A VISION ON THE FUTURE OF AUTOMOTIVE LIGHTWEIGHTING

Accelerating the decarbonisation of automotive mobility by means of lightweighting.

alliance

BAX & COMPANY

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Abbreviations

BiW
Body-in-white

ICE
Internal combustion engine

M&S
Modelling and simulation

FCEV
Fuel cell electric vehicle

GHG
Greenhouse gas

EV
Electric vehicle

EoL
End-of-life

LCA
Lifecycle assessment

OEM
Original equipment manufactures

TRL
Technology radiness level

LCC
Lifecycle costing

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Executive Summary

The road transport sector is under increasing pressure to reduce its GHG emissions, which reached some 0.8Gt CO_2eq, 18% of total European greenhouse gas emissions in 2017. Aiming to deliver on the decarbonization targets of the European Commission, automotive OEMs and their value chain partners currently follow two distinct approaches; using alternative energy sources with lower environmental impact, and improving the fuel efficiency of vehicles. Both benefit from the reduction of vehicle weight, which ultimately increases the distance travelled per unit of energy.

Next to the policy push to decrease environmental impact – expressed mainly by EU Directives related to vehicle emissions and vehicle EoL treatment – the mobility sector is being transformed by strong market and technological forces, such as the switch to alternative powertrains, shared mobility, and autonomous driving.

Aiming to better understand the influence of these future trends and drivers on lightweighting, and from there formulate innovation priorities, members of the ALLIANCE H2020 project combined forces, to create a common vision for European automotive lightweighting.

Taking into consideration the trends and regulatory drivers, three main challenges that hold back lightweighting solutions from achieving their full potential have been identified. Those refer to the affordability of lightweighting; the time required to introduce novel solutions in mass-produced cars (material qualification, innovation mainstreaming); and the environmental impact (circularity, emissions etc.). For each of these challenges, solutions can be found in the area of technology, the market, and the ecosystem (e.g. policy). For each of these solutions to materialise, a combination of innovation activities need to take place. Both the solutions and the relevant innovation activities are outlined in this document.

Through this combined effort, ALLIANCE partners – and their extended network – provide Europe with a vision on vehicle lightweighting, aiming to support the road transport value chain in their decarbonisation targets, while ensuring its strong competitive position in the forefront of automotive lightweighting.

1. Preface

ALLIANCE (Affordable Lightweight Automobiles Alliance) is a research and innovation project on automotive lightweighting, co-funded by the European Commission's Horizon 2020 programme and supported by EUCAR, the European Council for Automotive R&D as well as EARPA, the European Automotive Research Partners Association.

Six leading European carmakers (Daimler, Volkswagen, Fiat-Chrysler Research Centre, Volvo, Opel and Toyota) joined forces to address the need for more efficient vehicles. Together with four suppliers (Thyssenkrupp, Novelis, Batz, Benteler) and eight knowledge partners (Swerea, Inspire, Fraunhofer LBF, RWTH-IKA, KIT-IPEK, University of Florence, Bax & Company, Ricardo) they formed the ALLIANCE consortium.

The main objectives of the ALLIANCE project were to enable a reduction of energy consumption by 10% and global warming potential (GWP) by 6%, compared to a conventional vehicle by decreasing the vehicle's weight by 31 to 33%. All of this while keeping the cost of lightweighting at around 3€ per kilogram saved.

The ALLIANCE project has focused on the development and demonstration of technologies with the primary purpose to holistically optimize fuel and energy consumption in both conventional and electric vehicles. This resulted in several demonstrators of real vehicle models, aiming at market application by 2025.

ALLIANCE, furthermore, has developed several support tools to ensure the market viability of the developed technologies as well as to accelerate pre-assessment of technologies over existing designs.

" The ALLIANCE project has focused on the development and demonstration of technologies with the primary purpose to holistically optimize fuel and energy consumption in both conventional and electric vehicles"

Figure 1 Objectives of the ALLIANCE consortium

2. Introduction

Transport is one of the most important building blocks for society and its growth. This is particularly true for road transport in Europe which is an essential pillar of European employment, trade and economic productivity, and development.

The three catalysts of accelerated technological advancement, deep societal change (e.g. changing consumer preferences, environmental awareness), and effective public policy currently revolutionize the way people and goods are moved. Using minimum energy, at minimum costs, with maximum efficiency, while guaranteeing safety and comfort is the major task that OEMs and their partners currently face.

Next to this, the automotive industry sees high-impact disruptive developments emerging, and new players with innovative solutions entering the market leading to changes in the value chain. With the lightweight sector undeniably and inseparably linked to this industry, these developments finally affect also all lightweighting players.

The roundtable discussion at the ALLIANCE Future Lightweighting Day in Aachen in September 2018, showed an aligned understanding of these developments and this major task with its current and future challenges. However, the priorities and strategies on how to address those challenges are not always aligned between the different automotive lightweighting stakeholders in Europe, not excluding their future vision regarding lightweighting.

Therefore, this document's objective is to outline a common vision for European automotive lightweighting with the aim of reducing the environmental impact of the road transport sector, and increasing Europe's competitiveness in the field. It will provide an understanding of the challenges and future/evolution of lightweighting in Europe. The vision is based on input from stakeholders of the European automotive lightweighting industry and completed with knowledge compiled from current market research reports, technology studies and impact assessments.

The contributors aim at supporting the European Commission in defining the R&D&I priorities on lightweighting for the Horizon Europe Framework Programme and to set a basis for future R&D&I collaborations of multiple stakeholders of the entire automotive value chain as seen in the ALLIANCE project.

" However, the priorities and strategies on how to address those challenges are not always aligned between the different automotive lightweighting stakeholders in Europe,not excluding their future vision regarding lightweighting"

Figure 2 Input and contribution to the vision development

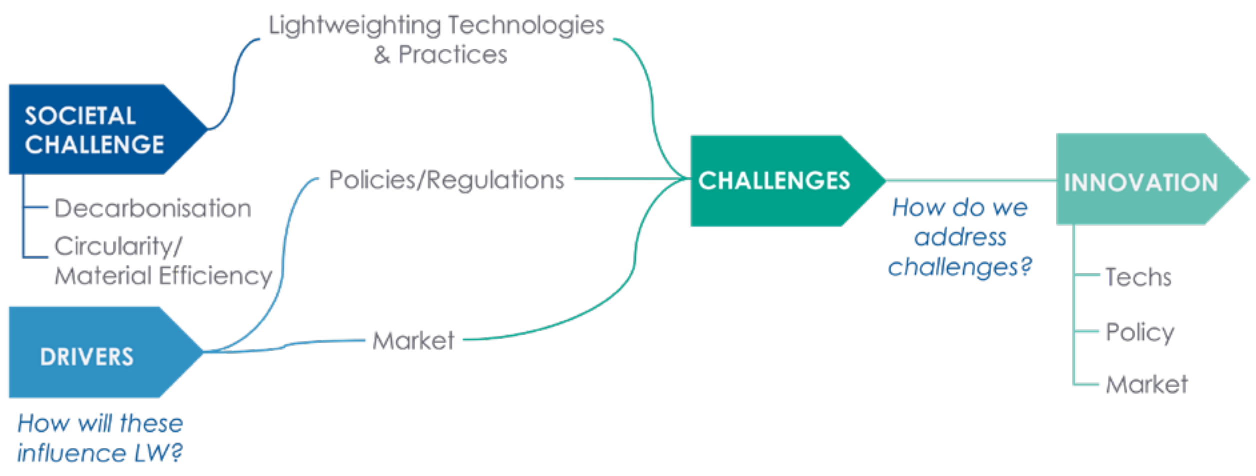

Figure 3 Methodology of the vision development

2.1. Methodology

The present document intends to create a holistic overview of the current situation of the European lightweighting arena and to provide a clear vision and strategy for the future. The identification of all relevant technologies and practices, important players and market developments is therefore key to create an understanding of the preconditions and the framework that future scenarios and strategies are based on. Contributions to the vision were made on (1) material design, processing and component design, (2) policies and regulations and (3) the market with a focus on the future of mobility.Drivers that directly or indirectly influence the lightweighting sector were determined and their impact or influence was defined. The identification and prioritization of the current challenges that may be a result of these drivers or technological constraints are key points that are addressed in this vision. By creating an understanding of how these challenges can be potentially addressed, an allocation of responsibilities can be made. The innovation steps proposed by the contributors in working groups, interviews and during a workshop that took place throughout 2019 follow approaches looking at these challenges from different angles and include different groups of stakeholders (technical, regulatory and market innovation).

3. Background

3.1. The big picture – Decarbonisation

The reduction of GHG emissions has been on the global political agenda for many years expressed in several of the Sustainable Development Goals by the UN. But the climate deal that became known as Paris Agreement signed by 195 parties within the United Nations Framework Convention on Climate Change in 2016 was a clear push to go way beyond ongoing efforts. The agreement revolved around the clear target scenario to keep the global temperature increase below 2°C compared to pre-industrial levels to avoid a global climate crisis.[1] With the European greenhouse gas emissions reaching 4.5 Gt CO_2eq only in 2017, the EU is one of the main contributors and accelerators of the accumulation of GHGs in the atmosphere.[2,3]

The European member states decided to sign the agreement not only individually but as a supranational confederation of states, expressing the ambition to develop and establish a common strategy and the necessary regulations to execute the related action plan jointly. When in March 2018 the European Council requested a long-term strategy for the reduction of greenhouse gas emissions in the attempt for compliance, the European Commission reacted with a vision for climate neutrality by 2050. That document also outlines the deep economic and societal transformations and the close collaboration among all stakeholders required to achieve this vision.[4]
While carbon emissions are caused by all activities of industry and society, the transport sector specifically has a major impact; it produces a quarter of all greenhouse gas emissions. Within that large portion, the sub-segment of road transport accounts for more than 70%[6]. Therefore, the decarbonisation plans of the EU prioritise changes in the transport sector aiming to achieve clean, safe and connected mobility by means of alternative transport, connected and automated driving and the roll-out of electric and alternative fuel vehicles.[7]

" While carbon emissions are caused by all activities of industry and society, the transport sector specifically has a major impact; it produces a quarter of all greenhouse gas emissions"

[1] European Academies' Science Advisory Council (EASAC), Decarbonisation of transport: options and challenges, March 2019
[2] Intergovernmental Panel on Climate Change (IPCC), Special report - Global Warming of 1.5°C
[3] European Federation for Transport and Environment (AISBL), How to decarbonise European transport by 2050, 2018
[4] European Commission, Our Vision for a Clean Planet for All, November 2018
[5] European Environment Agency (EEA), Greenhouse gas emissions from transport, September 2018
[6] European Commission, Transport emissions A European Strategy for low-emission mobility
[7] European Commission, Our Vision for a Clean Planet for All, November 2018

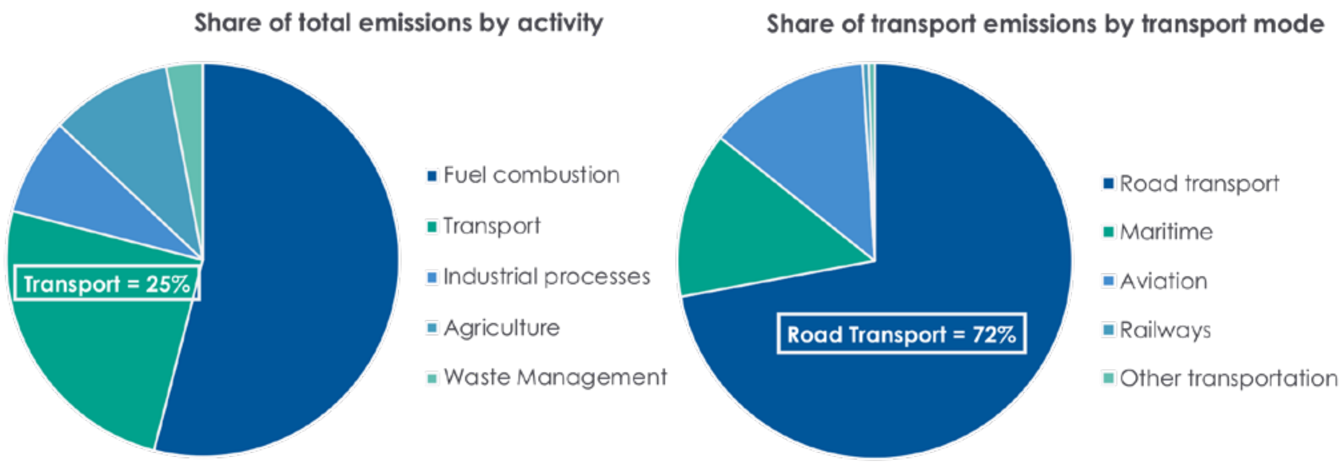

Figure 4 Shares of European greenhouse gas emissions (Source: EEA)[5]

3.2. Why lightweighting?

Automotive OEMs and their value chain partners currently follow two distinct approaches, in the attempt to deliver on the decarbonization targets of the European Commission:

1. **Using alternative energy sources:** this includes e.g. hybrid power technologies, fully electric vehicles and fuel cell vehicles, which have the potential for decreasing environmental impact.
2. **Improving fuel efficiency of vehicles:** Beyond the attempt to deliver on the targets for decarbonization, improved energy/ fuel efficiency of vehicles has been of interest for (European) players of the automotive industry for a while now.

