; product passports; and mobility platform
- Re-examine the underlying premise of anti-trust regulation and how it fits into a world of scaling clean technologies, as this task will require immense collaboration across the supply chain and between competitors
- Establish carbon pricing schemes that also aim to prevent carbon leakage at a global scale to properly price in the costs of carbon emissions to mobility and traffic
- Incentivize leasing and subscription services and vehicle on-demand services

6

## Next steps for the Circular Car Initiative

Achieving circularity is not a one-time effort – it requires intensive collaboration from the automotive industry over the coming years and decades.



“The Circular Car Initiative aims to lay the foundation for concrete actions and the further establishment of relevant methodology to realize the shared vision of a circular car industry.”

The Circular Car Initiative is set out as a multi-year initiative for private and public stakeholder collaboration.

Throughout 2020, the initiative’s 40-plus member companies helped to establish a common basis for understanding circularity in the automotive sector through half a dozen workshops and more than 50 in-depth interviews. During the interviews and workshops, it became apparent that there is a great interest in working on concrete pilot projects in the future to overcome barriers and restrictions that currently prevent the industry from operating in a more circular way.

For 2021, the initiative will focus on three key areas:

1. Operationalization of Accenture’s circularity taxonomy, transformation pathways and solutions

The proposed five-level taxonomy, four transformation pathways and 16 solutions for circular cars need to be detailed and operationalized.

2. Establishment of an “Automotive Circularity Board”

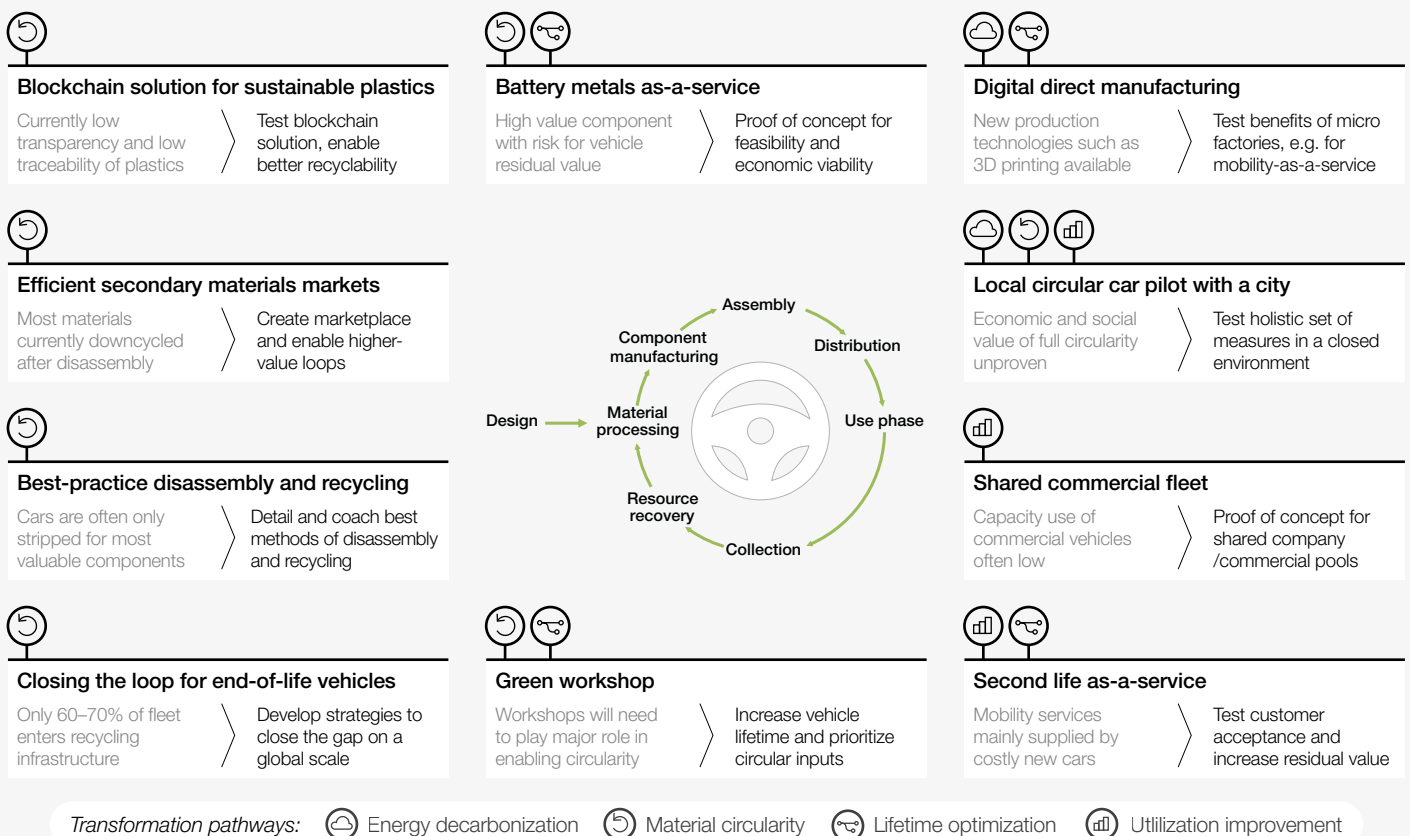
With the foundation of an “Automotive Circularity Board”, the initiative will elevate automotive circularity to the C-level agenda, channel investment needs and form a common voice with regard to third-party institutions.

