ACEA European Automobile Manufacturers Association · CLEPA European Association of Automotive Suppliers · jama Japan Automobile Manufacturers Association · kama

“11. Adaptation to scientific and technical progress of exemptions 2(c)(i). 3 and 5 of Annex II to Directive 2000/53/EC (ELV)”

To: Consultant Consortium of Bio Innovation Service (biois) and The United Nations Institute for Training &Research (UNITAR) and Fraunhofer Institute for Reliability & Microintegration (IZM))

Via Email to: **elv@biois.eu**

Cc:	DG ENV	Ms. Artemis Hatzi –Hull,	Mr. Mattia Pellegrini
	DG GROW	Ms. Joanna Szychowska,	Mr. James Copping
	Via Email		

Submission of ACEA, CLEPA, JAMA, KAMA et al. representing the affected automotive industry including the supply chain to the stakeholder consultation published by Biosis on 15.Sept. 2020 on the review of three entries in EU ELV Directive Annex II. 08. December 2020

Foreword

This set of documents provides the consolidated stakeholder submissions of the automotive industry associations ACEA, CLEPA, JAMA, KAMA, and associated industrial stakeholders to the “11th adaptation to scientific and technical progress of exemptions 2(c)(i)., 3 and 5(b). of Annex II to Directive 2000/53/EC (ELV)”. In the entry specific submissions, the names of the participating associations are listed separately.

The consultation was announced on 15 September 2020 and concludes on 08th December 2020 and addresses the following entries (exemptions) to be reviewed:

Under category Lead as an alloying element following entries are in our scope:

- 2(c)(i). ”Aluminium alloys for machining purposes with a Lead content up to 0,4 % by weight“
- 3 ”Copper alloys containing up to 4% Lead by weight“

And under category Lead and Lead compounds in components we address:

- 5(b).”Lead in batteries for battery applications not included in entry 5(a).“

ACEA and the joint associations welcome the opportunity to provide submissions to the stakeholder consultation of reviewing the three entries of ELV Annex II 2(c)(i). , 3 and 5(b). and are pleased by outlining technical requirements to address the necessity to continue these exemptions.

For meeting the antitrust conditions in prospects into the future and to support the evidence of our applications we mandated also studies at independent consultants. Their findings and opinions may differ from our direct views. Where appropriate, critical reviews by third parties were conducted.

The summaries of the studies mandated for entry 5 topics are published on the websites of ACEA (www.acea.be/publications) and EUROBAT. The detailed studies can be requested via the EU Commission for taking a look. The rights remain at disposition of the associations.

Introduction

The automobile industry actively supports environmental policy efforts to design products free of hazardous substances and as environmentally sound as possible. All car manufacturers and actors in the supply chain have set up internal goals and environmental guidelines relating to products as well as production processes.

As self-responsible partners of the manufacturers, the suppliers are affected in a special way, having to deal with their global supply chain, sometimes down to the raw material basis and missing availability of specific materials due to import restrictions. The automotive industry and their associations fully accept their product responsibility, but emphasize the need for proportionate actions or initiatives. The represented industry stakeholders agree upon the minimization of negative environmental impacts during all phases of a vehicle life.

In order to reach this common goal to manufacture, market, operate service and recover products with the lowest possible impact on environment or human health, the environmental impact, the relevance of certain substances and their technical and economic implications need to be understood prior mandating substance restrictions. In addition, at our opinion, interference with EU flagship initiatives like circular economy[1] resp. critical resources strategy[2] or the EU general safety regulation and the new waste framework directive needs to be considered. E.g. Bismuth, which is under consideration to replace Lead in some applications, is part of EU critical resources strategy[2] and is recommended to be used with preference in essential applications and has today challenges in recycling.

Achieved progress in heavy metals reduction

The automotive industry has been continuously reducing the amount of heavy metals including Lead necessary for the production of vehicles since the year 2000. Cadmium, hexavalent chromium and mercury have no more meaning in actual car production. As concluded in previous submissions the statement remains valid that – battery excluded because of being used in closed loop - the intentional use of Lead per vehicle is now in the range of background level concentration of all the raw materials used therein. Based on the fact that the potentials for significant and impacting Lead reduction have been realized, any further measures with real benefits for the environment are missing in our opinion.

Further comments to stakeholder contribution

The enclosed entry specific contributions reflect the work of our industry expert groups since the last review of these exemptions in 2014. With high effort we took the challenges addressed to our industry within the consultant report from 2016. In general, technical information given in the course of previous consultations, is seen still as valid and not all times reproduced explicitly in the current submissions.

Where possible and necessary our search for Lead-free alternative metal alloys was supported by external expertise but without public funding over the last few years.

Our working groups are supported by well-educated and excellent experts with external acknowledged expertise in the vehicle and material producing industry.

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[1] https://ec.europa.eu/environment/circular-economy/pdf/new_circular_economy_action_plan.pdf; last accessed 04.12.2020

[2] COM(2020) 474 final Brussels, 3.9.2020 Critical Raw Materials Resilience: Charting a Path towards greater Security and Sustainability https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0474&from=EN Annex I last accessed 04.12.2020

We ask to keep wording for the entries and in addition to avoid any further split into new subentries. The total amount in the alloys for Copper resp. Aluminum applied alloying Lead sums up for around 185 t resp. 13 t related to the volume of vehicles placed on the EU market in 2019. This Lead is bound physically in the metal matrix and during use there is no significant release by corrosion, friction or wear observed. Even recycling is feasible without challenges and realized since decades.

For all the submissions the following data for vehicles new placed (registered) on the EU market and the year 2019 were used as basis for quantity calculations[3] :

Vehicles (passenger cars and light commercial vehicles) new registered in year 2019 in EU (28) including EFTA.

Registrations 2019	Passenger cars	Light commercial vehicles up to 3,5 t	Total
EU28 (without Malta)	15,340,188	2,115,650	
EFTA	465,564	73,674	
EU + EFTA	15,805,752	2,189,324	17.995.076
(Malta sales 2019)			8495
			18.003 571

Table 1: registration figures 2019; 2019 new registrations figures for Malta were not yet available in ACEA pocket guide so we added the corresponding OICA sales figures instead as new registrations. (OICA reports total vehicle sales in 2019 of 8495 vehicles)

As ACEA et al. do not have access to technical data of vehicles in some specific markets, worldwide figures on applications would be incomplete and therefore we concentrate on figures of EU market only. This matches also with EU ELV legislation.

In addition as communicated in previous stakeholder contributions, the development period for implementation of lab validated solutions into production is still 3 to 6 years if no failures occur. The average model cycle is typically around 8 years.

We would like to emphasize that vehicles and their components have to face harsh ambient conditions in Europe. Ambient temperatures from - 40 up to 50°C outside and interior temperatures to above 100°C have to be tolerated and operating temperatures e.g. of some engine components may exceed 800°C. Components e.g. like electronic control units have to be robust against vibrations and acceleration figures above 70 g_0. With more and more electronic assisting driving functions and sensor or camera signals triggered actions of software, also IT related endurance is an important task. - During vehicle use all components and their functions undergo long termed high levels of mechanical and thermo-mechanical stress and dynamic load conditions.

This is valid not only for a short period but over a use period of ten to fifteen years and sometimes longer. That is one of the reasons why development and validation of new components require such long development periods. This ensures that safety and reliability demands are fulfilled.

Furthermore the continued improvement of the overall environmental performance of vehicles and their production processes requires that we also assess the environmental performance of substitute materials in order to allow long lasting decisions for optimized materials in each application.

The entire industry, however, needs a reliable planning basis for these substitute materials for at least one development cycle of a vehicle. This needs to be considered in any future phase out recommendation and plans and EU Commission decisions.

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[3] ACEA Pocket guide edition July 2020 p.28, ACEA Brussels and OICA; https://www.acea.be/publications/article/acea-pocket-guide last accessed 03.11.2020

Attached you will find the submissions with technical justifications compiled by expertise of the entire automotive industry (together with the Copper, Lead and battery producers and their organizations) regarding Lead in Copper and Aluminum materials and Lead in batteries, based on the current knowledge.

We ask to recommend a succeeding consultation or review not before a time period of eight years to reflect developments of one product cycle and to enable current research efforts to find their way in a future volume production.

The automotive industry would also like to remind all decision makers in this subject that the still ongoing challenges of COVID 19 is significantly impacting our industry globally. Transformation towards E-Mobility, fulfillment of the very challenging EU CO_2 limits, realizing the General Safety Regulation (GSR) [4] and future autonomous drive modes, consume major parts of the R&D capacities.

We would welcome the opportunity to continue the open discussions with the Commission and the consultants also during the assessment process of the consultation and are willing to answer to further possible questions on the subject.

Should you need any further information, please address your requests in writing to the listed contact person below Cc'ing the listed associations representatives.

In conclusion, the automotive industry requests the extension of the exemptions as specified in the attached documents.

We would appreciate it if you could confirm the receipt of the present document.

We thank you in anticipation.

With best regards,

Amelie Salau & Reinhard S. Hoock

On behalf of the Joint Industry Associations and the Associated Industry Stakeholders

Enclosures: ./.

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[4] EU General Safety Regulation (EU) 2019/2144 of the European Parliament and of the Council of 27 November 2019

Enclosures:

Submission for entry 2(c)(i): ACEA et al response 11th SC_entry_2ci_08_12_2020

Submission for entry 3: ACEA et al response 11th SC_entry_3_08_12_2020

Submission for entry 5(b): ACEA et al response 11th SC_entry_5(b)_08_12_2020

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Associations [5](Registration ID number listed in EU transparency register can be found below)

Association of European Automotive and Industrial Battery Manufacturers (EUROBAT)

EUROBAT is the association for the European manufacturers automotive, industrial and energy storage batteries. EUROBAT has more than 50 members from across the continent comprising more than 90% of the automotive and industrial battery industry in Europe. The members and staff work with all stakeholders, such as battery users, governmental organisations and media, to deve- lop new battery solutions in areas of hybrid and electro-mobility as well as grid flexibility and renewable energy storage.

The European Automobile Manufactures Association (ACEA)

The European Automobile Manufacturers' Association (ACEA) represents the 16 major Europe-based car, van, truck and bus makers. BMW Group, CNH Industrial, DAF Trucks, Daimler, Ferrari, Fiat Chrysler Automobiles, Ford of Europe, Honda Motor Europe, Hyundai Motor Europe, Jaguar Land Rover, PSA Group, Renault Group, Toyota Motor Europe, Volkswagen Group, Volvo Cars, and Volvo Group.

ACEA works with a variety of institutional, non-governmental, research and civil society partners - as well as with a number of industry associations with related interests.

ACEA has permanent cooperation with the European Council for Automotive R&D (EUCAR), which is the industry body for collaborative research and development.

ACEA has close relations with the 29 national automobile manufacturers' associations in Europe, and maintains a dialogue on international issues with automobile associations around the world

Japan Automobile Manufacturers Association, Inc. European Office (JAMA)

Japan Automobile Manufacturers Association, Inc. (JAMA) is a non-profit industry association which comprises Japan's fourteen manufacturers of passenger cars, trucks, buses and motorcycles. JAMA works to support the sound development of Japan's automobile industry and to contribute to social and economic welfare

Korea Automobile Manufacturers Association (KAMA)

The Korea Automobile Manufacturers Association (KAMA) is a non-profit organization representing the interests of automakers in Korea. We are promoting the sound growth of the automobile industry and also the development of the national economy.

International Lead Association (ILA)

ILA is the only global trade association dedicated to representing lead producers and companies with a direct interest in lead and its use. The Association's team of technical, regulatory, environment and health experts work with stakeholders to promote the benefits of lead and the safe and responsible use of the metal in manufacturing and other applications.