Both approaches benefit from the reduction of vehicle weight as a means to increase the distance travelled per unit of energy consumed (fuel or electricity). According to research commissioned by the US Department of Energy (DoE), a reduction of the weight of an ICE vehicle by 10% will lead to a 6 to 8% rise in fuel economy. Similarly, a weight reduction of 10 kilograms reduces emissions by approximately 1 gram of CO_2 per kilometre driven[8].

[8] Mordor Intelligence, Global Lightweight Car Market (2019-2024), 2019

4. Lightweighting background for policymakers

Weight reduction in the automotive sector requires collaboration among multiple disciplines such as material science, metallurgy, mechanical engineering, systems engineering, design among others. Fundamentally two approaches can be distinguished (even though often a combination is found in reality):

1. Material approach: Traditional automotive materials with high specific weight are replaced by materials that have lower densities while retaining the rigidity and durability (and other performance aspects) of the components. Furthermore, several materials are combined to achieve better overall performance-weight-affordability balances (multi-material approach). Ideally, a higher cost can be at least partially offset by a lower amount of material needed and energy savings during the use-phase.

2. Design Approach: The designs of components, assemblies and the entire vehicle (load carrying elements and non-load-carrying ones) are geometrically optimized while retaining their functionality. By 'lean' design approaches, any excess material can be eliminated, and by optimizing geometries further 'leanness' of structures can be achieved. Novel, more flexible or tailored manufacturing technologies allow for locally optimized wall thicknesses, locally optimized cross sections and even locally optimized base material characteristics (in some cases even different depending on the direction in which a load is applied). Smarter designs squeeze out any superfluous material in components and can even re-define the way components can together deliver on a certain overall vehicle or assembly level performance requirement. Even in less fundamental design optimization exercises, engineers can sometimes achieve weight reductions of around 5%[9].

As successful examples show, the approaches cannot be separated from each other. Lightweighting is not simply replacing one material with another but requires in parallel also changes in the design serving the manufacturability according to the properties of new materials as well as to improve material usage. More recently, due to the introduction of simulation tools, secondary reduction potential started to be explored (e.g. reducing the weight of brakes and suspension without affecting performance due to lighter body structures).

In general, lightweighting is not purely about the reduction of weight, but an approach that focuses among many other aspects on structural efficiency as well as on the economic and environmental impact.

" Lightweighting is not simply replacing one material with another but requires in parallel also changes in the design serving the manufacturability according to the properties of new materials as well as to improve material usage"

[9] International Council on Clean Transportation (ICCT), Lightweighting technology development and trends in U.S. passenger vehicles, December 2016

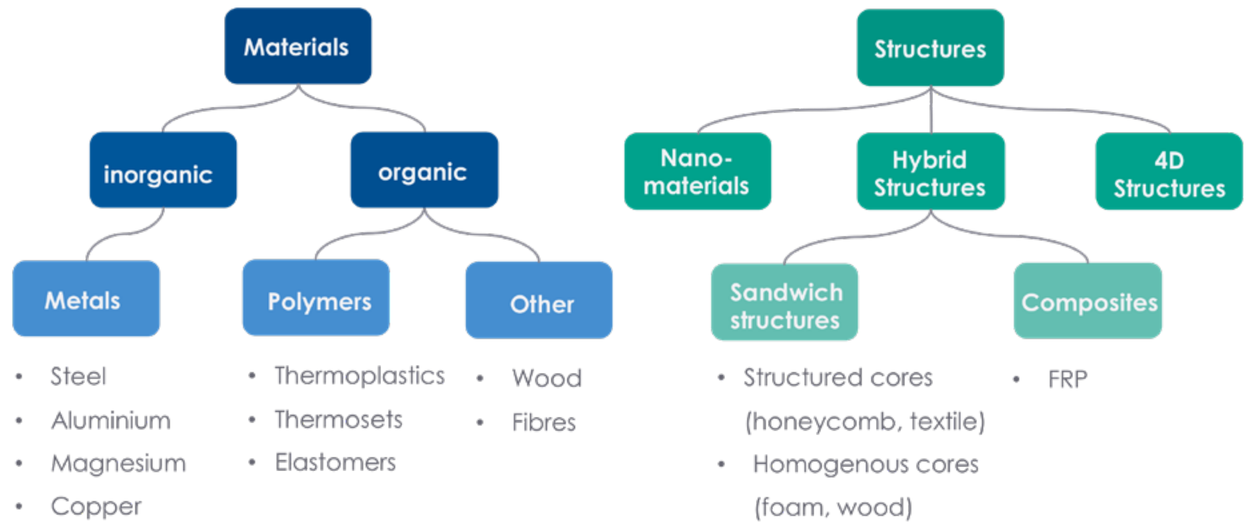

Figure 5 Overview of the most relevant lightweight materials and structures (list not exhaustive)

" There is a common understanding that certain materials are more favourable in certain applications than others due to specific properties, yet there are no standardised material-application matches. Today's application of advanced lightweight materials is rather driven by the related costs"

4.1. Lightweighting technologies and practices

The quest for lighter vehicles led to an extensive research in material sciences and process technologies. Entire categories of such advanced materials such as high-strength steels, aluminium and composite materials have been the results of research efforts. Significant improvements in properties compared to the originally used base level materials have been achieved by profound multi-level material optimisation (from atoms to component level) or through advancements in manufacturing processes, which also have given rise to additional material solutions with significant lightweighting potential, such as polymers, ceramics, and hybrids.
Figure 5 shows relevant lightweight materials and structures that are already introduced in mass production (e.g. Steel, Aluminium) or are still under investigation (4D structures). The main "material families" include metals, ceramics, polymers, and to some extent other organic materials such as wood or natural fibres (e.g. bamboo, hemp, sisal). A comparative analysis of materials is found in ANNEX A together with some basic facts on the materials.
There is a common understanding that certain materials are more favourable in certain applications than others due to specific properties, yet there are no standardised material-application matches. Today's application of advanced lightweight materials is rather driven by the related costs.
With individual materials reaching their performance limits, the combination of advantages of various mono-materials into one application has been gaining attention. These multi-material solutions are promising to not only increase the performance but also offer the opportunity to reduce the cost of lightweighting substantially. The multi-material approach is expected to be predominant in the future, although end-of-life recyclability and assembly line joining technology pose challenges for the more complex combinations.

4.2. What has been achieved?

Lightweighting efforts and (collaborative) research in Europe go way back. Legislation aimed at reducing vehicle emissions has driven research and development of new technologies to unprecedented intensity. Lightweighting profited from this urgency as several success cases highlight. EU research funding supported this rapid development substantially, helping stakeholders create real impact. Super Light Car for example, funded under FP6, demonstrated a reduction in the Body-in-White weight of up to 35% compared to the reference model back in 2009 and the ALLIANCE project (H2020 funded) achieved a reduction of the global warming potential by 24% on average across the various demonstrator modules.Looking at the contribution of different approaches for lightweighting of vehicles, presented in Figure 8, the weight reduction in the last 30 years stemmed almost entirely from the introduction of advanced materials in the vehicle.[11] Although lightweighting efforts increased significantly the mass of the base car was almost unchanged since 1980. At the same time the total vehicle weight even increased due to the integration of entertainment and safety features and measures to reduce exhaust emissions.[12] The reasons for this development are safety regulations and consumer preferences for more spacious and comfortable cars which led to increased vehicle sizes. As safety regulations are expected to only become stricter in the next years, the integration of more safety measures and technologies will further add more weight.The introduction of solutions in mass-produced mainstream cars is a very lengthy process but still many technologies have been successfully implemented in the last years. At present, the body-in-white material composition of an average passenger vehicle consists of a mix of various grades of steel, aluminium and plastics while applications for composites have become more prevalent at the upper end of the market. Around 60% of today's car body structures are made of advanced high-strength steels (AHSS).[15] Plastics have found a wide range of lightweighting applications beyond the body-in-white structure and represent to date about 50% of the volume of today's vehicle but only about 10% of the weight.[16]

" Although lightweighting efforts increased significantly the mass of the base car was almost unchanged since 1980. At the same time the total vehicle weight even increased due to the integration of entertainment and safety features and measures to reduce exhaust emissions"

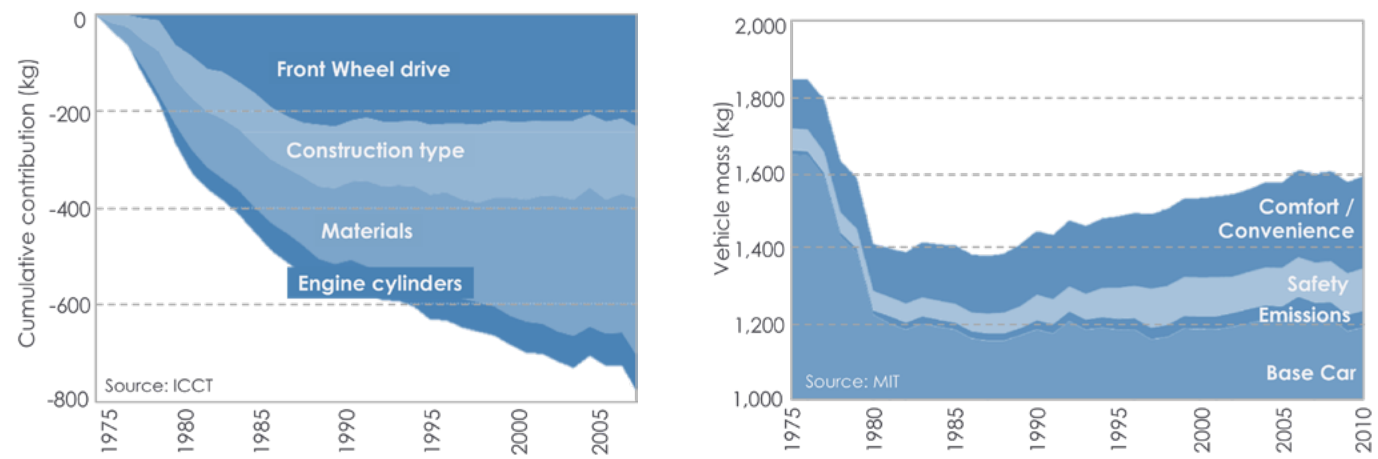

Figure 8 Cumulative contribution of different approaches to weight reduction in vehicles (Source: ICCT)[13] and the evolution of average passenger car mass between 1975 and 2010 (Source: MIT)[14]