3. Running of a pilot project programme

Pilot projects will aim to achieve proofs of concept for specific solutions as pieces of the puzzle. Throughout the workshops and interviews in 2020, a set of around 20 potential pilot projects were identified. Some of these pilot project ideas will be taken forward by member companies throughout 2021 and supported by the Circular Cars Initiative. Figure 11 provides a first view on these pilot project ideas.

The Circular Car Initiative aims to lay the foundation for concrete action and the further establishment of relevant methodology to realize a shared vision for a circular automotive industry.

FIGURE 11 Overview of pilot project ideas (non-exhaustive)



Source: Input collected during workshops and interviews

## Green workshop



**Solution:**

- Workshops as a circularity hub



**Transformation pathways:**

- Materials circularity
- Lifetime optimization



**Impact on measures:**

- Decrease non-circular materials in the car
- Decrease CO2 from materials
- Increase life-cycle km

**Pilot objective**

- The objective is to pilot how workshops can serve as a circularity hub, aiming for maximum vehicle lifetime and prioritizing circular inputs over new parts

**Benefits**

- Environmental benefit from longer lifetime of cars and from increased use of remanufactured components

**Barriers**

- Need for advanced technology for automization and predictive maintenance
- Upskilling of workers with respect to battery electric vehicles

**Enablers and synergies**

- Digital ecosystem that connects vehicle owners through a green workshop network to the broader mobility community

**Owners and contributors of pilot**

- Owner: NEXUS, potentially further partners
- Contributors: supplier, OEMs, aftermarket, fleet operators

**Next steps**

1. Define the characteristics of a green workshop
2. Transform one workshop into a green workshop and document the transformation as an example of best practice
3. Understand customer acceptance of the green workshop concept
4. Discuss how to scale the number of green workshops

# Appendix: Solutions and pathways

## The solutions and pathways can be distilled into five business-model archetypes

Five circular-economy business-model archetypes offer a comprehensive view of how a fully circular value chain in the automotive sector might look (see Table 2).

The archetypes are:

**Circular inputs:** using renewable, recycled, recyclable materials, as well as renewable energy/fuel.

**Product-as-a-service, including:**

**Cars-as-a-service:** such as corporate and consumer leasing, car rental and sharing, as well as ride hailing and sharing.






**Components-as-a-service:** component leasing or pay-per-use models, as well as materials-as-a-service.

**Sharing platforms:** peer-to-peer car sharing, as well as peer-to-peer ride hailing or sharing.

**Product use extension:** through maintenance, refurbishment or used car sales; at the component level resale and reuse, and remanufacturing/repurposing.

**Resource recovery:** closed-loop recycling of manufacturing scrap and end-of-life vehicles, but also open-loop recycling or even energy recovery.