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[5] The associations are registered at the EU Transparency register as follows:

European Automobile Manufacturers Association (ACEA) Identification No. 0649790813-47

European Association of Automotive Suppliers (CLEPA) Identification No. 91408765797-03 Japan Automobile Manufacturers Association, Inc. (JAMA) Identification No. 47288759638-75

Korea Automobile Manufacturers Association (KAMA

Association of European Automotive and Industrial Battery Manufacturers (EUROBAT) ID. No. 39573492614-61

International Lead Association (ILA) Identification No. 311414214793-82

European Copper Institute (ECI) Identification No. 04134171823-87

The European Association of Automotive Supplier (CLEPA)

CLEPA, the European Association of Automotive Suppliers, represents over 3,000 companies supplying state-of-the-art components and innovative technologies for safe, smart, and sustainable mobility.

CLEPA brings together over 120 global suppliers of car parts, systems, and modules and more than 20 national trade associations and European sector associations. CLEPA is the voice of the EU automotive supplier industry linking the sector to policy makers.

- The automotive sector accounts for 30% of R&D in the EU, making it the number one investor.
- European automotive suppliers invest over €30 billion yearly in research and development.
- Automotive suppliers register over 9,000 new patents each year.
- Automotive suppliers in Europe generate close to five million direct and indirect jobs.

For entry •2(c)(i). ”Aluminium alloys for machining purposes with a Lead content up to 0,4 % by weight“

For entry 3 ”Copper alloys containing up to 4% Lead by weight

Japan Auto Parts Industries Association (JAPIA)

The Japan Auto Parts Industries Association (JAPIA) is an industry organization that was established in August 1969, when its predecessor, the Auto Parts Industries Association was reorganized as an incorporated association with a higher level of public interest. Today, the value of shipments of auto parts from member companies has reached approximately 20 trillion yen, supporting the manufacture of automobiles not only in Japan but also around the world.

Each and every one of these high-quality parts makes a significant contribution to the safety and comfort of automobiles. The environment surrounding the automotive parts industry is becoming more and more severe, and the industry is facing many challenges such as responding to structural changes, dealing with environmental issues, and promoting international cooperation.

JAPIA will continue to develop proactive business activities to contribute to the growth of the Japanese economy and society while promoting the sound progress of the "motorized society" through the automotive industry.

For entry •3 ”Copper alloys containing up to 4% Lead by weight“

European Copper Institute (ECI)

The European Copper Institute (ECI) is the voice of the International Copper Association (ICA) in Europe. The International Copper Association, with its 35 members, represents a majority of the world’s primary copper producers, and some of the largest mid-stream smelters/refiners, and 10 of the world’s largest copper fabricators. It aims to bring together the global copper industry to develop and defend markets for copper and to make a positive contribution to society’s sustainable development goals.

Exemption Evaluation under Directive 2000/53 EC

ACEA et al. Answers to Stakeholder Consultation Questionnaire
of Bio Innovation Service, UNITAR and Fraunhofer IZM dates 15.9.2020

ENTRY 3 Lead in copper alloys

Application for an extension of Annex II EU ELV exemption No. 3

(Copper alloys containing up to 4 % lead by weight)

This application is supported by the following associations:

- ACEA, the European Automobile Manufacturers Association, Brussels
  (transparency registration ID number 0649790813-47)
- JAMA, the Japan Automobile Manufacturers Association, Tokyo / Brussels
  (transparency registration ID number 71898491009-84)
- JAPIA, the Japan Auto Parts Industries Association, Tokyo
- KAMA, the Korea Automobile Manufacturers Association, Seoul
- CLEPA, the European Association of Automotive Suppliers, Brussels
  (transparency registration ID number 91408765797-03)
- European Copper Institute, Brussels
  (transparency registration ID number 04134171823-87)

Table of Contents

1. Scope

This document aims to provide a comprehensive overview about the Exemption 3 (lead in copper alloys) of the European ELV Annex II, by describing the related activities that have been carried out in the last years, the last findings and the challenges for the future developments of lead-free copper alloys.
Moreover, the document contains the answers of the above-mentioned automotive associations to the questions of the Consultation Questionnaire for the upcoming revision of the Exemption 3 of the ELV Annex II and provides arguments for supporting the extension of this exemption.

2. Current situation

The last review of the ELV Annex II Exemption 3 started in the end of 2014 and resulted in the Commission Directive (EU) 2017/2096 that renewed the exemption without modifying it and that set its next revision for 2021. During the last stakeholder consultation in 2014, the joint automotive associations ACEA, JAMA, JAPIA, KAMA and CLEPA proposed a review time of 8 years for the ELV Exemption 3. In fact, even if new promising alloys had been developed and characterized, it was still inconceivable to substitute leaded copper alloys for all the automotive applications for which they were in use within the upcoming decade.

Since the last revision of the ELV Annex II Exemption 3, many stakeholders put a lot of effort in developing and identifying lead-free alternatives with physical, mechanical and technological properties comparable to those of lead-containing copper alloys. However, even if some good results have been achieved, it is still mostly not possible to substitute leaded copper alloys due to their unique mix of metallurgical tolerability, machinability, outstanding self-lubricating properties, thermal and electrical conductivity.

It is important to underline that the challenges regarding the substitution of lead in copper alloys do not involve only the production and the use of the components made of these alloys, but also their recycling and that of their production scrap. Nowadays, the production of leaded-copper alloys is carried out using very high fractions, close to 100%, of recycled material that allow material producers to save costs and resources[27]. Furthermore, these alloys tolerate a higher amount of impurities from other elements compared to lead-free copper alloys and thus they require a lower degree of purification of the raw materials used in their production. Due to their well-established recycling loop, both people and the environment are not exposed to the lead contained in copper alloys. A sudden restriction of leaded brass would therefore cause an adverse effect, as the required material could not be made by direct recycling anymore. Since to our knowledge the selective removal of lead from scrap is currently not technically achievable, the use of virgin material, and the disposal of scrap as waste or inclusion of scrap in other material flows where lead is not restricted, while showing the same toxicology, would be the only other possibility. For example, due to their high global demand, lead-containing copper scraps might be exported, used and/or disposed outside EU, potentially contradicting the principles of the circular economy. Moreover, it should be considered that in Europe a large fraction of copper comes only either from the "Urban Stock" or the end-of-life scrap and a large part of the primary copper comes from abroad[27].

3. Answers to questionnaire

3.1. Question 1

Please explain whether the use of lead in copper as addressed under exemption 3 of the ELV Directive is still unavoidable so that Art. 4 (2) (b) (ii) of the ELV Directive would justify the continuation of the exemption. In the last review of this exemption, it was found that 4 % of lead addition is still justified.

- **a. Which lead-free copper alloys have become available meanwhile besides Ecobrass (c.f. last review)?**
- **b. For which applications can these lead-free copper alloys be used?**
- **c. For which applications can the content of lead be reduced if the use of lead-free copper is not viable?**

Copper is a ductile corrosion resistant metallic material with excellent thermal and electrical conductivity. Copper and copper-based alloys are used in a huge variety of applications that mainly include:

- Electrical components, such as power cable, building wiring, energy generators, motors, transformers.
- Electronics and Communications; the main uses include technologies for high-speed data transmission (e.g. HDSL, ADSL), domestic subscriber lines, wide and local area networks, and the production of components for mobile phones, computers, connectors and switches.
- Constructions. Copper and brass (copper-zinc alloy) are widely used for plumbing, taps, valves.
- Industrial machinery and equipment. Due to their durability, machinability and ability to be cast with high precision and tolerances, copper alloys are ideal for making products such as gears, bearings and turbine blades. The high corrosion resistance and the outstanding heat transfer capabilities are the mean reasons why copper alloys are chosen for heat exchange equipment, pressure vessels and vats.
- Consumer and general products, such as coins, cookware, brassware, keys.
- Transportation. Copper and its alloys are mainly used in wiring, radiators, batteries, connectors, bearings, brakes, windings and copper rotors used in electric motors, wiring, busbars and charging infrastructure.

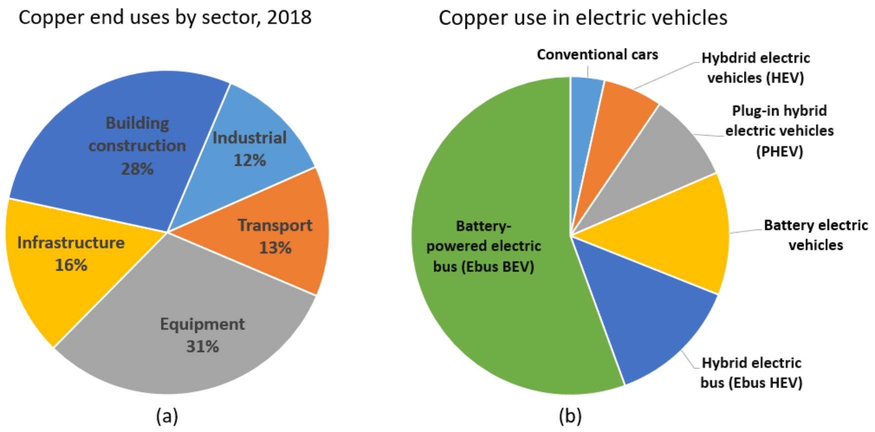

Figure 1. (a) Copper end uses divided by sector and (b) use of copper in electric vehicles in 2018. It is important to notice that the "transport" sector includes not only cars and other road vehicles, but also aeronautical and marine vehicles[1].

Although its many excellent physical and chemical properties, copper has a high specific gravity, approximately 230 % higher than that of aluminum, and it is much more expensive than aluminum and steel. For these reasons, and especially in the automotive sector where costs and weight are particularly important, copper and its alloys are selected and used only when it is strictly necessary.

Figure 2. Key physical properties of copper[1].

Different chemical substances, especially zinc, tin, nickel, aluminum, manganese and many others are added to copper as alloying elements to modify its thermal, physical, mechanical and chemical properties and to obtain the best mix of properties for the intended applications.

The enhancement of a specific mechanical property (e.g. hardness) of a metallic material depends on the concentration of the alloy element and follows a trend similar to curve showed in Figure 3.

At relatively high concentrations of an alloy element (zone 1 of Figure 3), the relative performance index is close to its maximum value and almost to saturation. These conditions are optimal and particularly recommended for the mass production since, if they verify, the specific property of the metallic alloy is maximized and not considerably influenced by small variations in the concentration of the alloying element.

On the other hand, at low concentrations of an alloying element (zone 3 of Figure 3), the specific material property is similar to that of the pure metal and its values are very sensitive to small variations of the amount of the added element. In these conditions, also other metallurgical parameters, such as impurities, grain sizes, phase morphologies, etc., have an important impact on the properties of the alloy[2].

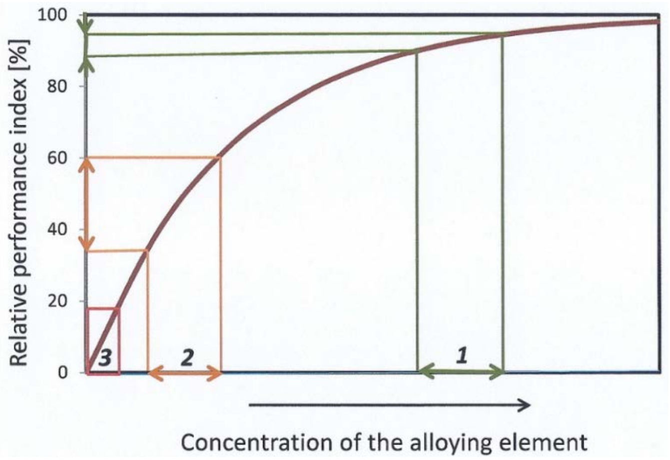

Figure 3. Dependence of a specific material's property (expressed as a relative performance index) on the concentration of an alloying element, emphasizing the three zones 1, 2, 3.