[10] Germany Trade & Invest (GTAI), Industry Overview -The Lightweight Industry in Germany, February 2018
[11] International Council on Clean Transportation (ICCT), Lightweighting technology development and trends in U.S passenger vehicles, 2016
[12] Baron, J. (Center for Automotive Research), Identifying Real World Barriers to Implementing Lightweighting Technologies and Challenges in Estimating the Increase in Costs, 2016

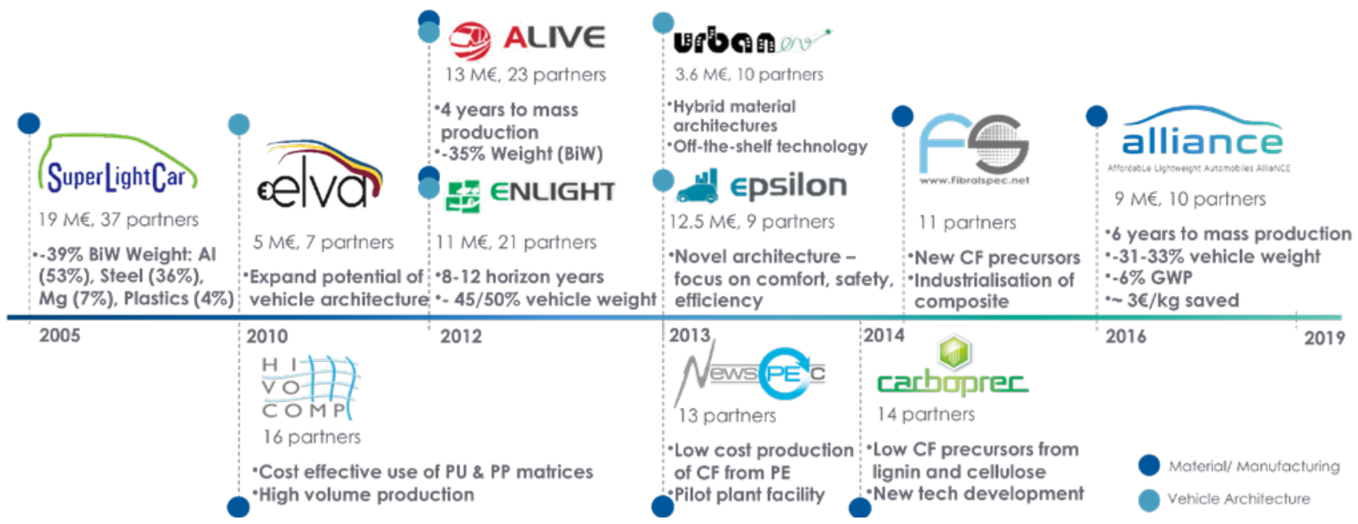

Figure 7 Past European initiatives in the area of lightweighting

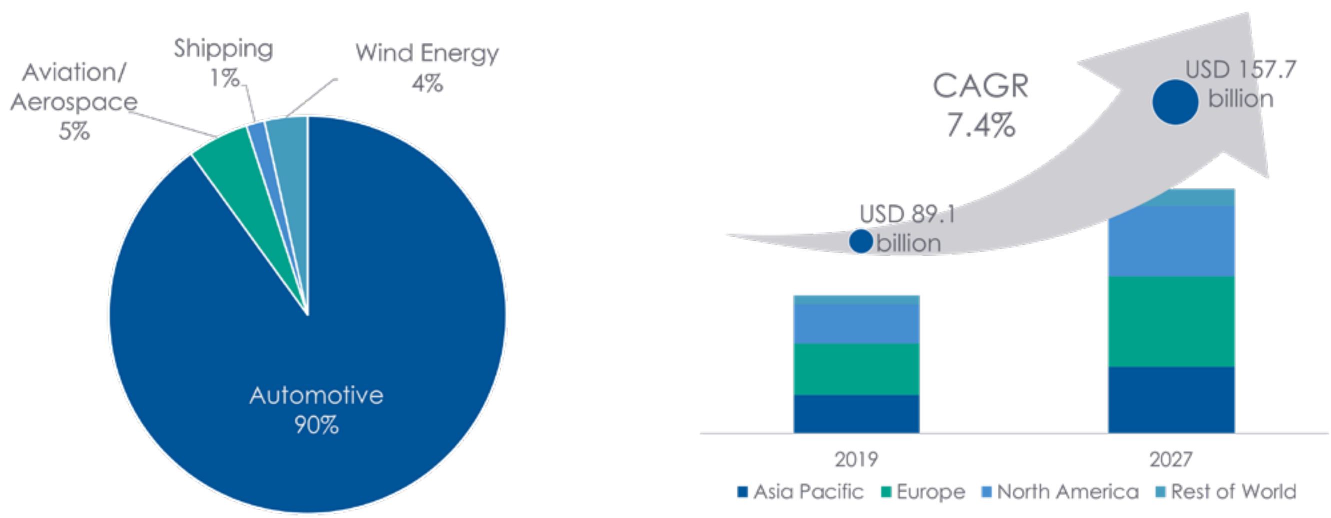

Figure 9 Share of lightweight materials in main sectors (Source: Allied Market Research)[19] and automotive lightweight materials market forecast (Source: Markets&Markets)[20]

4.3. The lightweight Market

The market for lightweight materials is driven primarily by the large volume of automotive applications. The automotive sector claims close to 90% of the total lightweight materials market, partly due to the moderate penetration of lightweight materials in this sector (Figure 9)[17] . The automotive lightweight material market is estimated to reach 89.1 billion US dollar in 2019 and to continually grow with a CAGR of 7.4% probably exceeding 157.7 billion US dollar by 2027. Metals are expected to remain the prevalent material choice forming the largest segment.[18]

Europe as a big car manufacturing hub also became a hub for vehicle lightweighting. The European market for lightweight vehicles is led by developments and initiatives within the EU, driven by both technological advancements and the regulatory framework (Euro 6 norms). The move towards a competitive low-carbon economy by 2050 is expected to also pull other economies in this direction.

Although there was a consensus among the industry that the reduction of weight was an important feature for the next generation of cars, since 2011 R&I in some lightweighting areas was stagnating. This was right around the time when the hype for electrification started shifting the focus of European carmakers towards other trends and features. Nonetheless, Europe is still the largest market for automotive lightweight materials. Manufacturers and suppliers of lightweight materials are investing in the development of new and advanced lightweight materials driving market growth in Europe.[21]

Throughout **North America** fuel economy regulations become stricter. In the US, lightweighting is mainly driven by the Corporate Average Fuel Economy (CAFE) standards and general fuel price instability. Next to this, the steel, aluminium and magnesium industries are a big push in the US market. The demand for lightweight materials is expected to continuously grow.

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Primarily metals (aluminium and high-strength steel) are used mostly in structural applications. Freeform manufacturing (additive manufacturing) for metals and engineering polymers is gaining attention for lightweighting driven by many important players and providers being present and leading globally in this area.[22]

Asia-Pacific is expected to witness the fastest growth in the lightweight market which is closely linked to the fast-growing automotive industry in China and India. Growth is forecasted for both the demand due to a rise in income levels and also the production due to a rapidly growing manufacturing landscape. Increasing awareness about fuel efficiency and environmental benefits is also in this region a very strong driver. Important material suppliers are present in this region and offer highly competitive solutions that put players in other regions under pressure. [23]

4.4. European SWOT

As lightweighting is very closely linked to the automotive industry, the strengths, weaknesses, opportunities and threats of that industry also affect all players of the lightweighting sector. This analysis compiles the most important points directly or indirectly related to lightweighting and stem from all related areas (technology, market and the ecosystem).

[13] International Council on Clean Transportation (ICCT), Lightweighting technology development and trends in U.S passenger vehicles, 2016
[14] Baron, J. (Center for Automotive Research), Identifying Real World Barriers to Implementing Lightweighting Technologies and Challenges in Estimating the Increase in Costs, 2016
[15] World Steel Association, Steel in Automotive (https://www.worldsteel.org/steel-by-topic/steel-markets/automotive.html)
[16] American Chemical Council, Automotive Plastics (https://www.automotiveplastics.com/automotive-plastics-today/interior/)
[17] Allied Market Research, Lightweight Materials Market – Global Opportunity Analysis and Industry Forecast, 2014-2022

[18] Markets&Markets, Automotive Lightweight Material Market - Global Forecast to 2027
[19] Allied Market Research, Lightweight Materials Market – Global Opportunity Analysis and Industry Forecast, 2014-2022[15] World Steel Association, Steel in Automotive (https://www.worldsteel.org/steel-by-topic/steel-markets/automotive.html)
[20] Markets&Markets, Automotive Lightweight Material Market - Global Forecast to 2027
[21] Markets&Markets, Automotive Lightweight Material Market - Global Forecast to 2027
[22] Freedonia, Lightweight Automotive Mate rials in North America, 2014
[23] Mordor Intelligence, Lightweight Car Market . Growth, Trends, and Forecast(2019 – 2024)

STRENGHTS

- High level of knowledge and expertise on advanced materials (metallurgy, material science) and lightweight structures (e.g. expertise in material hybridization) and in advanced processing technologies (e.g. additive manufacturing)
- Europe is especially strong in adding value to raw materials (primary material supply), manufacturing of components.
- The European research landscape has a very deep understanding of the basics/fundamentals of most topics related to lightweighting.
- European players are very good at modelling and simulation which is highly relevant for new materials, components, manufacturing technologies.
- Europe has a quite advanced recycling landscape with several key players especially in the field of metal recycling.

- The EU is a landscape of highly specialized SMEs that offer many specialized solutions.
- Lightweighting technologies are available like nowhere around the globe.
- Players in Europe provide the majority of advanced steels.

- Regulations (e.g. emissions) are pushing for novel (material) technologies.

WEAKNESSES

- The strict separation of fundamental and applied research slows down innovation processes.
- Lacking structure for transfer of fundamental/ applied research outcomes to industry
- The EU lacks relevant multidisciplinary engineering education programs at Universities and Colleges and life-long learning programs.
- The EU innovation activity is weak. Although significant know-how exists in Europe, the collaboration between entities that possess this knowledge is not strong/efficient.
- Research partly focuses on hyped materials and technologies (excluding potentially better but less "innovative" solutions).
- Multi-material research and development currently lacks focus especially on EoL options.
- Lack of data and the uncertainties around data ownership prevents the implementation of AI/ machine learning.
- Lacking adoption of intelligent knowledge and data management systems connected with lacking compatibility of different data types
- Open Innovation stops usually at TRL 6/7 due to competitiveness reasons which slows down higher TRL development steps.

- Industrial point of view on intellectual properties hinders the fast uptake of promising technologies (lack of open access to R&I outcomes)
- Lacking investments of OEMs in lightweighting:
  - Automotive lightweighting requires new architecture and hence new production plants. Uncertainty about future mobility architectures is freezing investments
  - Innovative materials not always implemented in series because of existing investments in manufacturing lines
- Lack of communication and openness between stakeholder in the value chain (e.g. OEMs and their suppliers) or even departments (design & development and testing & validation) lead to unclarities about requirements.
- Complications for non-EU entities to do business with EU entities (very time- and cost-intensive processes) hindering important collaboration.

- Slow regulation and legislation processes within the EU
- Regulations on safety, emissions, sustainability and circularity create uncertainties.
- Environmental impacts outside the EU are not considered in regulations (e.g. material sourcing impacts).