TABLE 2 Archetypes, business models, solutions/enablers and pathways

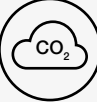



Business model archetypes	 Circular inputs	 Product-as-a-service	 Sharing platforms	 Product use extension	 Resource recovery
<b>Solutions</b>	<ul style="list-style-type: none"> <li>– Low-carbon material</li> <li>– Low-carbon production</li> <li>– Circular material stock</li> <li>– Alternative drivetrain</li> <li>– Energy grid integration</li> </ul>	<ul style="list-style-type: none"> <li>– Component-as-a-service</li> <li>– Leasing and subscription</li> <li>– Vehicle on demand</li> <li>– Mobility on demand</li> <li>– Breathing fleets</li> </ul>	<ul style="list-style-type: none"> <li>– Energy grid integration</li> <li>– Vehicle on demand</li> <li>– Mobility on demand</li> <li>– Breathing fleets</li> </ul>	<ul style="list-style-type: none"> <li>– Modular vehicle design</li> <li>– End-of-life logistics</li> <li>– Reuse and remanufacturing at scale</li> <li>– Workshops as a circularity hub</li> <li>– Purpose-built vehicle</li> </ul>	<ul style="list-style-type: none"> <li>– Minimized production scrap</li> <li>– End-of-life logistics</li> <li>– Circular material stock</li> </ul>
<b>Enablers</b>	<ul style="list-style-type: none"> <li>– Recoverable and recyclable materials</li> <li>– Product passport</li> <li>– Advanced recycling technology and infrastructure</li> <li>– Market maker for circular inputs</li> <li>– Renewable energy at scale</li> </ul>	<ul style="list-style-type: none"> <li>– Autonomous driving</li> <li>– Mobility platform</li> </ul>	<ul style="list-style-type: none"> <li>– Autonomous driving</li> <li>– Mobility platform</li> </ul>	<ul style="list-style-type: none"> <li>– Product passport</li> <li>– Balanced production capacity</li> </ul>	<ul style="list-style-type: none"> <li>– Recoverable and recyclable materials</li> <li>– Product passport</li> <li>– Advanced recycling technology and infrastructure</li> <li>– Market maker for circular inputs</li> </ul>
<b>Transformation pathways</b>	<ul style="list-style-type: none"> <li>– Energy decarbonization</li> <li>– Materials circularity</li> </ul>	<ul style="list-style-type: none"> <li>– Utilization improvement</li> <li>– Materials circularity</li> </ul>	<ul style="list-style-type: none"> <li>– Utilization improvement</li> </ul>	<ul style="list-style-type: none"> <li>– Lifetime optimization</li> </ul>	<ul style="list-style-type: none"> <li>– Materials circularity</li> </ul>

Source: Accenture Strategy



## Details on solutions and enablers:

TABLE 3 Overview of solutions and enablers, matched to pathways and levels

Levels of circularity	1	2	3	4	5
 <b>Energy decarbonization</b>		<ul style="list-style-type: none"> <li>– Low carbon production</li> <li>– Alternative drivetrain</li> </ul>	<ul style="list-style-type: none"> <li>– Low-carbon materials</li> </ul>	<ul style="list-style-type: none"> <li>– <b>Renewable energy at scale</b></li> </ul>	<ul style="list-style-type: none"> <li>– Energy grid integration</li> </ul>
 <b>Materials circulation</b>		<ul style="list-style-type: none"> <li>– Minimized production scrap</li> <li>– Workshops as a circularity hub</li> <li>– Leasing and subscription</li> <li>– Vehicle on demand</li> <li>– <b>Recoverable and recyclable materials</b></li> <li>– <b>Advanced recycling technology and infrastructure</b></li> </ul>	<ul style="list-style-type: none"> <li>– Component-as-a-service</li> <li>– End-of-life logistics</li> </ul>	<ul style="list-style-type: none"> <li>– Circular material stock</li> <li>– <b>Product passport</b></li> <li>– <b>Market maker for circular inputs</b></li> </ul>	
 <b>Lifetime optimization</b>		<ul style="list-style-type: none"> <li>– Workshops as a circularity hub</li> <li>– Leasing and subscription</li> <li>– Vehicle on demand</li> </ul>	<ul style="list-style-type: none"> <li>– Reuse and remanufacturing at scale</li> <li>– End-of-life logistics</li> <li>– Modular vehicle design</li> </ul>	<ul style="list-style-type: none"> <li>– Purpose-built vehicle</li> <li>– <b>Market maker for circular inputs</b></li> <li>– <b>Balanced production capacity: new vs. reman</b></li> </ul>	
 <b>Utilization improvement</b>		<ul style="list-style-type: none"> <li>– Vehicle on demand</li> </ul>	<ul style="list-style-type: none"> <li>– Mobility on demand</li> </ul>	<ul style="list-style-type: none"> <li>– Breathing fleets</li> <li>– Purpose-built vehicle</li> <li>– <b>Mobility platforms</b></li> <li>– <b>Balanced production capacity: small vs. large-scale</b></li> </ul>	