Lead as an alloy element is usually added to copper and copper alloys for the following reasons:

- It improves their machinability, with regards to excellent chip breakage, low tool wear and high applicable cutting parameters[3].
- It improves their castability[4].
- It improves the surface quality of the parts being machined[5].
- It increases their electrochemical stability and thus their resistance to harsh corrosive environments[2].
- It improves the surface adaptability of components made of copper and its alloys, due to the superficial plastic deformation of its nodules. This results in a better contact and adhesion between different components, fundamental for example in the field of electrical connectors.

The effect of lead on the machinability of free-cutting brass CuZn36Pbx is showed in Figure 4[2].

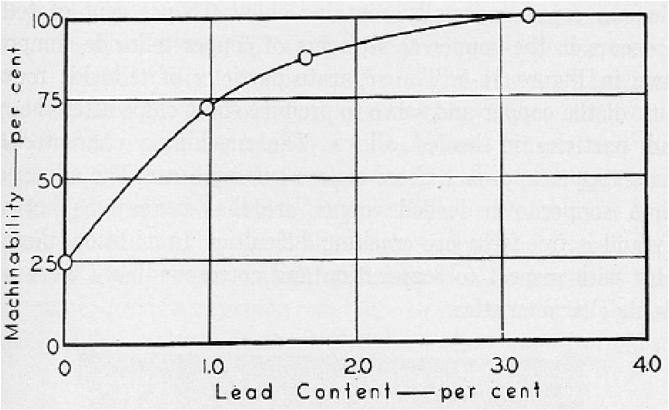

Figure 4. Lead concentration dependence on the machinability of free-cutting brass CuZn36Pbx (Crampton 1944).

The by far most used leaded copper alloys are leaded brasses (copper-zinc alloys). Other leaded copper alloys are leaded nickel-silver alloys, leaded bronzes and some special alloys.

Brasses, like many industrial alloys, are based on solid solutions of a base metal, in this case copper with a face centered cubic (FCC) structure. In the normal casting fabrication, brass alloys exhibit a single α-phase FCC state below 35 wt. % of zinc; above this zinc content, the intermetallic β-CuZn (CsCl type) would be formed, which induces precipitation strengthening, but at the expense of the reduced plasticity. For this reason, industrial copper-zinc alloys contain at most about 40.0 wt. % zinc, which is slightly above the solubility limit of zinc in copper[7]. Above around 40-42 % of zinc the tensile and the yield strength of the brass as well as its elongation at break drop very rapidly. The increase of the amount of β-phase leads to a higher brittleness of the material and thus to a higher machinability. Mainly for this reason, most of the lead-free brasses have a quite high amount of zinc.

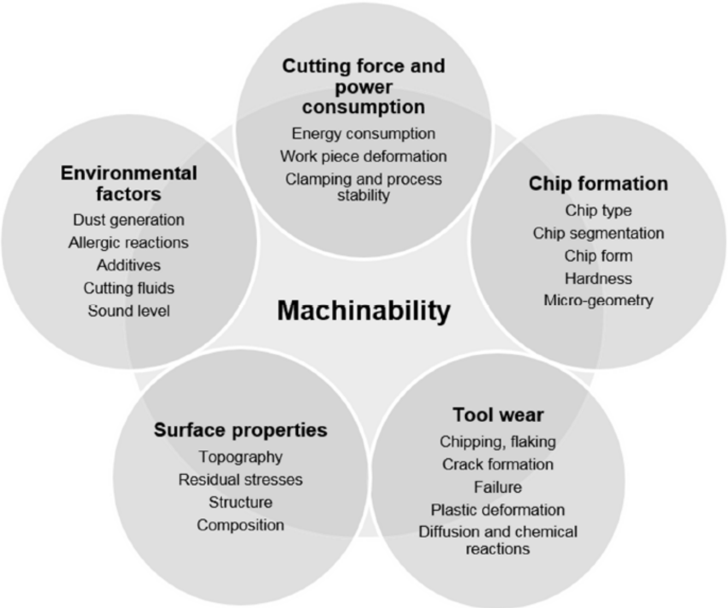

Figure 5. A schematic illustration of the overall parameters that is included in the complex machinability concept[8].

Currently, there are only a few standardized lead-free* copper alloys, whose composition is regulated by the following four European Standards. Table 1 lists the lead-free both the standardized copper-zinc alloys and those that are commercially available with a lead content lower that 0.1 % w/w.

- EN 12163:2016 - Copper and copper alloys - Rod for general purposes
- EN 12164:2016 - Copper and copper alloys - Rod for free machining purposes
- EN 12165:2016 - Copper and copper alloys - Wrought and unwrought forging stock
- EN 1982:2017 - Copper and copper alloys - Ingots and castings

Standard	**Material designation**		**Lead amount (% by weight)**		**Remarks**
	Symbol	Number	Limit	Value	
EN 12163:2016	CuZn5 CuZn10 CuZn15 etc.	CW500L CW501L CW502L etc	-	-	Not machinable
EN 12163:2016 EN 12164:2016 EN 12165:2016	CuZn40	CW509L	Min. Max.	- 0.20	commercially available also with a lead content below 0.1% w/w
	CuZn42	CW510L	Min. Max.	- 0.20	
	CuZn38S	CW511L	Min. Max.	- 0.20	
EN 12163:2016 EN 12164:2016	CuZn21Si3P	CW724R	Min. Max.	- 0.10	
EN 12165:2016	CuZn37	CW508L	Min. Max.	- 0.10	
EN 1982:2017	CuZn38Al-B	CB767S	Min. Max.	- 0.10	
	CuZn38Al-C	CC767S			
	CuZn42Al-B	CB773S			
	CuZn42Al-C	CC773S			
	CuZn21Si3P-B	CB768S			
	CuZn21Si3P-C	CC768S			

Table 1. Nomenclature and types of lead-free European Standardized brasses and of brasses commercially available in a lead-free version.

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* In this document the term „lead-free“ means that the material has a lead content less or equal to 0.1% w/w and fulfils the substance requirements of the ELV Directive Art. 4.2(a).

As already mentioned in the documentation related to the last revision of the ELV Exemption 3 in 2014[26], the main applications of leaded brass in the automotive industry can be divided in the following groups:

- Sliding elements, such as valve guides, bearing shells, clutch, door locks, etc.
- Mechanical connecting elements, such as fittings for fuel feed injection systems, bearings, etc.
- Electric applications, that include battery clamps, connectors pins, cables, etc.

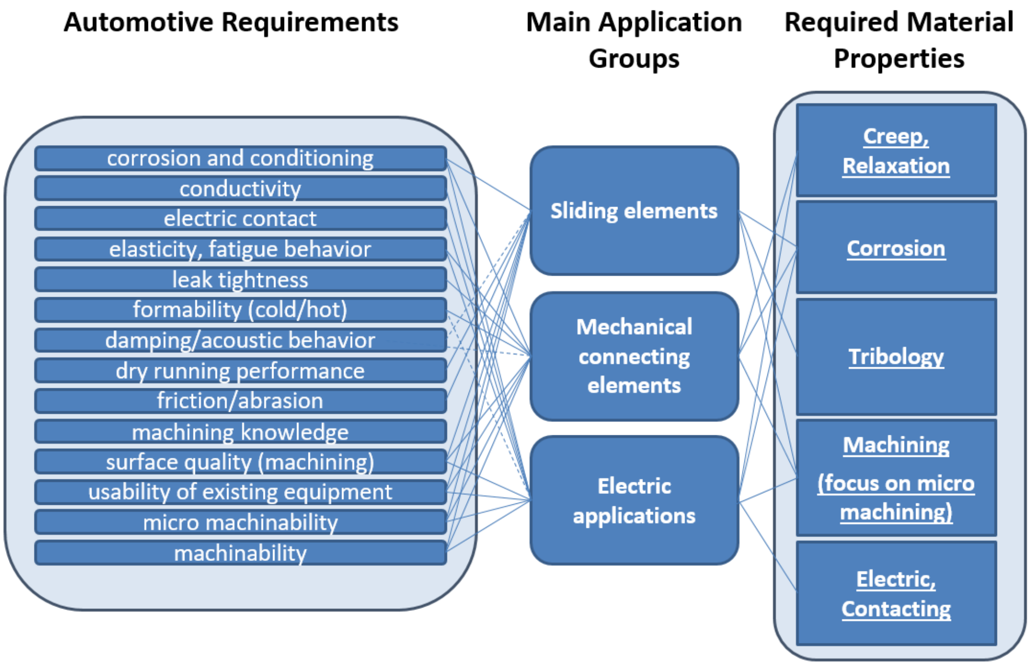


Figure 6. Correlation between main application groups of leaded copper brasses and automotive and material requirements.

In the last few years, many efforts have been made to characterize the standardized lead-free brass alloys and to find approaches to enhance their machinability.

Toulfatzis et al.[6] evaluated the machinability of three lead-free brass alloys, CuZn42 (CW510L), CuZn38As (CW511L) and CuZn36 (C27450) in comparison with a reference free-cutting leaded brass CuZn39Pb3 (CW614N). Even though their study showed promising results, especially in terms of surface roughness, it also demonstrated that the leaded alloy CW614N exhibited the highest machinability performance in terms of cutting-force optimization.

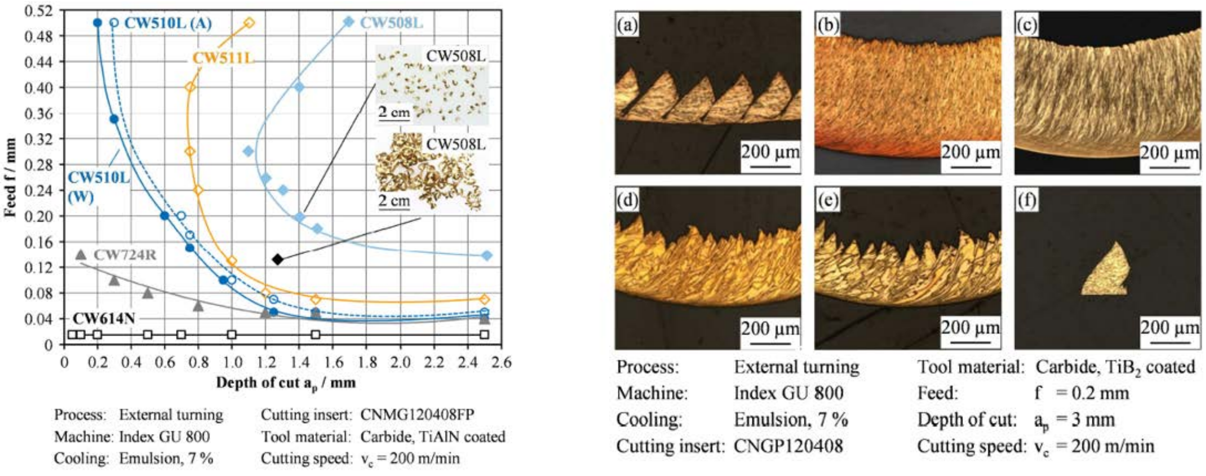
Nobel et al.[3] analyzed the effect of microstructure and silicon as alternative alloying element of commercially available lead-free brass alloys and they investigated various approaches for machinability enhancement in order to enable high performance cutting operations, particularly for mass production. The machinability of lead-free brass alloys CW508L, CW511L and CW510L as well as silicon alloyed special brass CW724R were investigated and compared to the machinability of leaded brass CW614N. The chemical composition of these alloys is showed in Table 2.