OPPORTUNITIES

- Better use of M&S tools and AI throughout the lifecycle
- Implementation of methodological product development and systems of systems (SoS) thinking
- Increasing research in design and optimization of multiparameter design systems
- New university programs with an interdisciplinary focus
- Creation of a pan-European organization to coordinate research transfer.
- The available infrastructure (Research/ Value Chain) and open innovation offer opportunities to become the global leader in affordable lightweight materials and technologies, recycling of composites, circular economy and reversible structural adhesives.
- New vehicle configurations will require new modules/component design. This creates the opportunity to design vehicles having in mind lightweight material manufacturability.
- Combining efforts for developing multifunctional materials/ components with lightweight character (combine forces with people from multidisciplinary areas) can reduce development costs.

- New emerging business models make more expensive lightweighting technologies viable.
- Shared mobility concepts create new business cases for lightweighting.
- The new era of mobility brings the opportunity for OEMs to closer cVollaborate which enables them to address multiple challenges (e.g. costs, common material qualification, circularity).
- New design approaches are required offering the opportunity to develop common component interfaces (e.g. interchangeable parts that increase circularity). Commonly developed parts would increase production volumes which can influence the choice of lightweight technologies.
- Mobility trends influence vehicle configurations and architectures. This creates an opportunity to integrate lightweighting early in the design.

- Creating competitive value through LCA-based regulations.

THREATS

- The inability to develop acceptable sustainable end-of-life (EoL) technologies/ scenarios poses a threat for the application of (certain) lightweight technologies.

- Lightweighting is not a priority of European carmakers since the market is not asking for it.
- The EU heavily relies on non-EU countries for raw material supply especially for alloying elements creating material dependencies.
- Local players in the export markets show growing technological expertise and suppliers and/or equipment manufacturers are being acquired by players outside the EU.
- New vehicle concepts driven by mobility trends might have entirely new requirements which current LW techs might not comply with. The industry might need to come up with completely new LW approaches.
- The European Lightweighting sector faces a shortage of skilled human resources due to a high turnover of employees and increasing need for innovative solution.
- Main growth in vehicles sales (potential lightweight applications) comes from outside Europe (mainly US and Asia-Pacific).

- Unbalanced technology promotion (e.g. EVs) leads to a neglect of other valid solutions.
- Changing political environment/ instability (e.g. the US and China trade war, Brexit impacting the EU, and overall instability in the middle east) creates disturbances in the complex and interwoven value chain that relies heavily on partners in these regions.

Table 1 SWOT analysis for the European automotive lightweighting scene.

5. Lightweighting drivers and barriers

Many technological breakthroughs in material laboratories and design departments have led lightweighting to unprecedented levels. But lightweighting with its R&D landscape and value chain is also always influenced by external factors. Societal, policy, economic drivers and finally mobility trends all impact the priorities and strategies of OEMs and will continue to influence the future of European lightweighting. Those drivers can be related specifically to certain material technologies and practices or to the lightweighting approach in general.

The main drivers have been identified and assessed and are portrayed in Figure 10. Those drivers can have both positive (driving) and negative (decelerating) as well as undefinable effects/ impacts, with no clear "net" impact. In the following section, the most critical drivers related to policies and regulations as well as the market trends are discussed in more detail.

5.1. Policies and Regulations

The regulatory framework for European car manufacturers is a complex and constantly changing construct creating the boundary conditions also for automotive lightweighting.

Throughout a vehicle's life cycle, regulations that influence lightweighting exist - covering all steps and stakeholders in the value chain from emission targets for material extraction and manufacturing, over emission standards and safety regulations in the use-phase to regulations on waste and circularity at EoL.

The combination of regulatory requirements and boundary conditions does not clearly favour any specific materials category; on the other hand, the present landscape also does not offer a completely holistic and fair framework to incentivise the choice for lifecycle impact optimising choices in car design.

5.1.1. Vehicle emission regulations (use-phase)

Over the last decade, national and European regulations on emissions during the use-phase have become stricter step by step. The trend furthermore goes towards increasingly tightened regulations at a local level (e.g. vehicle bans in cities). Figure 11 shows the evolution of regulation targets for the past and coming years and the targeted evolution for emissions

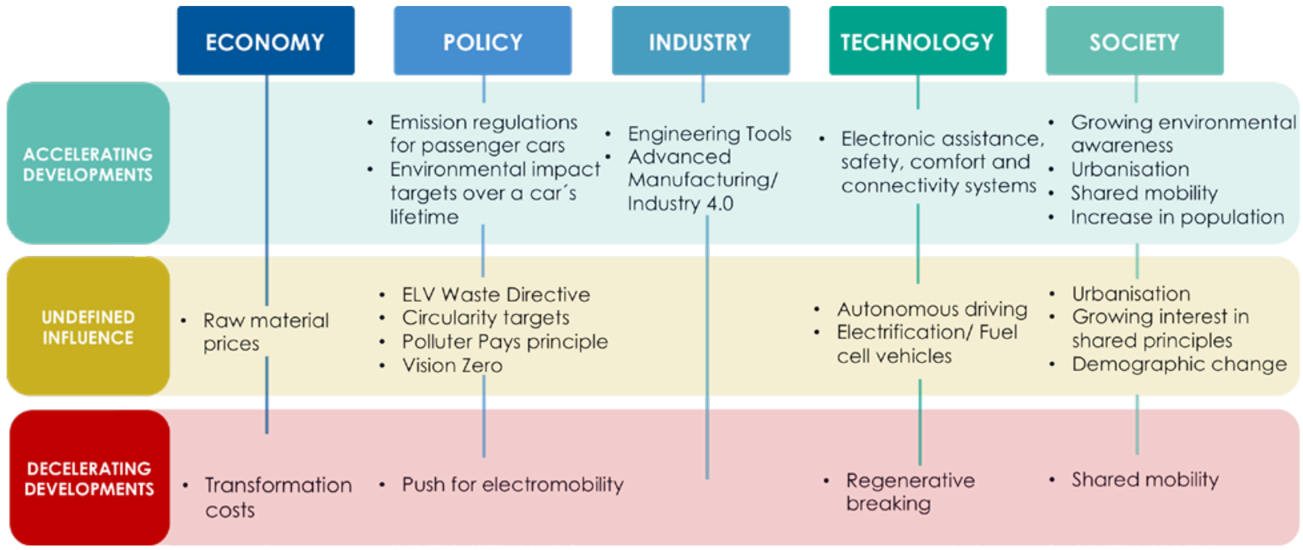

Figure 10 Drivers of change and their impact on lightweighting.

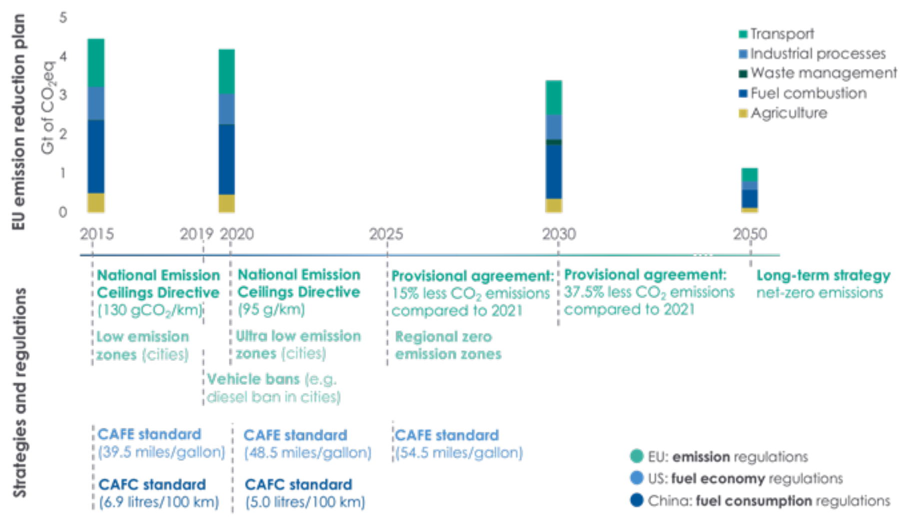

Figure 11 Evolution of EU emission regulations and the expected impact on overall EU GHG emissions plus regulations in the US and China (Source: EEA)[24]

> **"While some carmakers are shifting more towards alternative powertrains, others may primarily focus on developing highly energy-efficient ICE-driven cars"**

in different sectors in the EU until 2050. According to the EC, transport emissions should be reduced to a third of the current emissions by 2050.[24]

Around the globe regulations are based on different strategies. While the EU bases their regulations on emission targets, the US and China are focusing on fuel economy and fuel consumption – the differences of course increase the complexity for the globally operating carmakers. Such regulations are translated into different OEM strategies. While some carmakers are shifting more towards alternative powertrains, others may primarily focus on developing highly energy-efficient ICE-driven cars. Both approaches actually benefit from weight reduction, but the ability of carmakers to invest themselves heavily in this area is conditioned by the wide range of R&D investments that they need to make in order to maintain their future competitiveness.

5.1.2. Material related regulations: The ELV Directive and beyond (extraction emissions, critical raw materials, circularity

With the global material footprint rapidly growing and outpacing population and economic growth – the UN sustainable development goal 12: "Ensure sustainable consumption and production patterns" is increasingly receiving attention. In Europe, the policy framework includes several regulations and strategies currently focusing mainly on the EoL.

The ELV Directive aims at making dismantling, recycling and reusing more environmentally friendly and minimizing the presence of hazardous substances with clearly set targets.

Currently, the implementation and success of the Directive are reviewed with a stricter and more ambitious version expected to be introduced by 2021. Separability and ease of dismantling are expected to be key aspects affecting lightweighting options. Since multi-material options are more challenging to comply with such regulations (dismantling and material-specific recycling becomes more difficult), few-material approaches could be favoured (probably metals). This, in turn, eases manufacturing and assembly processes for OEMs significantly but limits the lightweighting potential and, therefore, the decreased energy or fuel consumption. As for the future, it is expected that extraction and processing of materials will be in the focus. This might cause shifts in material choices. Although restrictions for certain materials are at the moment not expected, there might be higher tolls for certain materials imported to the EU as seen before with steel from China. Material-

[24] European Environment Agency (EEA), Greenhouse gas emissions from transport, September 2018

specific regulations especially related to circularity will be on a more sophisticated level in the future. This will require specific data on environmental performance throughout a vehicle's lifecycle. Zero-emission targets are expected to be broken down in the future also to the material-level leading to increasing requirements on materials.

5.2. Market trends (future mobility)

As new technological, societal, economic and political developments are in motion, the automotive market is in the midst of a historic change. Those trends that already start shaping mobility are an increasing adoption of alternative powertrains (specifically electromobility) and shared mobility coupled with an increase in connectivity and finally level of driving autonomy. None of those disruptive developments can be looked at separately (e.g. shared mobility will go at least partly hand in hand with autonomous driving and electrification).

New trends will change the configuration/ architecture of vehicles introducing new requirements on materials and component design. Existing lightweighting (material) technologies might not comply with those in the future creating a demand for new approaches to lightweighting. At the same time these trends will offer opportunities for new players to establish themselves with innovative ideas in the market which will lead to a shake-up of the value chain. Ultimately it is expected that more materials will be entering the market. The cost for lightweighting is here an important driver or hurdle. The choice for certain lightweight materials or practices does already today and will also in the future highly depend on the type of vehicle it is applied to:

- Mass-produced vehicles vs. customized vehicles
- Shared vs. personal vehicles
- Autonomously- vs. human driven vehicles

5.2.1. Shared mobility

On average private cars are used only 4% of their lifetime. If depreciation, repair and maintenance costs are allocated only to the time of use then the cost per kilometre can be actually substantial. This fact, together with changing consumer preferences and the advancing urbanisation has resulted in consumers (especially younger generations) questioning car ownership.[26] The trend is fuelled by aggregators with "use & pay as per requirement" services which constantly optimize their models and offer high coverage at more affordable prices leading to a high acceptance. Especially for short-distance travellers, shared mobility offers a monetary incentive (compare Figure 13).