Normal text: Solution; **Bold text: Enabler**

Source: Accenture Strategy analysis, based on interviews and research

TABLE 4 Descriptions of selected solutions

	<b>Solution</b>	<b>Description</b>	<b>Impact description</b>
1	<p><b>Low-carbon materials</b></p> <p><b>Business model</b> – Circular inputs</p> <p><b>Definition element</b> – Energy use</p> <p><b>Measure</b> – Carbon efficiency: CO2 from materials</p>	<p>Recyclers and material suppliers deploy energy efficiency measures and scale the use of renewable energy in the recycling of automotive materials. Where virgin materials cannot be replaced by recycled materials, new technologies are deployed to decarbonize energy-intensive processes in virgin material production.</p>	<p>This solution focuses on decarbonizing energy use in material recycling as well as in virgin material production (where recycling does not represent a feasible solution). This can help lower CO2 from materials. In fact, this solution will eliminate the CO2 that is not abated by the solution “circular material stock”. It is assumed that by combining this solution with the solution “circular material stock”, 100% of CO2 from materials can be abated.</p>
2	<p><b>Low-carbon production</b></p> <p><b>Business model</b> – Circular inputs</p> <p><b>Definition element</b> – Energy use</p> <p><b>Measure</b> – Carbon efficiency: CO2 from component production and assembly</p>	<p>OEMs and component suppliers deploy energy efficiency measures and scale the use of renewable energy in component production and vehicle assembly.</p>	<p>This solution focuses on decarbonizing energy use in component production and assembly. CO2 emissions from production and assembly that are caused by the current energy mix are eliminated.</p>
3	<p><b>Minimized production scrap</b></p> <p><b>Business model</b> – Resource recovery</p> <p><b>Definition element</b> – Materials</p> <p><b>Measure</b> – Carbon efficiency: CO2 from materials – Resource efficiency: Total scrap, % non-circular outflow</p>	<p>OEMs and component suppliers collaborate with material suppliers to reduce material scrap in production. Processes to optimize recycling rates and quality of unavoidable production scrap are established.</p>	<p>This solution focuses on minimizing production scrap and increasing recycling rates where production scrap cannot be avoided. The reduction of total production scrap leads to a reduction in CO2 from materials. Improved recycling of production scrap reduces the amount of non-circular outflows per car.</p>
4	<p><b>Modular vehicle design</b></p> <p><b>Business model</b> – Product-use extension</p> <p><b>Definition element</b> – Materials</p> <p><b>Measure</b> – Carbon and resource efficiency: km driven over life cycle  – Carbon efficiency: CO2 from materials, CO2 from component production and assembly, CO2 from end-of life treatment – Resource efficiency: total material in the car, total scrap</p>	<p>OEMs and component suppliers integrate knowledge from repair and recycling experts in the product development process. Cars are designed based on a modular concept that simplifies repair, disassembly and remanufacturing, and allows for refurbishment, component upgrades and purpose adjustments.</p>	<p>The modular design achieved by this solution makes repair, maintenance and upgrades of outdated parts or systems economically viable, thereby enabling longer use time (measured in life-cycle km). Total material use and CO2 from material increases slightly due to more replacement parts used over the life cycle.</p>