Material	Cu	Zn	Pb	Si	As	P
CW724R	75.86	≈ 21	0.02	3.4	-	0.05
CW508L	62.97	≈ 37	0.01	-	-	-
CW511L	≈ 62	≈ 38	≈ 0.18	-	≈ 0.07	-
CW510L (A)	57.38	≈ 42	0.07	-	-	-
CW510L (W)	57.76	≈ 42	0.18	-	-	-
CW614N	57.61	≈ 39	3.32	-	-	-

Table 2. Chemical composition of the analyzed copper alloys.

This study showed that, in comparison to the leaded brass CW614N, longer chips were formed, as showed in Figure 7, higher cutting forces and temperatures were generated and higher abrasive and adhesive tool wear was caused. In comparison to lead-free brasses, silicon alloyed special brass CW724R showed an improved machinability in terms of better chip breakage and lower thermo-mechanical tool load, however, it caused higher flank wear due to its abrasive κ-phase.

Analogous results were found also during a study performed by the RWTH University of Aachen.



(a) (b)

Figure 7. (a) Chip breakage of brass alloys depending on feed and depth of cut and (b) Mechanisms of chip formation when turning (a) CW724R; (b) CW508L; (c) CW511L; (d) CW510L (A); (e) CW510L (W); (f) CW614N.

ACEA et al. compared several mechanical, chemical, electrical conductivity and machinability-related properties of three commercial lead-free brass alloys (EcoBrass®, CuZn42, CuZn38As) with those of the free-cutting leaded brass CuZn39Pb3 (CW614N). From the results of this analysis, summarized in Table 3, it is clear that none of the considered lead-free brasses can completely replace leaded-brass alloys for any of their main automotive applications groups[9].

	compared to CuZn39Pb3		
material requirements	CuZn21Si3 EcoBrass®	CuZn42	CuZn38As
tensile strength at 150°C	🟩 M	🟨 M	🟨 M
relaxation fittings (130°C)	🟥 M	🟥 M	🟥 M
wear of copper disc	🟩 S	🟩 S	S
adhesion	🟨 M, S	🟥 M, S	M, S
friction coefficient	🟥 M, S	🟨 M, S	M, S
relaxation el. contacts	E	🟥 E	E
machinability (incl. surface quality)	🟥 M, S, E	🟥 M, S, E	🟥 M, S, E
el. conductivity	🟥 E	🟨 E	🟨 E
galvanic corrosion	🟥 M, S, E	🟥 M, S, E	🟥 M, S, E
stress corrosion cracking	🟩 M, E	🟥 M, E	🟩 M, E
+ additional for small parts (micro machining)			
drilling time	🟥 M, S, E	🟥 M, S, E	🟥 M, S, E
tool life	🟥 M, S, E	🟥 M, S, E	M, S, E
tool force	🟥 M, S, E	🟥 M, S, E	🟥 M, S, E

	relevant for:
S	sliding elements
M	mechanical connecting elements
E	electric applications

better	🟩
similar	🟨
worse	🟥
not tested	

Table 3. Summary of the analysis of several properties of lead-free brass alloys in comparison with a reference free-cutting leaded brass CuZn39Pb3.

In addition to the analysis of the behavior and the machinability of commercial available lead-free brass alloys, efforts have been also made for developing and characterizing new lead-free alloys.

For example, the Sweden research institute RISE, together with Swerim and Nordic Brass Gusum, have recently developed the so called AquaNordic® lead-free copper alloy, that represent an evolution of an already well-known lead-free brass. According to its inventors, this alloy has good anticorrosion properties and machinability with significantly improved environmental performance and lower price levels than competing products[10]. The machinability of the AquaNordic® alloy have been recently characterized and compared with that of a standardized leaded-brass, CW625N (1.5% Pb), and that of standardized lead-free brass, CW511L[11]. The AquaNordic® brass has the same composition as the CW511L alloy but it contains ceramic inclusions in its microstructure. The analysis demonstrated that the CW625N alloy generates significantly lower cutting forces during the turning test than the other two alloys, CW511L, and AquaNordic®. This is due to the lubricating effect of lead globules in the cutting zone[13]. Although the cutting forces are significantly higher compared to those of the leaded alloy, the author of this study claims that the chip formation of the AquaNordic® brass shown promising character compared to CW511L and that the AquaNordic® alloy might be a substitute of leaded-brass from the point of view of the machinability. There were, however, indications suggesting that lead-free brass alloys are more sensitive to changes in cutting parameters (e.g. cutting speed) than leaded-brasses.

Another example regards the recent development of novel lead-free copper alloys for oil-hydraulic applications as bushings, slippers or distributor plates, carried out by the company Otto-Fuchs[31]. According to the study that Otto-Fuchs published, these alloys showed a good machinability behavior as well as good mechanical properties and compatibility with biolubricants (e.g. esters, PAOs, PAGs) that would allow them to be good candidates for substituting leaded-copper alloys in hydraulic applications. It shall be however noted, that the alloys described in the study aim to substitute leaded-alloys with a relatively low lead-content, not exceeding 0.8 % by weight.

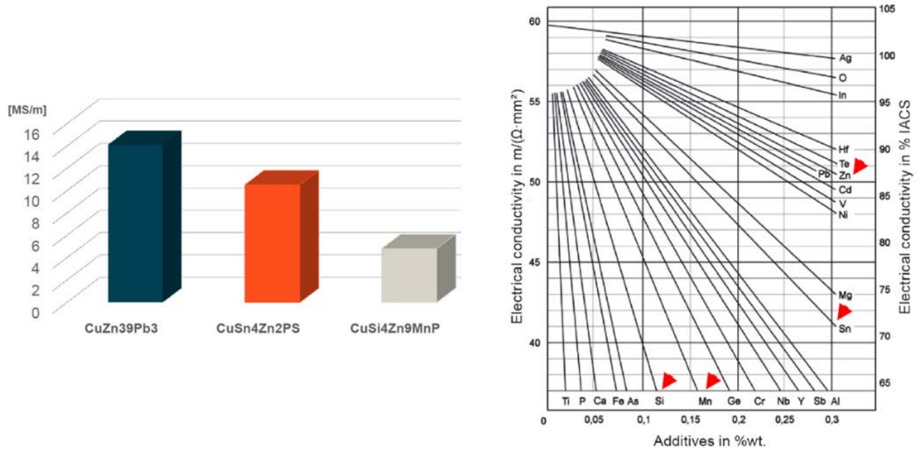
Another lead-free brass has been recently developed by the American company Aviva Metals mainly for plumbing and drinking-water-related applications. According to its developer, the Aviva Model 3^{TM} free machining alloy, containing less than 15 % by weight of zinc and tellurium in an amount between 0.3 and 0.9 % by weight, offers very good machinability, high conductivity and excellent dezincification-resistant properties[35]. ACEA and the joint automotive associations do not currently have specific experience or knowledge about this alloy and are not aware of any automotive applications for which the Aviva Model 3^{TM} alloy is in use or for which its use has been considered. Even though some tests performed by Aviva Metals revealed that the Aviva Model 3^{TM} does not negatively contaminate leaded-brasses during their recycling and production, the possible negative embrittlement effect of tellurium and its overall environmental impact have still not been completely analyzed.

In the last few years, ACEA et al. has closely collaborated with the German Copper Institute (DKI) to identify and characterize new lead-free copper alloys. In particular, the following two lead-free copper alloys were taken into account:

- CuSi4Zn9MnP (wrought alloy)
- CuSn4Zn2PS-C (casting alloy)

The two alloys underwent an initial screening where their tribology, stress corrosion cracking, galvanic corrosion and electrical conductivity were analyzed and compared with those of the CuZn39Pb3 alloy (CW614N). The overall results can be summarized as follows:

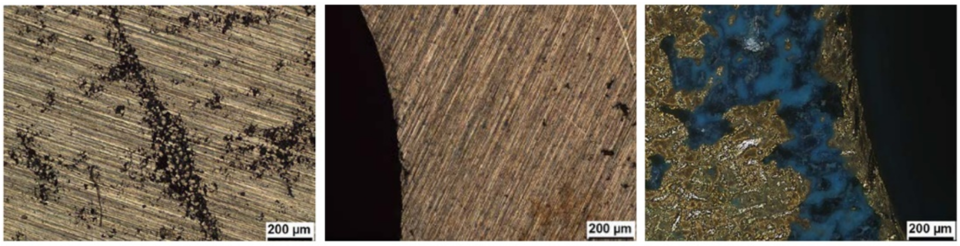
- The reference alloy CuZn39Pb3 has higher electrical conductivity than CuSi4Zn9MnP and CuSn4Zn2PS-C. This is due to the chemical composition of the materials: Si, Mn, P and Sn produce a higher decrease of the electrical conductivity of the copper than lead.



(a) (b)

Figure 8. (a) Electrical conductivity of CuZn39Pb3, CuSn4Zn2PS-C and CuSi4Zn9MnP and (b) influence of different alloying element on the electrical conductivity of copper (Source: DKI).

- The stress corrosion cracking test, performed according to the DIN 50916-1 in an ammonia solution (concentration 12,5 %; temperature 23°C) for 24 hours, showed that the two lead-free copper alloys, in contrast to reference leaded alloy, are not sensitive to this type of corrosion. This is due to their chemical composition and to the fact that their microstructure is free from any zinc-rich phase.

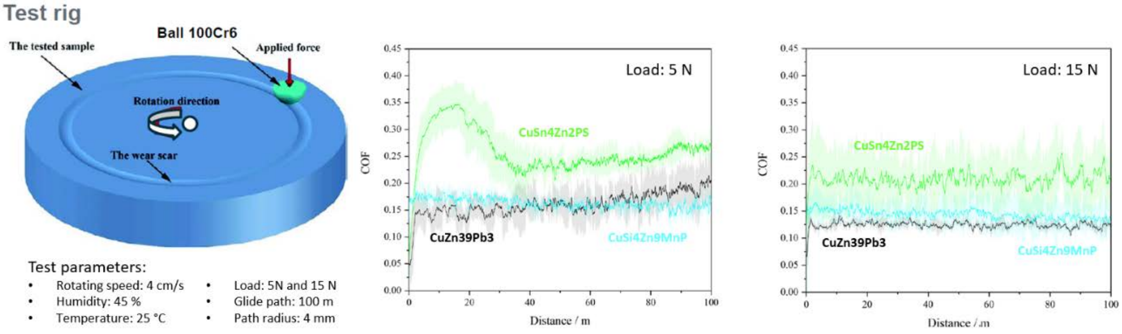


(a) (b) (c)

Figure 9. (a) CuZn39Pb3 specimen showing cracks after the SCC test, (b) CuSn4Zn2PS specimen, no cracks after the SCC test and (c) CuSi4Zn9MnP specimen; no crack after the SCC test (Source: DKI).

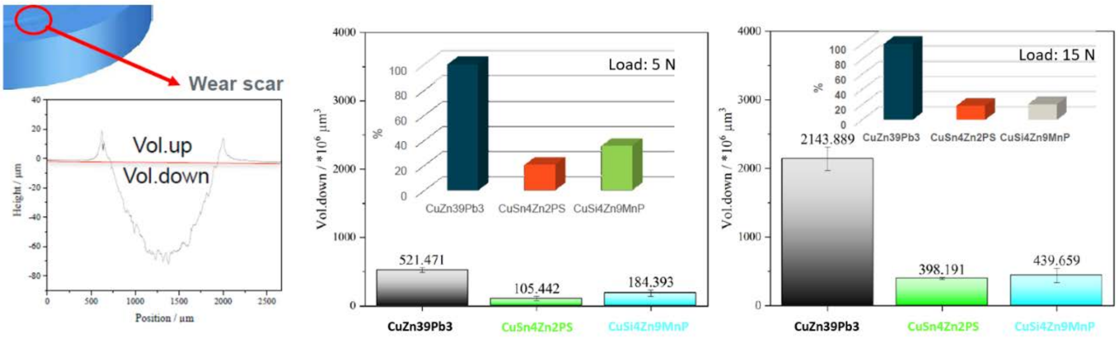
- The galvanic corrosion performances of the two lead-free copper alloys, evaluated against an AlSi9Cu3 alloy and in 5% NaCl at room temperature, were slightly better than those of the reference leaded-alloy, probably due to the positive effect of Si, Sn and Mn. In general, all three alloys provoked the galvanic corrosion of the Al-based anode.