" Material-specific regulations especially related to circularity will be on a more sophisticated level in the future. This will require specific data on environmental performance throughout a vehicle's lifecycle"

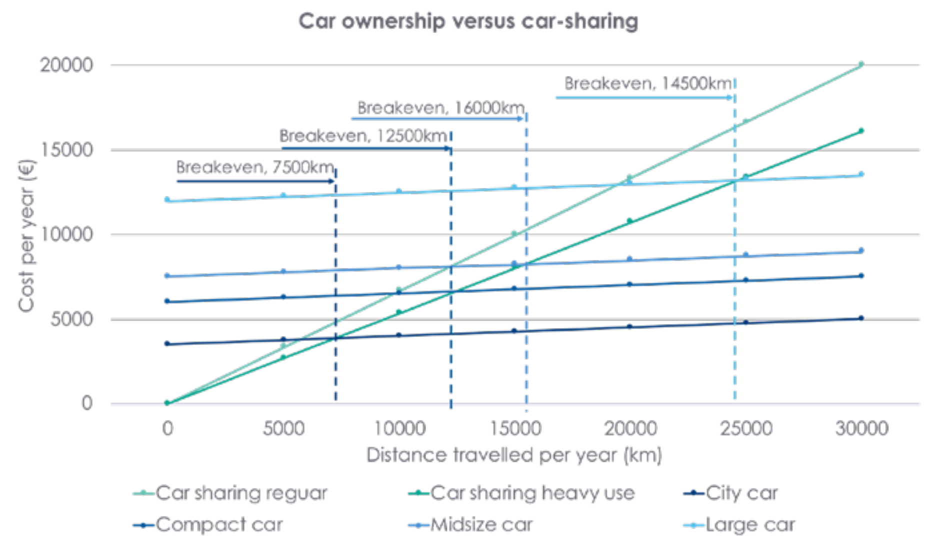

Figure 13 Cost analysis of car ownership versus car-sharing in relation to yearly-driven distance (Source: ADAC, car-sharing companies and BCG analysis)[27]

[26] Eljonna Pöllänen (MaaS Global Ltd.), Mobility as a Service - The End of Car Ownership, 2019
[27] Deloitte Consulting, The Future of the Automotive Value Chain - 2025 and beyond

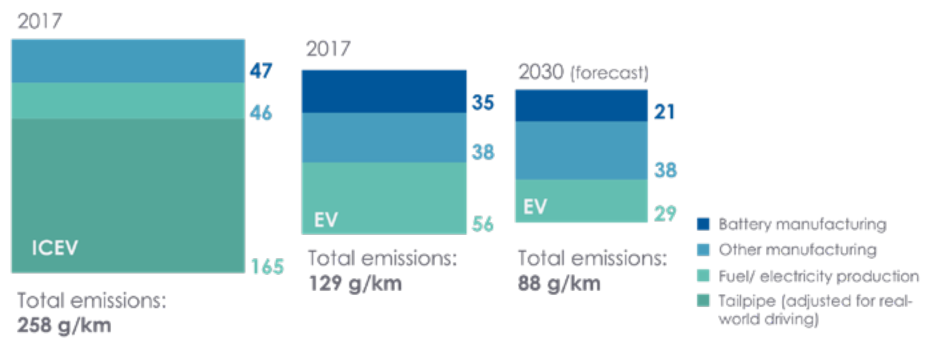

Figure 14 Average lifecycle (150,000 km) emissions of electric cars in Europe in 2017 and 2030 (Source: ICCT)[32]

Ultimately this leads to a shift in the loyalty from brands to car-sharing providers or platforms. Hence, several carmakers are exploring ways to become car-sharing fleet operators (examples for such already exist e.g. Daimler's car2go, BMW's ReachNow or Volkswagen's WeShare) or establish partnerships with providers. Deloitte expects that by 2025, globally up to 36%[27] of all citizens will be using shared mobility concepts.

Whether in the future car sales will decrease highly depends on whether cars will be built more durable or will be replaced much more frequently due to their more intensive use. Nonetheless, new vehicle concepts that meet the requirements of users and operators must be developed.[28]

For the automotive value chain it is essential to understand what is driving the popularity of shared mobility and how it will affect their business, i.e. which type of vehicle, and which lightweighting concept is required. This can be locally very specific also since regulations for such shared mobility concepts are starting to be crafted. The current regulatory framework is fragmented since car-sharing is individually regulated e.g. at city level which leads to growth at different speeds and different forms in the regions.[29]

5.2.2. Electromobility / Alternative powetrains

Since the beginning of this decade, electromobility has become the prevalent solution for the reduction of transport-related emissions. This led several OEMs to base their future strategy partly or entirely on electrification. Since 2016, Europe is the second biggest market for electric vehicles, only outpaced by China and followed by the US. According to PwC, the share of electric cars in global car sales will be 55% by 2030, with ICEs slowly disappearing.[30]

The boom for electromobility is currently driven by the promise to eliminate emissions during the use-phase entirely. In fact, although direct emissions are prevented due to the elimination of the combustion process, the emissions related to energy production still have to be taken into consideration. Those represent, with the current EU energy mix, still a big share of around 43% of the total CO2 emissions of EVs (see Figure 14).[31]

In the future, if electric powertrains become the majority, lighweighting technologies as a means to reduce emissions may become less important due to the parallel increase in renewable energy sources, as well as the ability to regenerate energy from braking. Yet, although mixed opinions on the relevance of lightweighting for electromobility exist, the general understanding is that lighter vehicles will be still relevant with the objective to increase the range per charge for electric-powered vehicles.

" Deloitte expects that by 2025, globally up to 36% of all citizens will be using shared mobility concepts"

[28] PwC, Five trends transforming the automotive industry, 2017-2018
[29] McKinsey, How shared mobility will change the automotive industry, April 2017
[30] PwC, Five trends transforming the automotive industry, 2017-2018
[31] International Council on Clean Transport Europe (ICCT), European vehicle market statistics – Pocketbook 2018/2019
[32] International Council on Clean Transport Europe (ICCT), European vehicle market statistics – Pocketbook 2018/2019

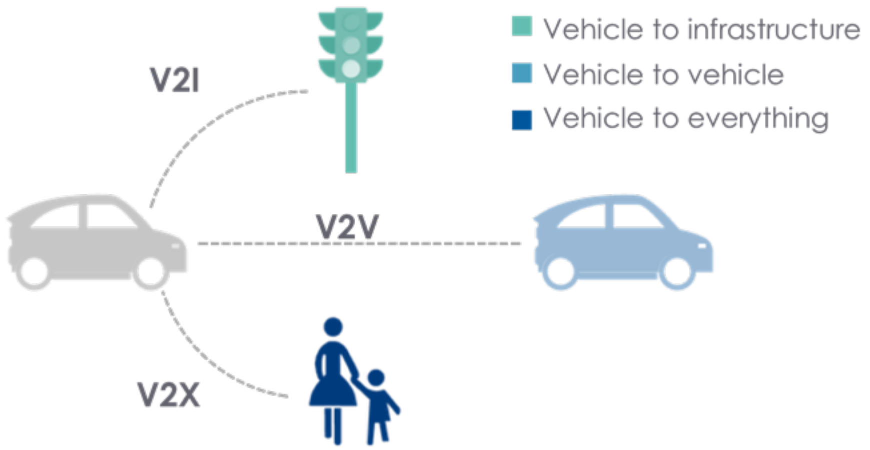

Figure 15 Connectivity as an enabler for autonomous driving (Source: PwC)[34]

5.2.3. Autonomous driving/connectivity

In the EU more than 95% of all traffic collisions are caused by human error, which led in 2017 to more than 25,000 deaths on European roads. Among the drivers for autonomous driving which include the protection of the environment, comfortable driverless experience for passengers or accessibility to personal transport, the drastic decrease of traffic accidents is the most important one.

In modern cars driving assistance and other features such as adaptive cruise control and lane-departure warnings or predictive ride technology are (becoming) already the standard.

The introduction of such digital technologies gradually decreases the responsibilities of the driver ultimately reaching self-driving vehicles. By 2030 McKinsey projects that 15% of all vehicles sold will be fully autonomous if all points such as building or retrofitting the infrastructure, dealing with cyber security issues and developing the supporting regulatory framework will be addressed thoroughly.[35]

Connectivity is one of the main enablers for autonomous driving since reliable high-speed data transmission to devices throughout the vehicle and to devices of other vehicles, infrastructure or road users is its precondition. Connectivity will also play an important role in shared mobility concepts to meet new lifestyle and workplace requirements of users. The trend creates the need for lightweight, multifunctional materials and components (e.g. a lightweight interior panel will also need to serve as a touchscreen or will have antennas embedded) as the key enabling hardware adds weight which can be up to 200 kilograms[37].

5.2.4. Impact of mobility trends on lightweighting

All those discussed trends and emerging technologies are impacting vehicle architectures and material concepts, thus, influencing research and innovation on lightweight materials in many different ways. Table 2 summarises expert opinions on the impact of such trends and new technologies on lightweighting. Even though changes are expected in the way weight reduction will be performed or in which type of materials will be used, lightweighting will be crucial for the next phases of mobility also beyond emission reduction.

> **"The boom for electromobility is currently driven by the promise to eliminate emissions during the usephase entirely. In fact, although direct emissions are prevented due to the elimination of the combustion process, the emissions related to energy production still have to be taken into consideration"**

[33] European Parliament, Self-driving cars in the EU: from science fiction to reality, January 2019
[34] PwC, Five trends transforming the automotive industry, 2017-2018
[35] McKinsey&Company, Automotive revolution – perspective towards 2030, January 2016
[36] Billington J., Connectivity challenges for next-generation autonomous cars, October 2018
[37] 3M, The promise of lightweighting, 2018

SHARED MOBILITY	ALTERNATIVE POWERTRAINS	AUTONOMOUS DRIVING/ CONNECTIVITY
• A shift in material choices for lightweighting is expected as shared vehicles have a much higher utilization leading to a higher use-phase impact on the overall lifecycle carbon footprint. Certain solutions would have a higher potential for lowering the carbon footprint in a long life cycle even though their production emissions are higher. • Certain lightweighting technologies become more attractive and others less economically viable as production volumes change. Changing boundary conditions (e.g. urbanization) and new consumer preferences, likely will change production volumes. • The development of lightweight technologies might be accelerated since new vehicle concepts that meet the requirements of users and operators for shared mobility must be developed. This will create the opportunity to rethink the overall design and integrate lightweighting solutions at an early stage. • Reducing the weight will become more important since shared mobility might show changes in payload requirements (e.g. for shuttles).	• Lightweighting in EVs may be accelerated since battery manufacturing for EVs has a high CO2 impact increasing the urgency to balance these emissions out in other phases. • The need for lighter cars could be accelerated due to EVs adding more requirements to safety which increases weight, e.g. the battery needs to be protected during a crash (applies to FCEVs for H2 storage tanks protection). It will be important to maintain the mass of the vehicle under a limit so users can drive it without requiring a different type of license. • Lighter cars will reduce the energy consumption and, therefore, increase the driving range which ultimately leads to reduced operating costs in the use phase. • The "urgency" to make vehicles more efficient, may be reduced due to energy regeneration from braking in EVs (temporary effect and will just apply for short-distances). • Lightweighting will be less important for the purpose of reducing emissions in the use phase with an increase in renewable energy sources. This is a far-future scenario and highly territory-specific therefore the impact is regarded insignificant at the moment. • The attention of OEMs could be diverted away from lightweighting research due to future efforts in developing EVs and fuel cell vehicles.	• R&D in advanced (lightweight) materials will be fuelled by the urgency to develop multifunctional components which play an important role in information systems and in-vehicle entertainment. • An increase in lightweight materials with lower structural properties is expected due to a decreasing need for structural components in vehicles in a scenario where autonomous vehicles are the majority. • The attention of OEMs could be diverted away from lightweighting research due to future efforts in developing autonomous technologies. • Lightweighting might be affected by changes in the vehicle architecture due to changing crash configurations/ crash-test requirements since autonomous driving promises absolute compliance with speed limits. This might lead to predominantly shorter cars due to a reduced crumpling zone. • Low-emission lightweight material will become important to compensate for high emissions in the use-phase. The operation of cameras, sensors and guidance systems in every vehicle is required. Thus, the amount of server capacity and activity globally will increase drastically. With diesel generators typically backing up the server mainframes, the emission output is expected to be immense.