Table 4 continues on the next page

	<b>Solution</b>	<b>Description</b>	<b>Impact description</b>
5	<p><b>End-of-life management</b></p> <p><b>Business model</b></p> <ul style="list-style-type: none"> <li>– Resource recovery</li> <li>– Product use extension</li> </ul> <p><b>Definition element</b></p> <ul style="list-style-type: none"> <li>– Materials</li> <li>– Lifetime</li> </ul> <p><b>Measure</b></p> <ul style="list-style-type: none"> <li>– Carbon efficiency: CO2 from end-of-life treatment</li> <li>– Resource efficiency: % non-circular outflow</li> </ul>	<p>OEMs, suppliers and recyclers work together to increase efficiency of disassembly, sorting and reverse logistics processes and enable recovery at the highest possible value. Components and materials are channelled towards specialized facilities (e.g. remanufacturing plant, recycling facility).</p>	<p>This solution improves circularity of outflows from end-of-life vehicles. Non-circular car outflows are reduced, resulting in lower CO2 from end-of-life treatment.</p>
6	<p><b>Circular material stock</b></p> <p><b>Business model</b></p> <ul style="list-style-type: none"> <li>– Product-as-a-service</li> <li>– (Circular inputs)</li> <li>– (Resource recovery)</li> </ul> <p><b>Definition element</b></p> <ul style="list-style-type: none"> <li>– Materials</li> </ul> <p><b>Measure</b></p> <ul style="list-style-type: none"> <li>– Carbon efficiency: CO2 from materials</li> <li>– Resource efficiency: % non-circular inflow, % non-circular outflow</li> </ul>	<p>A stock of material with fixed size is used and reused for cars. All materials are 100% recyclable (“same value loop recycling”). Waste (including downcycling) is reduced and materials are recycled at the highest level by specialized recyclers. A starting point is to establish circular stocks for selected materials (e.g. aluminium). Materials-as-a-service enables closed-loop recycling of selected materials.</p>	<p>In the assumed best-case scenario of this solution, 100% of materials in a car are circular. This means that non-circular car inflows and non-circular car outflows are eliminated. CO2 from materials is strongly reduced to lower carbon intensity of recycled materials. CO2 from end-of-life treatment is reduced.</p>
7	<p><b>Component-as-a-service</b></p> <p><b>Business model</b></p> <ul style="list-style-type: none"> <li>– Product-as-a-service</li> <li>– (Circular inputs)</li> <li>– (Resource recovery)</li> </ul> <p><b>Definition element</b></p> <ul style="list-style-type: none"> <li>– Materials</li> <li>– Lifetime</li> </ul> <p><b>Measure</b></p> <ul style="list-style-type: none"> <li>– Carbon efficiency: CO2 from materials</li> <li>– Resource efficiency: % non-circular inflow, % non-circular outflow</li> </ul>	<p>Critical components – generally those with higher value – are sold as a service, rather than as a product by OEMs. Batteries are an example of a high-value component with the potential for an extended life in automotive and non-automotive applications and closed-loop recycling at end of life. Probably, the focus will be on business-to-business (B2B) models, with the battery manufacturer providing the battery to the OEM in a full-service model. The OEM sells the car including battery to the consumer and provides the guarantee for the service. Alternatively, OEMs could sell cars without batteries, allowing aftermarket providers to supply and manage battery stocks.</p>	<p>The solution modelling focuses on battery-as-a-service as a main example. In the assumed best-case scenario, 100% of battery materials are circular. Non-circular car inflows and non-circular car outflows are reduced respectively. CO2 from materials is reduced to lower carbon intensity of battery materials. CO2 from end-of-life treatment is reduced.</p>
8	<p><b>Reuse and remanufacturing at scale</b></p> <p><b>Business model</b></p> <ul style="list-style-type: none"> <li>– Product use extension</li> </ul> <p><b>Definition element</b></p> <ul style="list-style-type: none"> <li>– Lifetime</li> </ul> <p><b>Measure</b></p> <ul style="list-style-type: none"> <li>– Carbon efficiency: CO2 from materials</li> <li>– Resource efficiency: % non-circular inflow, % non-circular outflow</li> </ul>	<p>OEMs, component suppliers (original equipment and independent aftermarket) and workshops push for a vibrant reuse and remanufacturing market. Necessary technologies are improved, processes automated and large-scale facilities established to increase cost-competitiveness. Reused, remanufactured or retreaded components are the default option in the aftermarket. Remanufactured components are introduced in new car production.</p>	<p>This solution focuses on scaling remanufactured inflows and outflows. As reman shares of inflows and outflows increase, non-circular car inflows and non-circular car outflows are reduced respectively. CO2 from materials is reduced due to lower carbon intensity of reman components.</p>