- During the tribology characterization, the reference leaded-alloy copper alloys showed a coefficient of friction similar to that of CuSi4Zn9MnP and significant lower than that of CuSn4Zn2PS at both loads of 5N and 15N (Figure 10).
  Nevertheless, the wear behavior of the lead-free copper alloys resulted significantly better than that of the reference leaded alloy (Figure 11).



(a) (b) (c)

Figure 10. (a) Setup used for the friction and wear test, (b) coefficient of friction of the three specimens under a load of 5 N, (c) coefficient of friction under a load of 15 N (Source: DKI).



(a) (b) (c)

Figure 11. (a) Evaluation of the wear process. The "Volume down" is the most important effect, (b) wear behavior of the three specimens under a load of 5 N and (c) under a load of 15 N (Source: DKI).

Due to the promising first laboratory results showed by the two selected lead-free copper alloys during this first screening, ACEA and DKI planned to further analyze them, evaluating in particular their corrosion behavior, their warm forming performances and their ability to be machined and drilled.

Even though the whole automotive industry and many further industry stakeholders have been working intensively on the substitution of leaded-copper alloys and brasses, obtaining in many cases positive and promising results, it is currently still not possible to imagine a forthcoming complete substitution of leaded-copper in the automotive industry.

The reduction of the amount of lead, especially for very small components requiring extremely high machinability and small tolerances it is mainly not possible because of the reasons explained in Figure 3 and Figure 4. For example, the reduction of the lead amount from 3.5 % by weight to 2.0 % would provoke a significant decrease of the machinability of the leaded-copper alloy and an increased sensitivity of its machinability behavior to small variations of the lead content and of other metallurgic parameters.

Even though several potentially lead-free brass and copper alloys have been recently developed and in some cases even commercialized, it appears clear that none of them is able to substitute leaded-copper alloys in all applications and fields where they are currently used. It is also important to mention that most of the studies performed on new lead-free alloys are mainly focused on their machinability and mechanical/electrical/chemical properties. However, only a very limited number of studies take currently into account the overall environmental and circular economy-related aspects of the new alloys, even if these aspect are as important as the material technical performances. Once and if new lead-free alternatives able to effectively substitute leaded-copper alloys for all their current applications and from all points of view will be commercially available, a long time might still be needed for the large scale implementation, re-design and validation of the automotive components made out of them.

3.2. Question 2

In the last review, ACEA et al. stated that parts using leaded copper become smaller and smaller. Can such and possibly other parts be 3D-printed thus avoiding the use of lead?

3D printing, also called additive manufacturing, transforms computer-aided design (CAD) virtual 3D models into physical objects and it allows the production of 3D structures with high shape complexity[14]. This technology has emerged during recent years as a flexible and powerful technique and has been widespread used in many countries, especially in the manufacturing industry[15]. Nowadays, 3D printing technologies are no longer limited to prototyping usage but are increasingly also being used for making variety of products[16].

According to ASTM[17], the additive manufacturing technologies can be catalogued in the following seven groups: binder jetting, directed energy deposition, material extrusion, material jetting, powder bed fusion, sheet lamination and vat photo-polymerization. Each of these technologies has its targeted applications and it is particularly suitable for certain materials rather than for others[16].

Materials to make parts/objects by 3D printing can be nowadays of a widely varying type. These include metallic, ceramic and polymeric materials along with combinations in the form of composites, hybrid, or functionally graded materials (FGMs)[18]. However, machines and specific additive manufacturing technologies are linked to certain types, forms and states of materials, as showed in Figure 12[18].

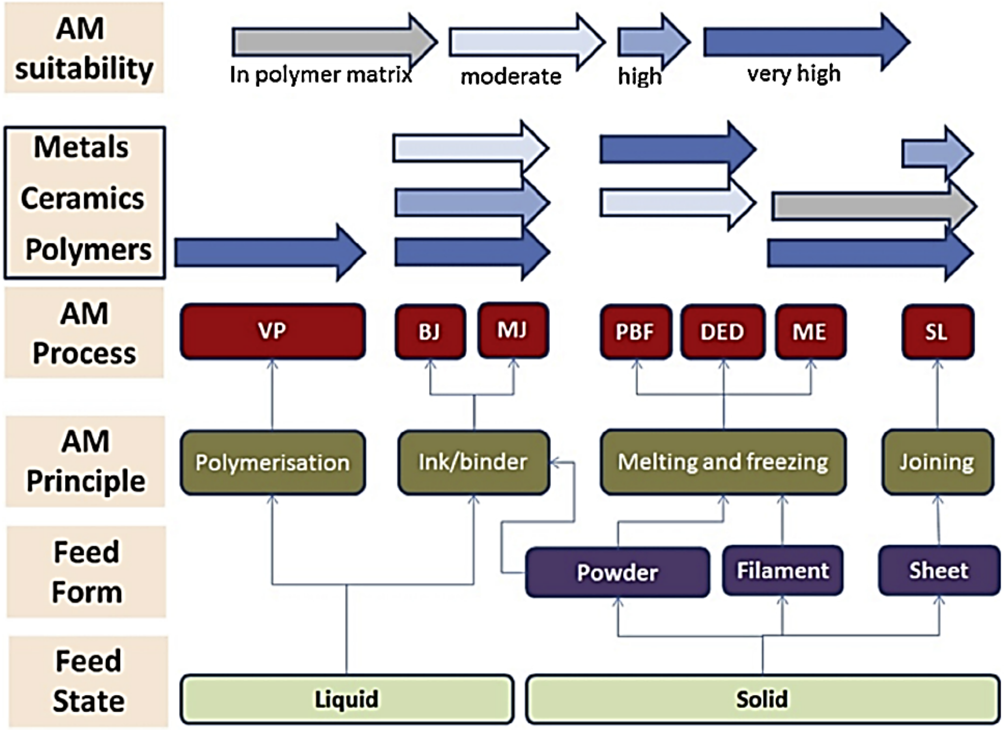


Figure 12. Schematic diagram of the relative suitability of additive manufacturing of three major types of materials (polymers, ceramics and metals) in various feedforms and states using ASTM processes: Binder jetting (BJ); directed energy deposition (DED); material extrusion (ME); (4) material jetting (MJ); powder bed fusion (PBF); sheet lamination (SL); and vat photopolymerization (VP).

For example, since the basic principle of the 3D printing is to originate parts through a layer-by-layer deposition of the selected material, it is clear that polymers and polymer-based products can be manufactured at relative low temperature and without any vacuum or inert gas environment. Furthermore, the achievement of curing and bonding upon cooling in polymers is also relatively easy.

On the other hand, bonding involving metals and ceramics are not easy to achieve due to their high melting tempartures[18].

3D printed metals parts are usually produced by taking advantage of solid state sintering processes that involve surface melting of the metals particles, followed by grain growth. However, direct laser melting techniques have been shown to work as well[18, 19, 20]. Therefore, the additive manufacturing technologies that are suitable and usually used for producing metals parts are the following:

- Binder jetting (BJ), in which a liquid binding agent is selectively deposited onto powder particles to join them and to form a layer. This process is fast and cheap and it allows to produce large products[15]. However, it produces fragile parts with limited mechanical properties and that often require a post processing[18].
- Directed energy deposition (DED), that is similar in principle to material extrusion but that uses a nozzle that is not fixed to a specific axis and can move in multiple directions. This process normally involves metals and metal-based hybrids in form of wire or powder and it is often used to repair or add additional material to existing components. Directed energy deposition has the high degree control of grain structure and can produce objects with good quality[15, 18].
- Powder bed fusion (PBF), which uses either an electron beam or laser to melt or fuse the material powder together. This process includes the electron beam melting (EBM), the selective laser sintering (SLS) and the selective heat sintering (SHS) printing technique[15]. PBF is relatively inexpensive but also slow, due to powder preheating, vacuum generation and cooling of the parts. Moreover, parts produced with this additive manufacturing technique needs a post processing and do not have high structural properties and have usually a quite high surface roughness that it is dependent on the grain size of the used powder.
- Sheet lamination (SL), in which sheet of materials are bond together to produce a part of object. This process is relatively inexpensive, it allows an easy material handling, to manufacture complicated geometrical parts and to easily recycle the extra material[15]. However, the strength and integrity of components produced by SL depend on the adhesive used and the parts often need a post process[18]. Furthermore, the presence of an adhesive within the parts may affect many physical and chemical properties of the metal used.

The main advantages and disadvantages of each of the ASTM additive manufacturing technologies, as well as their basic principles, the materials they are suitable for and the dimensions of the components that they can produce are showed in the Table 4.

3D manufacturing technologies play nowadays an important role in the automotive sector and they are often widely used in many different phases of the development of vehicle components and tooling. Adoption of additive manufacturing in the automotive industry has evolved from prototype production activities, which is still leading activity in additive manufacturing usage among commercial vehicle manufacturers, to more advanced applications which include functional prototype parts, 3D-printed tooling, sand molds for casting, and in some unique cases, end use parts[22]. In particular, 3D printing technologies are being increasingly evaluated for the production of automotive spare parts[21].