Table 2 Impact of different trends in mobility on lightweighting

6. Lightweighting dilemmas, controversies and discussions

In the area of lightweighting several dilemmas, discussions or controversies that stem from the introduction of new materials, the regulatory framework or consumer preferences among others lead to insecurities and unaligned agendas among OEMs. The most frequently and intensively discussed ones are exemplarily highlighted below.

1 Multi-materials versus ease of recyling

Lightweighting often suggests a multi-material approach to decrease weight and consequently to offer optimum GWP emission reductions during the use-phase. Yet, multi-materials solutions may not be optimal in terms of circularity, since mixed material- streams create challenges at EoL. Vehicle configurations with only a few materials on the other hand offer favourable end-of-life options/ circularity performance, yet might be limited in reducing the weight. A certain trade-off related to the ELV Directive and National Emissions Ceiling Directive seems with current technologies unavoidable.

2 Heavier cars on average safer than lighter ones

Although advancements in safety measures made small cars safer than ever, physics gives heavier cars an inherent advantage in crash situations and in particular in frontal crashes since a heavier car would push the lighter car backwards reducing the force on the occupants in the vehicle. A study carried out by the Insurance Institute for Highway Safety (IIHS) found that very large SUVs had the lowest fatality rate in 2015 compared to all other vehicle types while the highest was found in mini cars.[38]

3 Consumer preferences for spacious cars

Although lightweighting efforts increased significantly, the average mass of cars did not decrease. This is due to the increasing sizes of vehicles, driven by consumer preferences for comfortable and spacious cars. Although safety, fuel economy and the brand are often named as important criteria for buyers, vehicle size and comfort are especially in the US and in the European market a determining factor for a buyer's decision. In the EU, SUVs were the fastest-growing segment in the last 10 years making up about 35% of the vehicles on European roads. In comparison, the SUV penetration in the US market and in Asia-Pacific is at 45% and 27% respectively. At the same time the share of small and mini cars continues to decrease.[39,40]

4 New materials groups (bio-based etc.) add complexity to the material choice

There is confusion on biomaterials among the industry. The term is often associated with bio-based materials although it is much broader combining all materials either based on biomass or biodegradable - or both. Consequently-, fossil-based biodegradable materials are as much considered as (non-)biodegradable bio-based materials.[41]

The impact of bio-based materials and their overall lifecycle performance is still under considerable debate due to lack of experimental data. Bio-based materials have lower non-renewable energy use and GHG emissions, yet increased land-use which also translates in GHG emissions. Another consideration to be made evolves around the question whether biodegradation of the material at the end of use is more favourable than keeping materials in the technical cycle. Straightforward answers for both discussions don't exist but have to be understood on a case-by-case level. Therefore, an evaluation of all materials in a holistic way is required to allow for sustainable material choices.

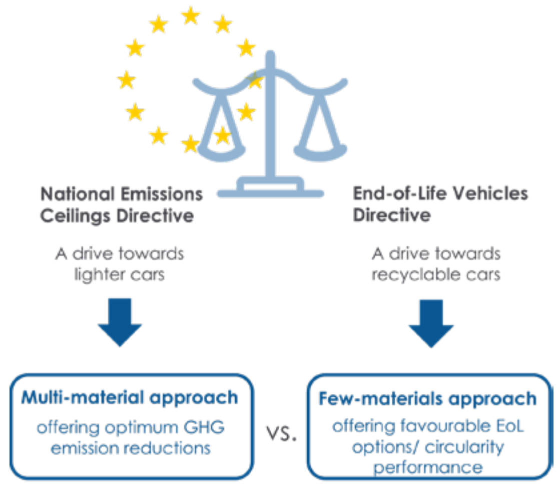

Figure 16 The controversy between the EU emission and circularity targets

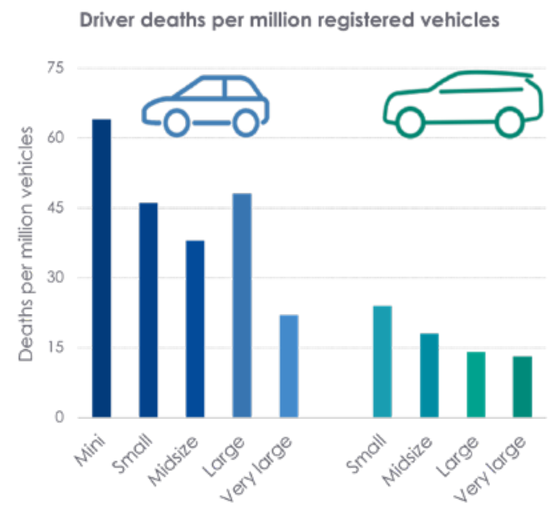

Figure 17 Driver deaths per million registered passenger vehicles 1-3 years old (Source: IIHS)[38]

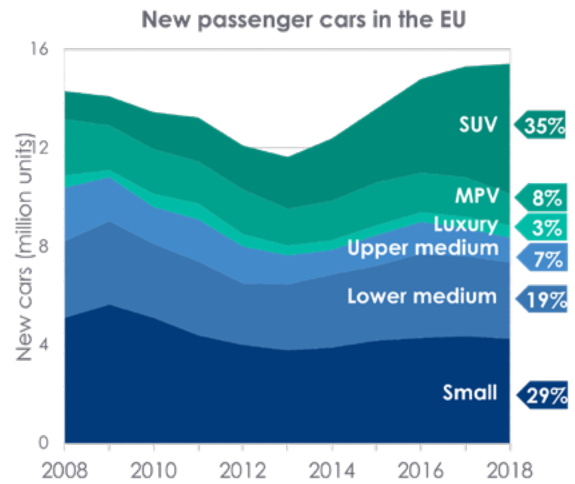

Figure 18 Shares of vehicle types in the EU in 2018 (Source: ACEA)[39]

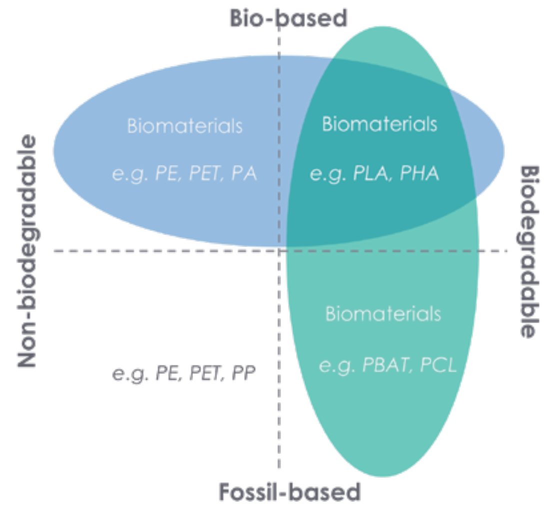

Figure 19 Biomaterials introduce new solutions and new challenges (Source: European Bioplastics)[41]

38 Insurance Institute of Highway Safety (IIHS), Fatality Facts 2017 – Passenger vehicle occupants, 2018

39 European Automobile Manufacturing Association (ACEA), The Automobile Industry Pocket Guide 2019-2020.

40 F. Munoz (Jato), Global SUV boom continues in 2018 but growth moderates, 2019

41 European Bioplastics, Fact Sheet: What are bioplastics?, 2016

7. Scoping lightweighting: Challenges and proposed innovation actions

Among the many challenges faced within automotive lightweighting three main points have been highlighted in the discussions with value chain players. These refer to the **affordability** of lightweighting, the time required to introduce novel solutions in mass-produced cars (material qualification, innovation mainstreaming) and the **environmental impact** (circularity, emissions etc.) of these solutions.

This vision document is aimed at showing the way forward in European lightweighting. It highlights the potential that is still unused, the developments and research still to be done related to the strengths and weaknesses of the European lightweighting scene focusing on these three main challenges. Challenges can be addressed by several innovation activities at the same time, in parallel or following different approaches. Each point that addresses a challenge bears more challenges in itself. Innovation activities stem from the market or the ecosystem or are of technical nature which clearly highlights the strong interrelation between those areas regarding lightweighting innovation. (Figure 20)

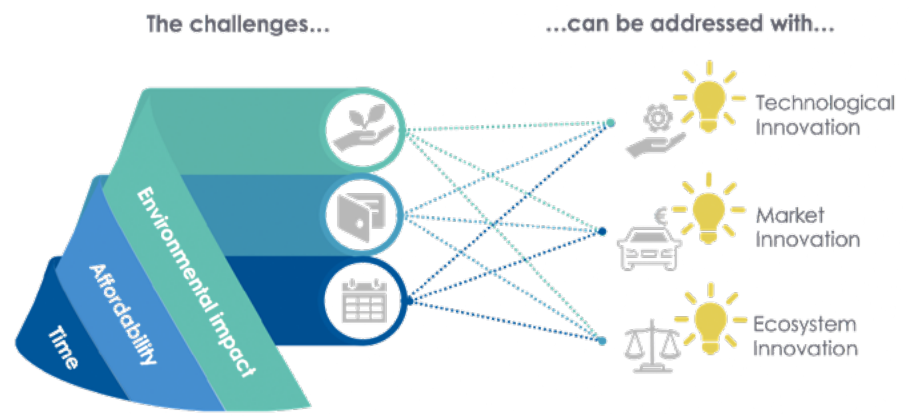

Figure 20 Methodology for challenges and the related proposed innovation actions

7.1. Challenge: Affordability of lightweighting solutions (cost)

Affordability remains an issue for many lightweighting solutions. The highest performing lightweight solutions suffer from high raw material prices (alloying elements, carbon fibres), high manufacturing costs (tooling, equipment, machinery, labour-intensive processes) and long cycle times (process and delay times) leading to overall higher costs in comparison to traditional solutions preventing the introduction of materials in mass vehicle production.

Additionally, as the industry is challenged by new mobility trends, the integration of additional functions is an important focus in R&D. Yet, apart from insufficient performance, multifunctionality is currently limited by too high additional costs for mass-market applications.

The correlation between fuel or energy consumption and a vehicle's weight creates an economic benefit for the customer. At the same time, the lightweighting acceptance (what the customer is willing to pay for it) is not in line which leads to costs being carried by OEMs and suppliers. This makes it increasingly difficult to make the business case for lightweighting.

Several opportunities exist to address the cost challenge focusing on different steps in the value chain. Some of them are discussed in more detail in the following.

"Additionally, as the industry is challenged by new mobility trends, the integration of additional functions is an important focus in R&D. Yet, apart from insufficient performance, multifunctionality is currently limited by too high additional costs for mass -market applications"

7.1.1. Automation and advanced manufacturing

Many materials and parts are manufactured still in labour-, resource- and time-intensive processes which is ultimately also reflected in costs. Many of such processes still have the potential for an increased level of automation. Furthermore, advanced manufacturing technologies such as additive manufacturing (3D printing) reduce at least partly the reliance on external vendors and can speed up certain processes (e.g. tooling) or enable repair of components of high-value material reducing costs.