*Table 4 continues on the next page*

	<b>Solution</b>	<b>Description</b>	<b>Impact description</b>
9	<p><b>Workshops as a circularity hub</b></p> <p><b>Business model</b> – Product use extension</p> <p><b>Definition element</b> – Lifetime</p> <p><b>Measure</b> – Carbon and resource efficiency: km driven over life cycle – Carbon efficiency: CO2 from materials Resource efficiency: % non-circular inflow</p>	<p>Workshops take a central role in optimizing the life cycle of cars and components. Workshops increase cost efficiency, optimize maintenance services based on predictive analytics and use remanufactured parts as the default option.</p>	<p>This solution models the positive impacts workshops can have on non-circular resource consumption and life-cycle carbon emissions. It is assumed that optimized maintenance enables longer lifetime of vehicles (measured in life-cycle km). The increased use of remanufactured components instead of new components reduces non-circular car inflows and reduces CO2 from materials due to lower carbon intensity of remanufactured components.</p>
10	<p><b>Purpose-built vehicle</b></p> <p><b>Business model</b> – Product use extension</p> <p><b>Definition element</b> – Lifetime – Usage</p> <p><b>Measure</b> – Carbon and resource efficiency: km driven over life cycle – Carbon efficiency: CO2 from materials, CO2 from component production and assembly – Resource efficiency: total mass of the vehicle, total scrap % non-circular inflow</p>	<p>OEMs provide purpose-built/purpose-adjusted vehicles to mobility providers that enable improved capacity use and optimized vehicle lifetime. OEMs assess use phase requirements and use insights to provide vehicle variations that better align vehicles with their purpose, especially in terms of size, reparability and durability.</p>	<p>As seat capacity usage rates for vehicles today are low, the average purpose-built vehicle is assumed to be considerably smaller than the average vehicles today. This can lead to a reduction of total materials in the car and a respective reduction of CO2 from materials, CO2 from component production and assembly and CO2 from end-of-life treatment.</p>
11	<p><b>Alternative drivetrain</b></p> <p><b>Business model</b> – Circular inputs</p> <p><b>Definition element</b> – Energy use</p> <p><b>Measure</b> – Carbon efficiency: CO2 from materials, exhaust emissions, energy generation emissions – Resource efficiency: total mass of the vehicle, % non-circular inflow, % non-circular outflow</p>	<p>OEMs scale alternative drivetrain solutions with substantially lower – ultimately zero – exhaust emissions to reduce use phase emissions. Drivetrain optimization considers the full market picture – i.e. energy use of the full vehicle portfolio on the streets and available supply of green energy (e.g. renewable electricity, green hydrogen).</p>	<p>The impact is modelled based on a battery-electric vehicle (BEV). Transitioning from the internal combustion engine vehicle (ICEV) to the BEV reduces exhaust emissions to zero. Emissions from energy generation probably increase depending on the energy mix of the local grid. CO2 emissions from materials, component production and assembly and end-of-life treatment are assumed to increase due to the higher weight of the BEV and the production of the battery.</p>
12	<p><b>Energy grid integration</b></p> <p><b>Business model</b> – Sharing platform – Circular inputs</p> <p><b>Definition element</b> – Energy use – Usage</p> <p><b>Measure</b> – Carbon efficiency: energy generation emissions</p>	<p>OEMs scale smart charging and vehicle-to-grid (V2G) technology for battery-electric vehicles, plug-in hybrids and fuel cell-electric vehicles. Emissions from electricity generation in electric mobility (well-to-tank) are reduced and cars help to balance loads in the energy grid. Fleet management companies (mobility services, financial services) make use of this integration for their fleets.</p>	<p>It is assumed that due to optimum integration of car and energy grid, cars are charged when renewable energy is available, thereby reducing the CO2 emissions from energy generation.</p>

Table 4 continues on the next page

	<b>Solution</b>	<b>Description</b>	<b>Impact description</b>
13	<p><b>Leasing and subscription</b></p> <p><b>Business model</b> – Product-as-a-service</p> <p><b>Definition element</b> – Lifetime</p> <p><b>Measure</b> – Carbon and resource efficiency: km driven over life cycle</p>	<p>OEMs and fleet management companies (mobility services, financial services) increase their offerings for fleet-based private mobility. New forms of ownership align incentives for value chain players to the principles of a circular economy. The most prominent models in this area to date are (lifetime-) leasing and subscription-based ownership that have the potential to transform the automotive market at scale to as-a-service models.</p>	<p>This solution models the positive impacts workshops can have on non-circular resource consumption and life-cycle carbon emissions. It is assumed that optimized maintenance enables longer lifetime of vehicles (measured in life-cycle km). The increased use of remanufactured components instead of new components reduces non-circular car inflows and reduces CO2 from materials due to lower carbon intensity of remanufactured components.</p>
14	<p><b>Vehicle on demand</b></p> <p><b>Business model</b> – Product-as-a-service – Sharing platform</p> <p><b>Definition element</b> – Lifetime – Usage</p> <p><b>Measure</b> – Carbon and resource efficiency: km driven over life cycle</p>	<p>Mobility service providers increase capacity use of vehicles through offering vehicles on demand to customers. A variety of on-demand solutions are already on the market, including car rental, car sharing, P2P sharing and micro mobility. The consolidation of these business models into holistic vehicle on-demand offerings that integrate different rental durations or vehicle types enables scaling these models.</p>	<p>This solution focuses on vehicles that are shared by a variety of users for short periods and are managed as part of a fleet. It is assumed that the shared vehicle is treated more inconsiderately but receives better maintenance, repair and refurbishment compared to a privately owned vehicle. Capacity use (in average km/year) is increased. Overall, an increase in lifetime (measured in life-cycle km) can be achieved.</p>
15	<p><b>Mobility on demand</b></p> <p><b>Business model</b> – Product-as-a-service – Sharing platform</p> <p><b>Definition element</b> – Lifetime – Usage</p> <p><b>Measure</b> – Carbon and resource efficiency: km driven over life cycle, average # of passengers in the vehicle</p>	<p>Mobility service providers increase capacity use through mobility on-demand solutions. To date, these business models include ride hailing, ride sharing and demand-responsive transport/ride pooling. Ride pooling in particular has the potential to optimize capacity use of the vehicle through increasing life-cycle km per vehicle as well as the number of average passengers.</p>	<p>This solution focuses on vehicles used by drivers in mobility-as-a-service applications. Maintenance, repair and refurbishment are assumed to be optimized compared to a privately owned vehicle. Capacity use (in average km/year) is increased. Overall, an increase in lifetime (measured in life-cycle km) can be achieved. In addition, the average number of passengers can be increased.</p>
16	<p><b>Breathing fleets</b></p> <p><b>Business model</b> – Product-as-a-service – Sharing platform</p> <p><b>Definition element</b> – Usage</p> <p><b>Measure</b> – Carbon and resource efficiency: km driven over life cycle</p>	<p>Fleet management companies increase capacity use of their fleets through sharing the fleet across multiple service offerings. Depending on demand cycles (e.g. weekends vs. workdays) and age/quality requirements, cars are shifted from one service offering to another, thereby achieving higher capacity use for each car over its life cycle.</p>	<p>This solution focuses on the optimized use management of car fleets. Capacity use (in average km/year) is also increased, compared to using “vehicle-on-demand” and “mobility-on-demand” solutions separately. Overall, an increase in lifetime (measured in life-cycle km) can be expected.</p>