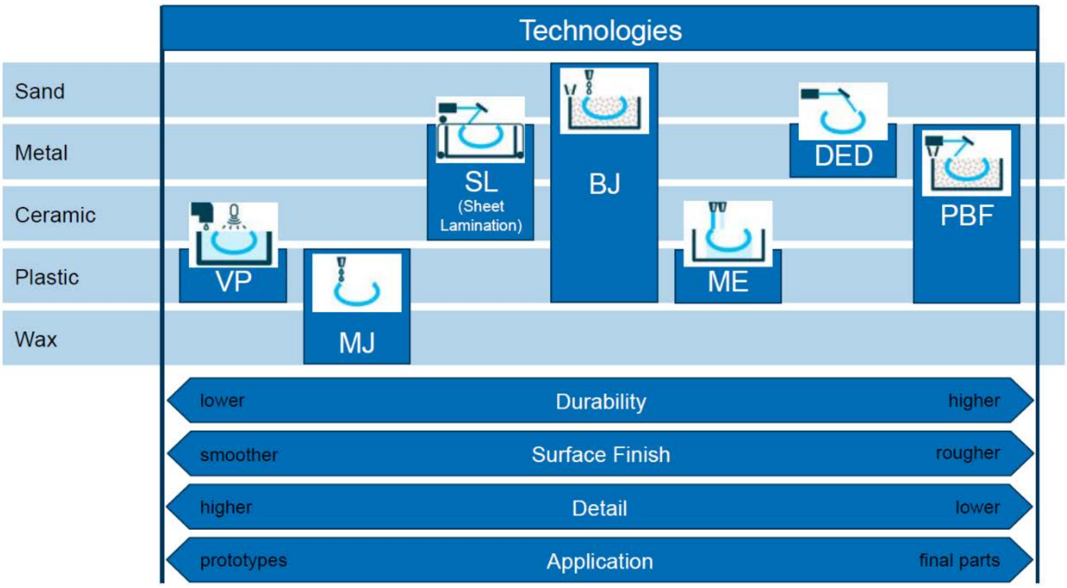
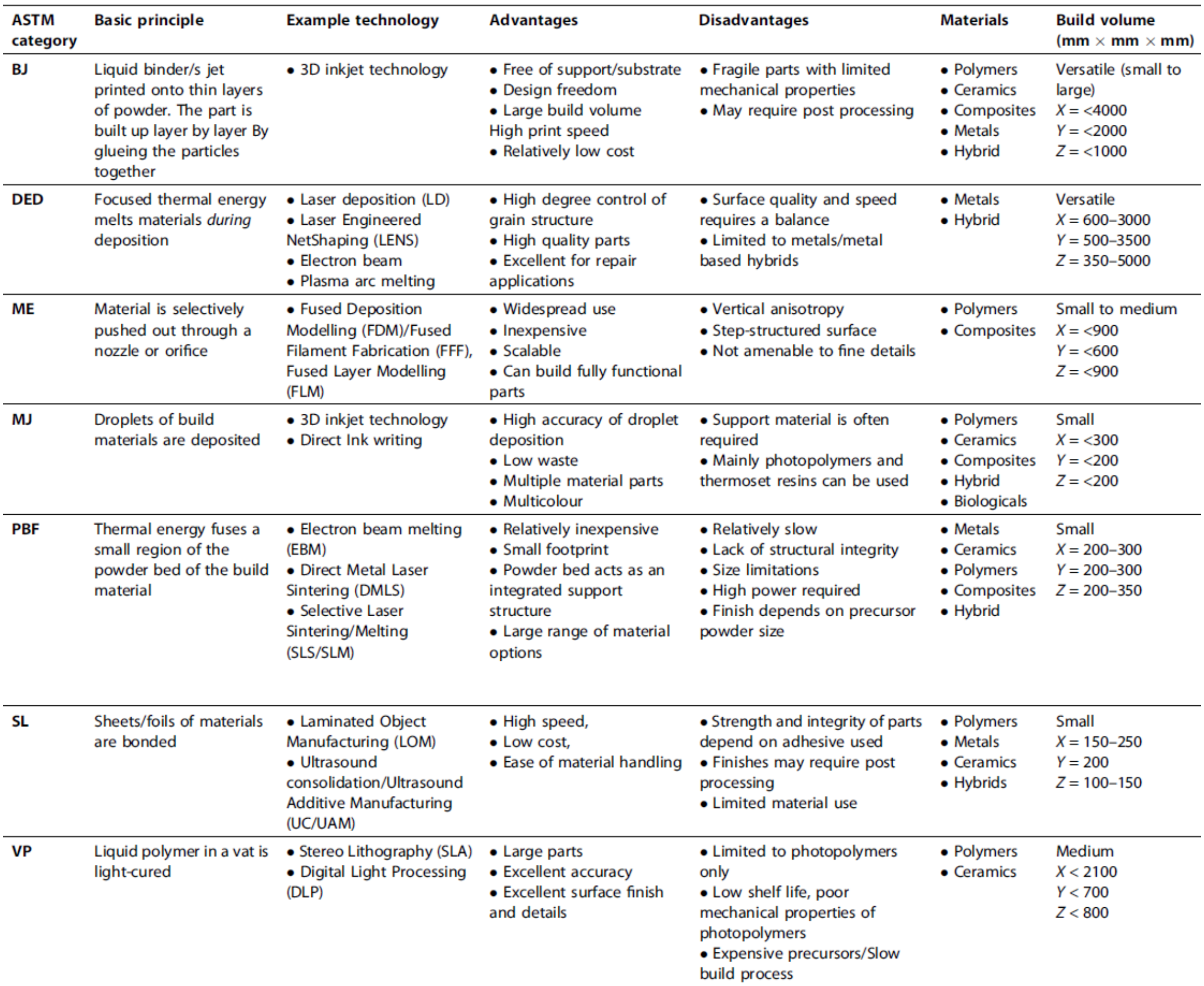


Figure 13. AM technologies and their respective characteristics[21].



ASTM category	Basic principle	Example technology	Advantages	Disadvantages	Materials	Build volume (mm × mm × mm)
BJ	Liquid binder/s jet printed onto thin layers of powder. The part is built up layer by layer By glueing the particles together	• 3D inkjet technology	• Free of support/substrate • Design freedom • Large build volume High print speed • Relatively low cost	• Fragile parts with limited mechanical properties • May require post processing	• Polymers • Ceramics • Composites • Metals • Hybrid	Versatile (small to large) X = <4000 Y = <2000 Z = <1000
DED	Focused thermal energy melts materials *during* deposition	• Laser deposition (LD) • Laser Engineered NetShaping (LENS) • Electron beam • Plasma arc melting	• High degree control of grain structure • High quality parts • Excellent for repair applications	• Surface quality and speed requires a balance • Limited to metals/metal based hybrids	• Metals • Hybrid	Versatile X = 600–3000 Y = 500–3500 Z = 350–5000
ME	Material is selectively pushed out through a nozzle or orifice	• Fused Deposition Modelling (FDM)/Fused Filament Fabrication (FFF), Fused Layer Modelling (FLM)	• Widespread use • Inexpensive • Scalable • Can build fully functional parts	• Vertical anisotropy • Step-structured surface • Not amenable to fine details	• Polymers • Composites	Small to medium X = <900 Y = <600 Z = <900
MJ	Droplets of build materials are deposited	• 3D inkjet technology • Direct Ink writing	• High accuracy of droplet deposition • Low waste • Multiple material parts • Multicolour	• Support material is often required • Mainly photopolymers and thermoset resins can be used	• Polymers • Ceramics • Composites • Hybrid • Biologicals	Small X = <300 Y = <200 Z = <200
PBF	Thermal energy fuses a small region of the powder bed of the build material	• Electron beam melting (EBM) • Direct Metal Laser Sintering (DMLS) • Selective Laser Sintering/Melting (SLS/SLM)	• Relatively inexpensive • Small footprint • Powder bed acts as an integrated support structure • Large range of material options	• Relatively slow • Lack of structural integrity • Size limitations • High power required • Finish depends on precursor powder size	• Metals • Ceramics • Polymers • Composites • Hybrid	Small X = 200–300 Y = 200–300 Z = 200–350
SL	Sheets/foils of materials are bonded	• Laminated Object Manufacturing (LOM) • Ultrasound consolidation/Ultrasound Additive Manufacturing (UC/UAM)	• High speed, • Low cost, • Ease of material handling	• Strength and integrity of parts depend on adhesive used • Finishes may require post processing • Limited material use	• Polymers • Metals • Ceramics • Hybrids	Small X = 150–250 Y = 200 Z = 100–150
VP	Liquid polymer in a vat is light-cured	• Stereo Lithography (SLA) • Digital Light Processing (DLP)	• Large parts • Excellent accuracy • Excellent surface finish and details	• Limited to photopolymers only • Low shelf life, poor mechanical properties of photopolymers • Expensive precursors/Slow build process	• Polymers • Ceramics	Medium X < 2100 Y < 700 Z < 800

Table 4. Basic principles, materials, advantages, disadvantages and typical build volumes of seven ASTM categories of AM: binder jetting (BJ); directed energy deposition (DED); material extrusion (ME); material jetting (MJ); powder bed fusion (PBF); sheet lamination (SL); and vat photopolymerization (VP). Build volumes are rounded to nearest number for convenience. Materials types have been ranked in order of suitability and common use[18].

As already mentioned it in the answer to Question 1, the main automotive applications of leaded-copper alloys include the production of sliding elements, mechanical connections and electric components. In all these cases, the components require high production volumes, usually not achievable with three-dimensional printing processes and, among other attributes, good and predictable mechanical properties and a very high surface quality. Additive manufacturing techniques, in spite of many advantages that allow their use to spread in an increasing number of fields, have still some limitations that prevent them to be a suitable mean for producing copper-alloy-based components for the automotive industry.

For example, the desired tensile, fatigue and creep properties of a metal wire result as a consequence of significant amount of thermal and mechanical treatments at each states of processing. Every step of these processes has impact on the density and imperfections, such as dislocations, in the structure which can play a critical role towards safe and reliable function of the end-use application of the wire in the wire mesh. A simple melt extrusion of metal powders or filaments in to a 3D printing built wire mesh may not necessarily produce the same end results as that would have been obtained from conventional manufacturing[18].

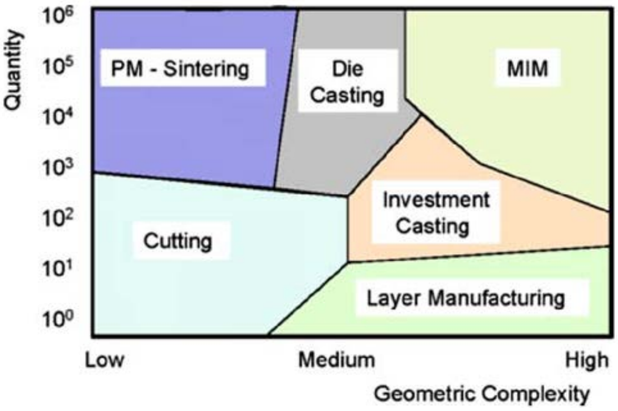


Figure 14. Qualitative situation of the additive manufacturing metal components production relative to usual options (MIM: Metal Injection Molding, PM-Sintering: Powder Metallurgy Sintering). The borders are floating and have to be evaluated from case to case[25].

Compared to the "conventional" production processes, the production of metal parts by additive manufacturing is usually slower and more expensive and thus more indicated for high value and low volumes parts. In many cases, post-processing operations on the 3D printed parts might be needed. Other challenges pertaining to additive manufacturing products are surface finish, part size, variations in product quality from machine to machine and between batches of productions, and a lack of fundamental understanding of the impact of operational variables on part quality.[18]

Moreover, in additive manufacturing the use of a layer-by-layer building of a 3D space tessellation ends up with a 2D building strategy, which may result in discontinuities in all directions of building. As a consequence, 3D printed products often suffer from dimensional inaccuracy, unacceptable surface finish state, structural and mechanical anisotropies[18, 23]. The dimensional resolution of additive manufacturing is limited by available tooling, the dimension of which is finite. This can lead to differences between the virtual and the real design of parts. As a result, internal structural features may not be well captured during the production process by 3D printing; internal discontinuities (porosities) may appear and the state of surface finish may not be limited due to rough profiles. In addition to these defects the AM product can have trapped unwanted material which change the local density of the structure, modify the local stress distributions and serve as an internal crack initiator thus affecting the performance expected from the virtual design[18].

Compared to other metals, the 3D printing of components from pure copper or copper alloys present significant additional process challenges. Due to its high thermal conductivity, copper rapidly conducts heat away from the melt area and this leads to high local thermal gradients. This can provoke layer curling, delamination, and build or part failure. Additionally, copper's high ductility hinders post-build powder removal and recovery. Copper particles also tend to agglomerate, reducing overall flowability and impeding powder deposition. In addition, copper is sensitive to oxidation, which requires a special handling and storage of it before, during, and after part fabrication[24].

3.3. Question 3

Please explain the efforts your organisation has undertaken to find and implement the use of lead-free alternatives for automotive uses. Please refer to alternatives, which at least reduce the amount of lead applied or eliminate its necessity altogether.