- Innovate raw materials processing and component shaping technologies with efficient and fast automation for mass production e.g. to ease handling of the flexible fibres in case of FRP or to allow for functional integration at acceptable cost. Hand in hand with this goes better production planning and set-up to reduce cycle times. The trend is now going to more flexible production lines.
- Further develop advanced manufacturing technologies (e.g. additive manufacturing) and increase the variety of advanced printable materials.
- Develop and introduce agile production methodologies.
- Better understand the potential and make use of blockchain for the collection/sharing of reliable data within the automotive value chain which is secure, access-regulated and instant.

7.1.2. Secondary materials

In some cases, secondary materials have the potential to reduce material costs. This is mainly due to the significantly lower energy consumption as e.g. for steel as electric arc furnace smelting for steel production from scrap requires only a third of the energy for virgin material production.[42]

For many materials recycling technologies and routes for reintroduction are well explored (e.g. metals) other materials are lacking behind (e.g. FRP). The innovation actions required are highlighted below:

- Further innovate material formulation/ combinations with secondary materials (e.g. fibre fillers) to reduce costs while maintaining performance.
- Increase the quality and quantity of recycling for lightweight materials by advancing recycling and separation processes.
- Develop surface coatings to enhance the properties of secondary alloys in order to increase durability.

[42] United Nations Environment Programme (UNEP), Metal Recycling: Opportunities limits, Infrastructure, A Report of the Working Group on the Global Metal Flows to the International Resource Panel. Reuter, M. A.; Hudson, C.; van Schaik, A.; Heiskanen, K.; Meskers, C.; Hagelüken, C., 2013

- Develop new business models e.g. by coupling the return-to-producer principle with closed-loop recycling wherever possible.
- Facilitate the recycling of scrap (e.g. aluminium)
- Better organise the reverse supply chain to ensure consistent volumes and clean waste streams which are the precondition for the mass introduction of secondary materials.
- Support the certification of secondary raw materials, the introduction of material passports for material identification and review the standards for vehicle dismantling to enable improved looping processes.
- Update regulatory framework on export of waste components so that waste components can be delivered across borders to material-specific recycling plants (especially important for thermoset FRP).

7.1.3. Lifecycle costing

An LCC analysis supports decision-making by providing with a holistic picture of the cost at an early stage, which allows a more comprehensive and informed comparison at all levels of the product's life. Such a tool will detect the steps that are cost-effective allowing targeted innovation actions to reduce the cost in this area.

Currently, many models lack adequate data or use secondary data from literature databases which makes the models inaccurate. Only few commercial LCC tools exist, and none of them has been established as a prevalent way of estimating lifecycle performance of automotive parts. Therefore, further development is required, to achieve useful and powerful decision-making tools.

- Improve the granularity of cost categories by including additional manufacturing processes, as well as by increasing the granularity in the estimation of various cost categories for each step
- Include feasible EoL scenarios modelling
- Significantly improve the accuracy of models by validating those with OEM and supplier input data.
- Develop open-access databases with data set boxes that don't disclose sensitive data.
- Perform validation cycles with stakeholders of the entire value chain from raw material sourcing to the end-of-use.
- Standardisation of the LCC approach as well as clear definition of boundary conditions.

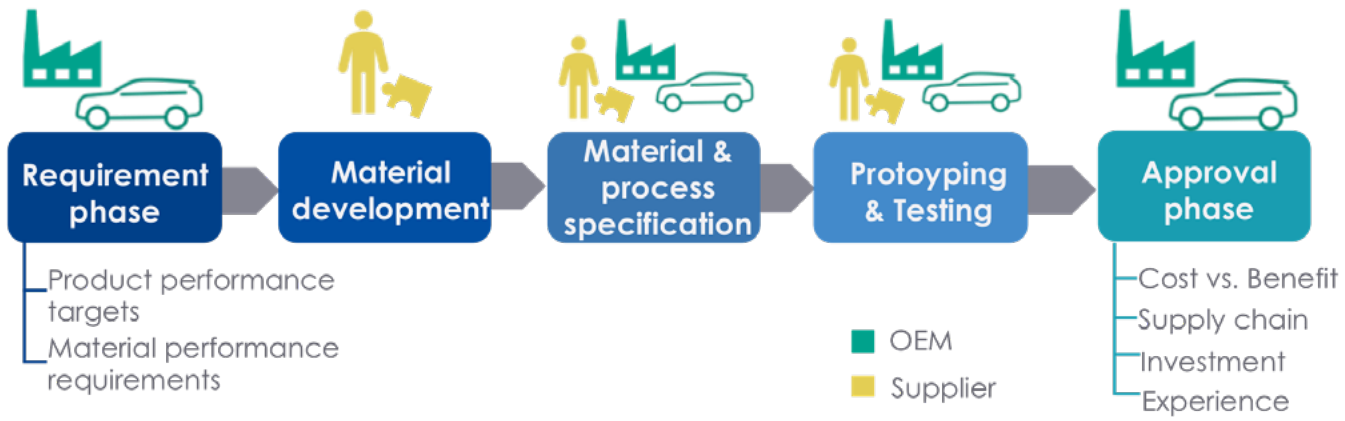

Figure 21 The material qualification process

7.2. Challenge: Time for novel material qualification and innovation mainstreaming

Lightweighting grew into more mature phases due to many breakthrough advancements in material and process technologies as well as in design approaches as seen in the last decades. Yet, the question remains why many more recent innovations have not yet made it into main-stream cars.

Currently, the process only for material qualification stretches over several years (up to 9 years). The long voyage from R&D results to mass-produced car designs is due to the need to manage risks (e.g. robustness of supply chain), ensure viability (compatibility with other materials, skill-set of workforce) and safety and maintain affordability, business viability and growth. This is also to the lack of understanding of systems as a whole.

The lack of understanding on how new mobility concepts, evolving legislation and societal changes will shape the requirements for future vehicle architectures and ultimately for the materials is fuelling the reluctance to invest in certain technologies. This is due to increased complexity to fully understand risks. E.g. by the time a material is ready for introduction the requirements could have changed.

Opportunities to reduce the material qualification time and the time for innovation mainstreaming are manifold. In general, the industry requires closer collaboration between involved actors to reduce the time needed to move through all the phases from R&D success to design-in into mass-produced car models. An EU-wide coordination among value chain stakeholders to pool resources and data where possible could speed up the innovation mainstreaming process substantially. Other innovation actions required in this area are highlighted in the following chapter.

> **" The lack of understanding on how new mobility concepts, evolving legislation and societal changes will shape the requirements for future vehicle architectures and ultimately for the materials is fuelling the reluctance to invest in certain technologies"**

7.2.1. Advanced modelling/ simulation tools

Advanced modelling and simulation tools opened up opportunities for unprecedented levels of material and design optimization - from the full vehicle all the way down to the nanoscopic material level. In early design stages M&S tools allow to digitally experiment with more lightweight materials and test those components in multiple scenarios speeding up qualification processes since the tools minimize the need for physical tests to verify performance, tolerances, long term behaviour which are time- and resource-intensive. Furthermore, additional support tools and methodologies (e.g. Extended Target Weighing Approach, design optimization methodologies, AI-supported design) allow to adapt the component design to material properties and prioritize application functions.

- Develop better and simpler M&S to understand the behaviour of technologies on different aspects early on. Here the dilemma between accuracy which is resource expensive and simplicity which has a lower accuracy needs to be balanced against one another.
- Improve simulation and semi-automated generation and assessment of design alternatives that allow to quickly and efficiently design, test, and validate new concepts that can go beyond basic material replacements (further improve model representation of physical reality)
- Further develop calculation models to reach higher accuracy and reliability. Address system calculation power, which is not sufficient for calculation systems. Study potential possibilities to improve it (e.g. mathematical approaches to make optimisation algorithms less "heavy", or increase of hardware calculation power).
- Address the diversity of tools by creating common digital interfaces.
- Implement automated workflows that make the use of M&S tools more efficient.
- Implement tools and methodologies throughout the supply chain to make use of existing data in technology development including the transfer of knowledge and development to new emerging vehicle architectures.
- Standardisation for common interfaces (e.g. file formats) between tools since existing tools show a lack in compatibility preventing seamless model transfer, coupling and co-simulation on different levels of detail.

7.2.2. Standarized material qualification programs

Collaborative efforts are required to faster introduce materials into mass-produced vehicles. Yet the necessary framework and boundary conditions are missing. The material qualification process is not standardized across the industry. In fact, it is highly dependent on the carmaker, their business and technology goals and the type of material. Addressing the issues that prevent the introduction of such a common program build to satisfy the needs of many purchasers of the material at a time would have an important impact in reducing the overall qualification time.

- Create a centralized source for material properties and performance data could improve communication among material developers, tiers and OEMs and optimize material selection.
- Innovate data collection processes: e.g. better understand the potential and make use of blockchain for the collection/sharing of reliable data within the automotive value chain which is secure, access-regulated and instant.
- Standardization of testing requirements based on material type across the industry for a faster, streamlined and cost-effective material qualification process.
- Invest in research to explore the optimal application for lightweighting technologies: It is necessary to get deeper knowledge on the dependency between parameters such as material properties and application requirements.

7.3. Challenge: Sustainability and material circularity

The reduction of the overall environmental impact e.g. raw material extraction, energy use, emissions during processing or recyclability at the EoL challenges several lightweight material technologies. As the industry leans more towards multi-material designs and multifunctionality (e.g. the integration of haptic, optic, acoustic or sensing functions), the circularity challenge is even increasing as EoL options are either not satisfying or not well explored at this stage.

Looking at the overall regulatory framework, strategies and regulations related to sustainability are complex. While some regulations favour certain materials or practices, others prioritize the opposite. This is also due to the lack of data on the lifecycle impact of technologies which can lead to erroneous conclusions or guestimates.

Solutions to improve the environmental impact are manifold in the following some options are highlighted. The introduction of secondary materials as discussed previously is not highlighted again, although it is, of course, a key innovation.

7.3.1. Life cycle assessments (LCA)

A holistic assessment of the environmental impact of a material/ component throughout its lifecycle gives an understanding where the shortcomings of materials are and gives an important decision-making tool for designers and for end-users. LCAs are a well-investigated tool but have certain shortcomings such as for example complexity and lack of databases which have to be addressed.

- Increase level of automation of software to make the data collection and evaluation of the assessment less time -intensive.
- Further develop objective, data-driven tools for Life Cycle Cost and Environmental Assessment.
- Create a holistic and objective understanding of the lifecycle impact of all technologies to make sure that all resources are used efficiently and that the environmental impact of a material can be included in the decision process in early development stages.
- Create common full LCA databases for different processes: Ensure that the data that is used is openly accessible and always up to date.
- Review of current standards and harmonization of approaches as well as clear definition of boundary conditions to reduce the diversity of tools and methodologies and the complexity.

" As the industry leans more towards multi-material designs and multifunctionality (e.g. the integration of haptic, optic, acoustic or sensing functions), the circularity challenge is even increasing as EoL options are either not satisfying or not well explored at this stage"

7.3.3. Design for circularity

Circular Product Design Principles allow to create solutions that are regenerative, resilient, create long-lasting value in the circular economy and give businesses a competitive advantage. It requires the understanding of all aspects of circularity and what it means for the implementation of the principals in new products.

This rather new design methodology requires a holistic design approach covering all steps from material to product design. Seamless joint development is therefore required which is among other points challenging.

- Increase the circularity of lightweight solutions by improving the materials. E.g. develop thermoset polymers with reversible cross-links or composites using thermoplastic polymers that comply with structural requirements.
- Ensure that EoL options are clearly defined during the design.
- Create and implement common design principles and methodologies among the stakeholders of the automotive value chain that include circularity practices preventing waste generation at the end of the first useful life to a certain extent.
- Revise regulatory framework: The focus of circularity regulations needs a shift from the processes at EoL towards the design stage. This will ensure that options such as reuse, refurbishment and prevention can be clearly defined. Leading to solutions at the end of the first useful life that are much more favourable than recovery, recycling or even disposal.