TABLE 5 Descriptions of selected enablers

Enabler	Description	Supported solutions
<p>1 <b>Recoverable and recyclable materials</b></p> <p><b>Business model</b></p> <ul style="list-style-type: none"> <li>– Circular inputs</li> <li>– Resource recovery</li> </ul> <p><b>Definition element</b></p> <ul style="list-style-type: none"> <li>– Materials</li> </ul> <p><b>Measure</b></p> <ul style="list-style-type: none"> <li>– Carbon efficiency: CO2 from materials</li> <li>– Resource efficiency: % non-circular inflows, % non-circular outflows</li> </ul>	<p>OEMs, component suppliers and material suppliers collaborate and combine knowledge of the vehicle design process to improve material recoverability and recyclability. The variability and complexity of the material mix in a car is reduced, and new innovative materials are developed.</p>	<ul style="list-style-type: none"> <li>– Circular material stock</li> <li>– Component-as-a-service (e.g. battery)</li> </ul>
<p>2 <b>Product passport</b></p> <p><b>Business model</b></p> <ul style="list-style-type: none"> <li>– Product use extension</li> <li>– Resource recovery</li> <li>– (Circular inputs)</li> </ul> <p><b>Definition element</b></p> <ul style="list-style-type: none"> <li>– Materials</li> <li>– Lifetime</li> </ul> <p><b>Measure</b></p> <ul style="list-style-type: none"> <li>– Carbon efficiency: CO2 from materials, CO2 from end-of-life treatment</li> <li>– Resource efficiency: % non-circular inflows, % non-circular outflows</li> </ul>	<p>OEMs, component and material suppliers and recyclers collaborate in the development and implementation of a product passport for vehicles and/or components and materials. Relevant information (e.g. origin, material composition) is shared to optimize reuse, improve recycling rate and quality, and enable better traceability.</p>	<ul style="list-style-type: none"> <li>– Circular material stock</li> <li>– Component-as-a-service (e.g. battery)</li> <li>– Optimized component reuse and remanufacturing</li> <li>– Professional EOL collection, sorting and reverse logistics</li> </ul>
<p>3 <b>Advanced recycling technology and infrastructure</b></p> <p><b>Business model</b></p> <ul style="list-style-type: none"> <li>– Resource recovery</li> <li>– (Circular inputs)</li> </ul> <p><b>Definition element</b></p> <ul style="list-style-type: none"> <li>– Materials</li> </ul> <p><b>Measure</b></p> <ul style="list-style-type: none"> <li>– Carbon efficiency: CO2 from materials, CO2 from end-of-life treatment</li> <li>– Resource efficiency: % non-circular inflows, % non-circular outflows</li> </ul>	<p>Research organizations, chemical companies and recyclers develop advanced recycling technologies to improve recycling rates and the quality of recycled materials from end-of-life cars. Players from the automotive industry (especially OEMs, material suppliers) integrate their practical knowledge, explore options for co-funding and support pilot projects.</p>	<ul style="list-style-type: none"> <li>– Circular material stock</li> <li>– Component-as-a-service (e.g. battery)</li> </ul>