In 2018 the transportation sector, including the automotive industry, contributed approximately 13 % to the European market share of copper and its alloys (Figure 1(a)). The amount of leaded-copper alloys is estimated to be around 25 % of the total amount of copper and its alloys[30]. Nevertheless, as already mentioned in the answer to Question 1, car manufacturers and automotive suppliers invested a high amount of money and resources in looking for solutions to possibly substitute or at least reduce the amount of lead in copper alloys. These activities include the analysis of the most recent literature studies on lead-free copper alloys, the characterization of new promising lead-free copper alloys, still ongoing, the testing of components made out of lead-free copper alloys and the generation of a new inventory evaluating the current use of leaded-copper in the European automotive industry. The mentioned activities shall be added to those already done in the last ten years and that are described in the ACEA et al. documentation for the revision of the ELV Exemption 3 that took place in 2014[26] and that are summarized in the Figure 15.

The 2020 leaded-copper inventory is the result of an assessment among ACEA and the joint automotive associations members and aimed to calculate the average amount of leaded-copper alloys in the following three car models: a best-selling standard model, a fully equipped high-end model, an electric model, if available. In addition, the inventory had the goal to identify the automotive parts that contribute the most to the total amount of lead as part of copper alloys and to find out how this amount changed in comparison with the results of the last automotive leaded-copper alloys inventory carried out in 2014.

As showed in Figure 16, the average number of parts made of leaded-copper alloys per car resulted higher in fully equipped models (147) than in electric models (127) and in standard best-selling models (78). For all three model types, more than 80 % of the leaded-copper alloy parts (and almost 90 % in case of the electric models) contain an amount of lead between 2.0 and 4.0 % by weight. Furthermore, as showed in the graph of Figure 17 for the standard models, and as confirmed by the findings related to the high-end and electric models, roughly 90 % of the parts with a lead content between 2.0 and 4.0 % by weight have a weight lower than 10 g. This result confirms the fact that the smallest parts, which require a high dimensional accuracy and therefore a high machinability, still need a relatively high amount of lead to make this happen.

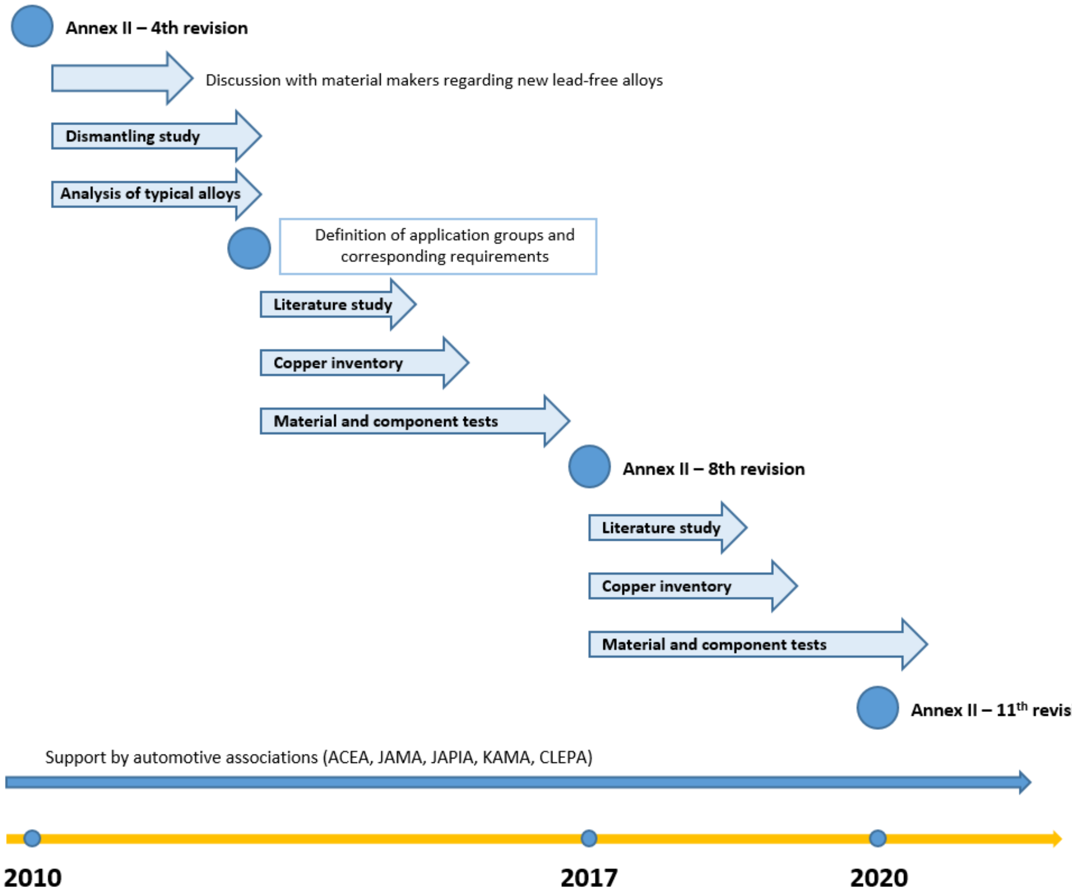


Figure 15. Summary of the activities carried out by the automotive industry in the last ten years and focused on the study and possible substitution of leaded copper alloys.

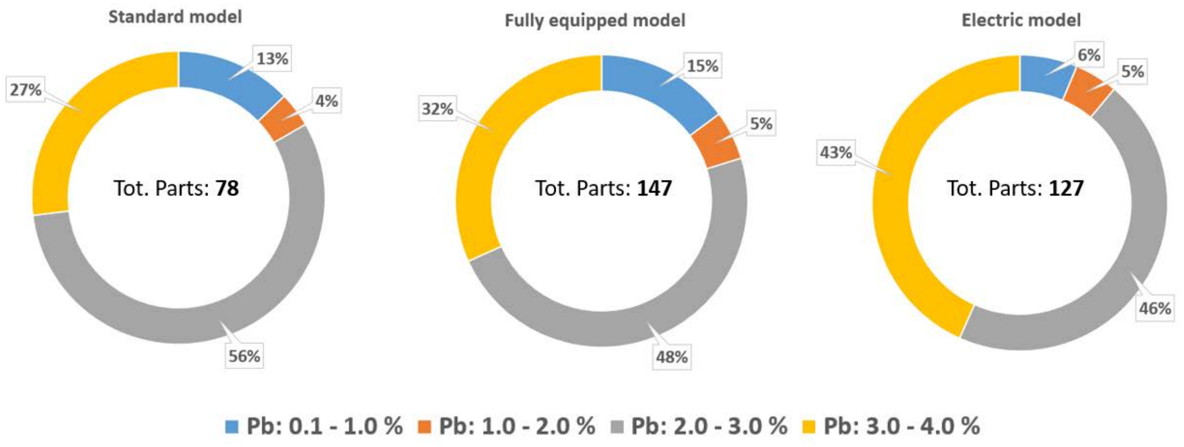


Figure 16. Number of leaded-copper alloy parts and their split based on lead-content for each of the three vehicle models taken into account.

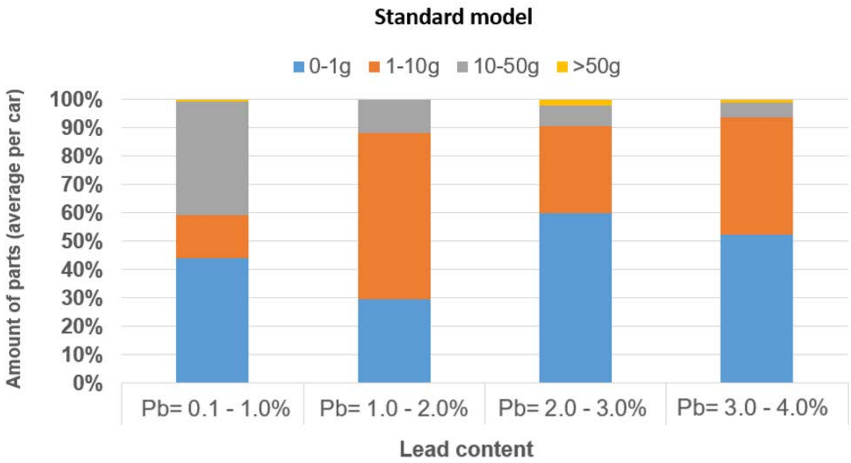
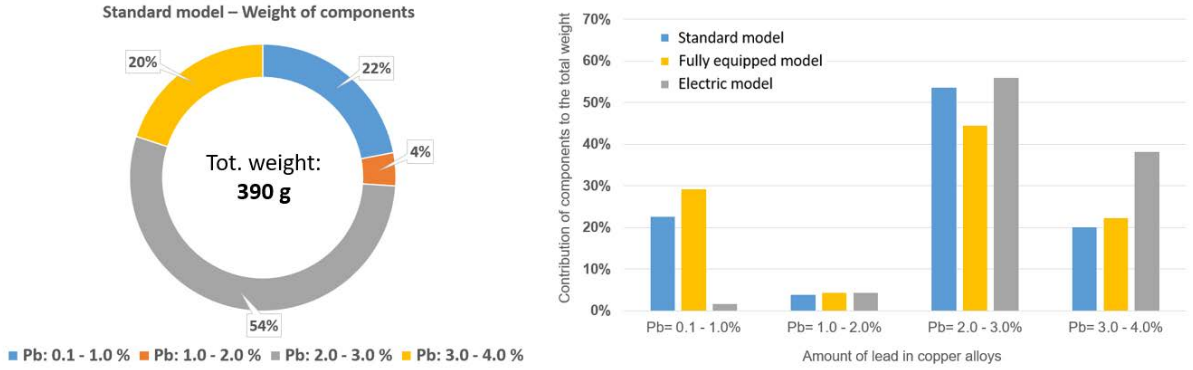


Figure 17. Average amount of leaded-copper alloy parts, expressed in percentage, in standard vehicle models and their split based on lead-content and weight.

The average total amount of leaded copper alloys used in the fully equipped models (about 700 g) is higher than that used in the electric models (about 510 g) and in the standard models (about 390 g). The graph of Figure 18 shows the contribution of the different components, in terms of content of lead, to the total weight of leaded-copper alloys.



(a) (b)

Figure 18. (a) Contribution of the different components, classified according to their lead content, to the total average weight of leaded-copper alloys in standard vehicles and (b) contribution of the different components to the total weight of leaded-copper alloys in all three vehicle model types.

As shown in Figure 19, compared to 2014, in 2020 the average number of components containing leaded-copper alloys per car has decreased for both the standard best-selling models and the fully equipped ones (electric models were not taken into account in 2014). Similarly, the average total amount of leaded copper alloys per car has substantially decreased, of about 60 %, for both standard and equipped models. The same trend has been observed for the total amount of lead included in copper alloys per car, which showed an average reduction of 36 % for standard vehicle models and of 58 % for fully equipped models. The fact that the average number of leaded-copper components has decreased at a lower rate than the amount in grams of leaded copper alloys per car suggests that relatively big/heavy components has been removed from 2014 to 2020. The absence of these components, together with the large number of very small parts containing a relatively high amount of lead, caused the average lead content per part to increase from 1.4 % in 2014 to 2.1 % in 2020.