7.3.4. Bio-based material solutions

Bio-based materials, including composites based on natural fibres such as flax, bamboo or hemp and bio-based matrices, or wood composites and laminates show a significant lightweighting potential and are increasingly explored for high-performance, structurally demanding applications.

Their renewable, sometimes even biodegradable character as well as the fact that materials can be usually manufactured at low cost and low emissions make those an attractive solution if the materials can also comply with requirements. This is to-date still one of the biggest challenges that next to others needs to be addressed thoroughly.

- Innovate manufacturing/ finishing processes to counterbalance variable mechanical properties as well as to improve performance of the materials.
- Fully develop the manufacturing processes for large scale production as for many of the materials under investigation those are not yet available.
- Develop open-access databases to overcome the limited availability of experimental data.
- Certification of bio-based materials

7.4. Overarching innovation actions

The innovation actions identified by the contributors as overarching are summarised in the following paragraph.

Holistic approaches to lightweighting that look into various aspects to address various challenges emphasizing on the issue of time, cost and sustainability at early research stages have to be developed. This requires a new generation of multidisciplinary engineers giving professionals the right tools to understand systems as a whole and not just individual parts. A review of education programs at Universities and Colleges and the creation of a framework that supports life-long learning programs is necessary.

In general, many of the highlighted challenges should be addressed jointly such as the issue of common digital interfaces, standardized material composition and material qualification processes as well as the creation of new material value chains. Further (financial) support to enable such a collaboration between stakeholders is required setting the right boundary conditions for a competitive European lightweighting arena. Here also Open Innovation Challenges are credible tools to address all kinds of common challenges as are lighthouse projects. The institutionalization of such competition prizes will help to accelerate all kinds of innovation substantially.

Furthermore, regulations must be technically feasible and need to be based on a fair evaluation (technology diagnostics) of all innovations, technological possibilities and developments. E.g. the prioritisation of electric vehicles over ICEs leaves out certain criteria in the evaluation such as the manufacturing emissions of batteries, the use of critical raw materials, the life-time of batteries, the EoL options or the range of vehicles.

Since most new developments around lightweighting are related to new trends in mobility the creation of scenarios for different mobility trends is useful to create a common understanding on how future requirements related to safety, emissions and circularity will look like. As those requirements will shape vehicle architectures substantially, carmakers and their suppliers need to understand the impact of these trends. New vehicle concepts and their integration into future mobility concepts must be based on user experience and business case analysis. The industry needs to create the agility to identify and scale new attractive business models. This can be also supported by the creation of a common EU-wide regulatory framework for the megatrends (e.g. Mobility as a Service, autonomous driving) based on these scenarios. This involves the creation of a report on European but also national and local/ city initiatives and regulations.

8.Key findings on lightweighting

With this vision document the automotive industry acknowledges and highlights the importance of lightweighting to address a large societal challenge and the contribution to achieve the ambitious climate targets set by the European Commission and many of its member states individually. Among the insights gained during its development the following five findings summarise the main points that were discussed by the contributing stakeholders from industry and research.

1

The future of lightweighting is moving from improving the performance of a single material, to gaining a better understanding of how multiple materials can be combined in a single component.

Furthermore, combining functionalities is another strategy to reduce the number of components and an enabler for automated and connected mobility. This will require further development and combination of processing technologies which, besides enabling multi-material and multifunctional structures, will also allow for reduction of costs and cycle times, and higher resource efficiency.

2

As the boundary conditions for lightweighting such as regulations (e.g. on emissions and circularity), crash requirements and material availability/ scarcity constantly evolve, lightweighting itself will (have to) continue to evolve.

Dealing with the consequences that can be expected as a result of these ongoing changes requires collaboration and aligned approaches among OEMs and the entire value chain. The multidisciplinary character of lightweighting suggests also the combination of technological, market and ecosystem innovation. A coherent regulatory framework among member states will be securing a strong automotive value chain that operates in a global context.

3

Lightweighting efforts need to pursue a reduction of overall lifecycle emissions, not just to make cars lighter which only affects the use-phase in the lifecycle.

Materials that offer strong light weighting benefits may have an unfavourable emission footprint in their raw material extraction, material processing or EoL process. Only the combined holistic lifecycle impact assessment can offer balanced insights into the relative benefits of a specific materials combination or design solution. Full lifecycle assessments in early development stages will need to become the standard to support the decision-making process for the best lightweighting solution backed by real numbers. This requires a new level of data quantity and quality (e.g. break-even calculation for GHG emissions require reliable data from all phases of a vehicle). Databases should be open-access and the data collection process should follow standardised methodologies.

4

Lightweighting continues to offer many benefits but must be affordable to reach adoption in mass-produced cars especially with lightweighting efforts expanding beyond the BiW focussing now also on interiors and auxiliary systems.

Mainstreaming novel lightweighting technologies necessarily takes a long time, with associated risks and costs carried by carmakers/ suppliers over several years. Customers show a low willingness to pay for lightweighting due to the lack of awareness of the benefits beyond emission reduction (e.g. better driving performance, ride, handling, and braking, as well as higher towing and payload capacity and better crash properties[43]) which usually limits efforts. Therefore, substantial R&D&I efforts that cover more than just technology are required to address affordability.

5

EU research funding has improved the impact of very substantial value chain player R&D investments in lightweighting creating real impact.

Lightweighting breakthroughs have been achieved mainly through the collaboration of several stakeholders of the value chain – some even competing, as success cases from past EU research projects show. Such initiatives should be in the focus to address future challenges especially in higher TRL levels as cooperation usually stops at TRL 6/7 due to competitiveness reasons. The collaboration among stakeholders will only become more important as lightweighting and the challenges become more complex. Supported by effective EU funding, lightweighting in Europe can continue to substantially contribute to a green and competitive automotive sector.

[43] International Council on Clean Transportation (ICCT), Lightweighting technology development and trends in U.S. passenger vehicles, December 2016

ANNEX A
Material comparison

Material	Type	Performance						
		Technical Performance	Lightweighting Potential	Environmental Impact	Recyclability	Manufacturability	Material Compatibility	Costs
Steel		+++	++	+	+++	++++	+++	++++
Aluminium		++	+++	++	++++	+++	+++	+++
Magnesium		++	++++	-	++++	+++	+++	+++
FRP	CFRP	++++	++++	-	+	++	+	-
	GFRP	+++	+++	+	-	++	+	++
Polymers		+	+++	+	++	+++	++	++++

Table 3 Most common lightweight materials and their performance (Source: EMIRI)

Table 3 lists the most common lightweight materials with their performance characteristics in a comparative analysis. Not included in the list are materials such as copper and biomaterials due to lack of comparative data.

Technical performance: The first eligibility criteria for a material is the compliance with the mechanical and thermal requirements which vary significantly between structural elements and e.g. interior applications.

Lightweighting potential: The material's properties such as low density, high specific strength, or a combination of these determine the possibility of the material to decrease the weight of the component.

Environmental impact refers: to the energy demand and emissions during the extraction of raw materials and their subsequent manufacturing into applications, as well consumables used for any of these processes (e.g. water).

Recyclability of materials from manufacturing scrap and especially at EoL reflects the possibility of these new materials to be reintroduced into the economy rather than having a linear life that requires extraction of raw materials.

Manufacturability: The industry largely invests in infrastructure and manufacturing capacity, and on the other hand new materials are being developed, with significantly different properties requiring different processing approaches. this makes manufacturability (the ease with which the material can be manufactured into components) an important criterion.

Material compatibility: As the multi-material approach gains momentum the ability of the material technology to be combined with other materials with existing joining technologies plays an important role.

Cost of lightweighting: The additional cost that is required to reduce the weight of an existing solution (kg saved) is an important indicator.

ANNEX B
Facts and figures on lightweighting Materials

Facts on steel[44]

- Approximately 60% of the vehicle's weight are made of steel.
- There are more than 3,500 different grades of steel.
- Steel is roughly 1,000 times stronger than iron in its purest form.
- Two production/smelting processes are predominant: blast furnace and oxygen steel converter, producing about 75% of the world's crude steel, and electric arc furnaces (EAF process) processing steel scrap.
- Steel can be recycled without loss of properties.
- The lightweight potential and specific properties of the grades are mainly defined by the alloying elements as well as the process parameters.

Facts on Aluminium[45]

- Aluminium is lightweight, functional and economical and the second-most-common metal in cars.
- Cost of components manufactured from lightweight aluminium alloys is 1.5 – 2 times higher than that of High Strength Steel (HSS).
- In theory, aluminium can be recycled endlessly with no loss of quality. In fact, 75% of the aluminium produced in the last hundred years is still in use.
- The energy consumption accounts for around 40% of manufacturing costs.
- Bauxite the most important raw material for the production of primary aluminium is imported from e.g. Brazil and Australia.
- The performance is mainly defined by alloying elements as well as the process parameters.

Facts on Plastics[46,47,48]

- Plastics make about 50% of the vehicle's volume but only 10% of its weight.
- Around 13 different high-performance plastics are used in an average vehicle with polypropylene, polyurethane, PVC, ABS and Polycarbonate accounting for almost 70% of plastics.
- The performance is defined by the material design (molecular structure) as well as process parameters and processing technologies.
- The embodied energy for plastic production is slightly higher than that of steel but lower than the energy needed for the aluminium production (per mass).

Facts on composites

- Composites are a combination of a matrix (usually polymers) and a reinforcing material (usually carbon or glass fibres) offering high strength-to-weight ratio.
- The cost of components manufactured (CFRP) is up to 9 times higher compared to steel mainly due to material and embodied energy costs as well as high labour cost.
- The performance is mostly defined by the type, orientation, and content of the reinforcement.
- FRP allow a more efficient structural design, as fibres can be placed in the direction(s) where the main load(s) occur (best mechanical properties achieved in the direction of the fibre placement).
- Depending on the type of matrix, composites are difficult to break down or recycle. Current practices include downcycling or incineration/ landfill.

[44] World Steel Association, Steel in Automotive and About Steel (https://www.worldsteel.org)
[45] The Aluminium Association (https://www.aluminum.org/industries)

[46] American Chemistry Council (https://www.automotiveplastics.com/automotive-plastics-today/)
[47] Jerin, M., Importance of Plastics in Automotive, Efficient Manufacturing (industr.com), 2018
[48] Gutowski TG, Sahni S, Allwood JM, Ashby MF, Worrell E. 2013 The energy required to produce materials: constraints on energy-intensity improvements, parameters of demand, 2013

ANNEX C
Key Performance Indicators

Table 4 and Table 5 show some key performance indicators on vehicle, vehicle-module and mono-material part level. The values have been validated with OEMs and material suppliers.

	KPI	Unit	2019	2025	2030
Vehicle	Energy consumption	kWh/pkm	0.5	0.4	0.3-0.35
	Recycled content	% per mass	15-20	25	>35
	Cost of lightweighting	€/kg saved	3	2.5	1.5
	Lifecycle performance*	gr of CO_2/km	180/130	135/90	100/75
Vehicle Module	Recycling	% per mass	80-85	90	>95

*includes emissions from production and use. Higher value represents a highly efficient ICE, lower value an EV operating in the average EU energy mix

Table 4 KPIs on vehicle and vehicle module level
(Source: EMIRI and Bax & Company)

	KPI	2019					2030				
Mono-material Part		Steel	Aluminium	Magnesium	FRP	Polymers	Steel	Aluminium	Magnesium	FRP	Polymers
	Cost compared to steel part	1	1.5-2.3	N/A	7-9	1-10	1	1.2-2	3-5	3-7	1-7
	Degree of downcycling **	4-5	4-5	4-5	1-3	1-5	5	5	5	4	4-5

** using commercially available recycling technologies; scale of 1-5 where 5 is no downcycling, 1 is complete loss of material properties.

Table 5 KPIs on mono-material part level in 2019 and 2030
(Source: EMIRI and Bax & Company)

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