Table 5 continues on the next page

Enabler	Description	Supported solutions
<p>4 <b>Market maker for circular inputs</b></p> <p><b>Business model</b></p> <ul style="list-style-type: none"> <li>– Circular inputs</li> <li>– (Resource recovery)</li> <li>– (Product use extension)</li> </ul> <p><b>Definition element</b></p> <ul style="list-style-type: none"> <li>– Materials</li> <li>– Lifetime</li> </ul> <p><b>Measure</b></p> <ul style="list-style-type: none"> <li>– Carbon efficiency: CO2 from materials</li> <li>– Resource efficiency: % non-circular inflows, % non-circular outflows</li> </ul>	<p>OEMs, material suppliers or recyclers to develop a platform that improves transparency for disassembly and recycling and matches supply and demand for circular inputs (e.g. remanufactured components, recycled material). A two-sided platform connects all interested value-chain players. Recovery-relevant product specification as well as available and required volumes of circular inputs are shared. Circular inputs can be traded via the platform.</p>	<ul style="list-style-type: none"> <li>– Circular material stock</li> <li>– Component-as-a-service (e.g. battery)</li> <li>– Optimized component reuse and remanufacturing</li> </ul>
<p>5 <b>Balanced production capacity</b></p> <p><b>Business model</b></p> <ul style="list-style-type: none"> <li>– Product use extension</li> </ul> <p><b>Definition element</b></p> <ul style="list-style-type: none"> <li>– Usage</li> </ul> <p><b>Measure</b></p> <ul style="list-style-type: none"> <li>– Carbon and resource efficiency: km driven over life cycle</li> </ul>	<p>OEMs and component suppliers optimize production capacities for long-term success in a circular automotive industry. Large-scale and small-scale production as well as new car/component production and remanufactured/refurbishment facilities are balanced depending on local demand. Overproduction of new cars is avoided, thereby reducing pressure for new car sales and supporting the success of new business models focused on product-use extension or product-as-a-service.</p>	<ul style="list-style-type: none"> <li>– Modularity for life-cycle optimization</li> <li>– Purpose-built vehicle</li> <li>– Vehicle on demand</li> <li>– Mobility on demand</li> </ul>
<p>6 <b>Renewable energy at scale</b></p> <p><b>Business model</b></p> <ul style="list-style-type: none"> <li>– Circular inputs</li> </ul> <p><b>Definition element</b></p> <ul style="list-style-type: none"> <li>– Energy use</li> </ul> <p><b>Measure</b></p> <ul style="list-style-type: none"> <li>– Carbon efficiency: CO2 from materials, CO2 from component production and assembly, energy generation emissions</li> </ul>	<p>Energy providers increase the supply of renewable energy for production and vehicle charging (e.g. clean electricity, green hydrogen) to decarbonize emissions from energy generation. Governments invest in national infrastructure and increase incentives for renewable energy production and storage solutions. Energy providers, OEMs and mobility services collaborate in the development of low-carbon production solutions and renewable charging infrastructure.</p>	<ul style="list-style-type: none"> <li>– Low-carbon materials</li> <li>– Low-carbon production</li> <li>– Alternative drivetrain</li> </ul>
<p>7 <b>Autonomous driving</b></p> <p><b>Business model</b></p> <ul style="list-style-type: none"> <li>– Product-as-a-service</li> <li>– Sharing platform</li> </ul> <p><b>Definition element</b></p> <ul style="list-style-type: none"> <li>– Usage</li> </ul> <p><b>Measure</b></p> <ul style="list-style-type: none"> <li>– Carbon and resource efficiency: km driven over life cycle, average # of passengers in the vehicle</li> </ul>	<p>OEMs, national and local governments integrate autonomous driving in future mobility scenarios. Autonomous driving will accelerate the distribution of vehicle-on-demand and mobility-on-demand business models and enable the uptake of these business models at scale.</p>	<ul style="list-style-type: none"> <li>– Vehicle on demand</li> <li>– Mobility on demand breathing fleets</li> </ul>

Table 5 continues on the next page

Enabler	Description	Supported solutions
<p>8 <b>Mobility platform</b></p> <p><b>Business model</b></p> <ul style="list-style-type: none"> <li>– Product-as-a-service</li> <li>– Sharing platform</li> </ul> <p><b>Definition element</b></p> <ul style="list-style-type: none"> <li>– Usage</li> </ul> <p><b>Measure</b></p> <ul style="list-style-type: none"> <li>– Carbon and resource efficiency: km driven over life cycle, average # of passengers in the vehicle</li> </ul>	<p>Mobility providers combine different services (e.g. vehicle on demand, mobility on demand, micro mobility, public transport) in one multimodal platform. Customers are encouraged to take the greenest route where sensible.</p>	<ul style="list-style-type: none"> <li>– Vehicle on demand</li> <li>– Mobility on demand breathing fleets</li> </ul>

Source: Accenture Strategy analysis, based on interviews and research



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# Endnotes

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