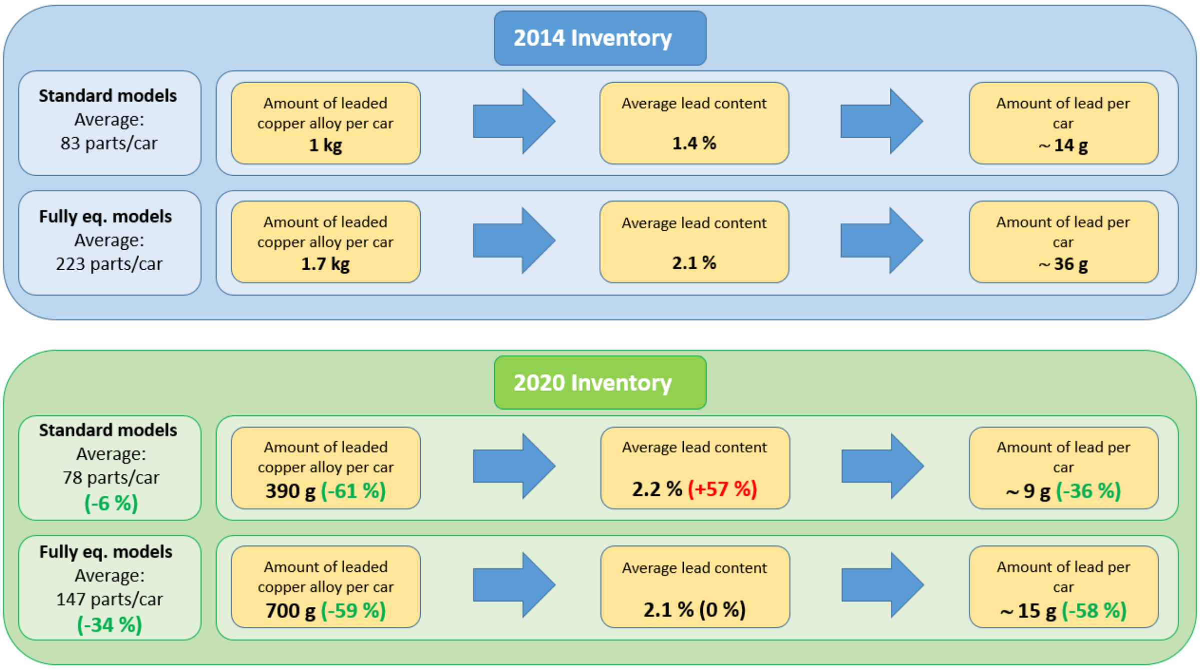


Figure 19. Comparison between the outcome of the 2014 and the 2020 leaded-copper alloys inventory.

In addition to the revised leaded-copper alloy inventory, the analysis of the literature studies and the selection and the characterization of two promising lead-free copper alloys, several attempts aiming to substitute leaded-copper alloys in real components have been carried out in the last few years by different stakeholders of the automotive and of the electric and electronic industry. In all the known cases where lead-free copper alloys were evaluated as potential substitutes of leaded-copper alloys, the produced components failed in fulfilling the needed requirements. For example, Figure 20 and Figure 21 show the defects obtained in a crimp connection and in a knurl made of CuZn42 instead of the normally used CuZn39Pb3 alloy[27].

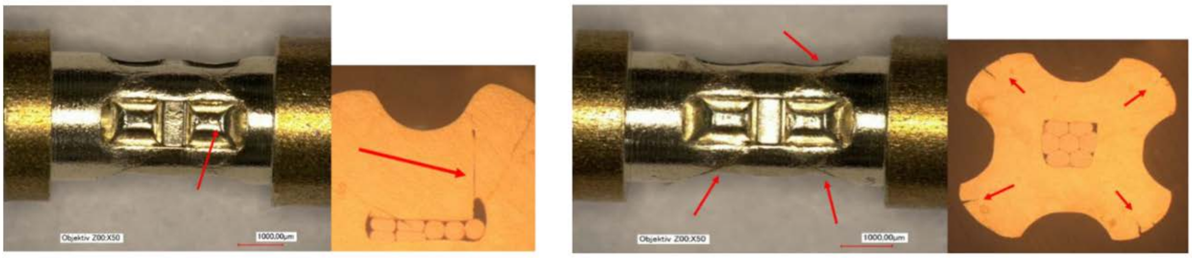


Figure 20. A crimp connection made of CuZn42 with cracks.

Figure 21. A knurl made from CuZn42 with sharp edges and broken material.

Similarly, the picture of Figure 22 shows a comparison between a knurl pressed on a component made of CuZn39Pb3 and on a component made of CuZn21Si3P (EcoBrass®)[27].

Figure 22. A knurl pressed on a component made of CuZn39Pb3 (left) and two knurls pressed on CuZn21Si3P with loose particles (right).

JAPIA reported a recent investigation performed by a company belonging to their association and aiming to substitute a leaded-brass JIS C3604 currently used for a tire valve. The lead-free alloys taken into account were three different bismuth-based alloys, named BZ-5U, BZ-5A and BZ-3N[36].

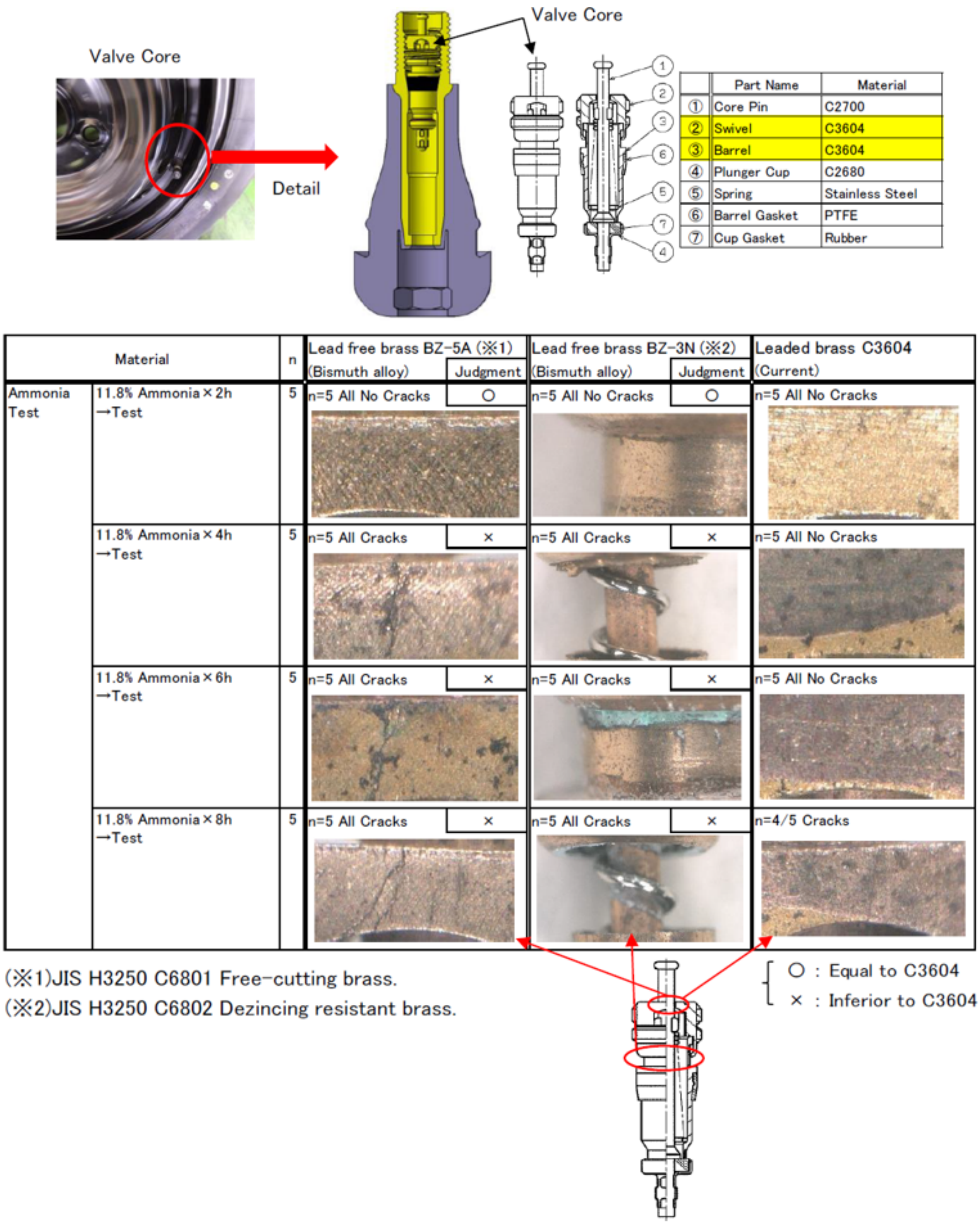
In the first part of the study, the adhesion of the rubber part onto a stem made of BZ-5U alloy was evaluated. In the test, the bismuth-based lead-free brass performed worse than the leaded-brass. Figure 23 shows the details of the evaluated part and the pictures of the tire valve stems after the rubber adhesion test.

Material		n	Lead free brass BZ-5U (※1) (Bismuth alloy)	Judgment	Leaded brass C3604 (Current)
Adhesion	Chemical Resistance ($10\%CaCl_2 \times 80°C \times 168h$ →Test)	5	27% Min. 	×	47% Min. 
	Acid Resistance ($0.2\%H_2SO_4 \times 168h$ →Test)	5	65% Min. 	×	83% Min. 

Figure 23. Tire valve with TPMS for which the substitution of the leaded brass C3604 was evaluated and pictures of the stems made of C3604 alloy and BZ-5U alloy after the rubber adhesion test.

In the second part of the evaluation, valve cores made of the reference leaded brass and of the bismuth-based lead free brasses BZ-5A and BZ-3N underwent a stress-corrosion cracking test in which they were initially exposed to an ammonia solution (concentration: 11.8 % by weight) and then washed with sulfuric acid (concentration: 10.0 % by weight). Also in this case, both bismuth-based alloy showed a stress-cracking behavior much worse that that of the reference alloy, as demonstrated by the pictures of Figure 24.

The described results convinced the company not to substitute the leaded-brass used for the tire valve.



	Part Name	Material
①	Core Pin	C2700
②	Swivel	C3604
③	Barrel	C3604
④	Plunger Cup	C2680
⑤	Spring	Stainless Steel
⑥	Barrel Gasket	PTFE
⑦	Cup Gasket	Rubber

Material		n	Lead free brass BZ-5A (※1) (Bismuth alloy)	Judgment	Lead free brass BZ-3N (※2) (Bismuth alloy)	Judgment	Leaded brass C3604 (Current)
Ammonia Test	11.8% Ammonia×2h →Test	5	n=5 All No Cracks	○	n=5 All No Cracks	○	n=5 All No Cracks
	11.8% Ammonia×4h →Test	5	n=5 All Cracks	×	n=5 All Cracks	×	n=5 All No Cracks
	11.8% Ammonia×6h →Test	5	n=5 All Cracks	×	n=5 All Cracks	×	n=5 All No Cracks
	11.8% Ammonia×8h →Test	5	n=5 All Cracks	×	n=5 All Cracks	×	n=4/5 Cracks

(※1)JIS H3250 C6801 Free-cutting brass.
(※2)JIS H3250 C6802 Dezincing resistant brass.

○ : Equal to C3604
× : Inferior to C3604

Figure 24. Valve core for which the substitution of the leaded brass C3604 was evaluated and pictures showing the results of the stress-corrosion cracking tests performed on valve cores made of leaded brass C3604 and bismuth-based brasses BZ-5A and BZ-3N.

3.4. Question 4

Please provide a roadmap specifying the past and necessary next steps/achievements in research and development including a time scale for the substitution or elimination of lead in this exemption.

Since July 2003, when the heavy metal ban set by the European ELV Directive 2000/53/EC became effective, the content of mercury, cadmium, hexavalent chromium and lead in new cars and in their components dropped significantly, as showed qualitatively by the graph of Figure 25. This process involved the re-design, testing and validation of several thousands of automotive components[9].

The Exemption 3 of the ELV Annex II allowing the use of lead in copper alloys up to 4 % by weight has been part of the ELV Directive since its first issue in 2000. In spite of that, and even though not being the main player in the leaded-copper alloys market, the automotive industry has been investing a lot of money and resources to try as much as possible to reduce or eliminate the amount of lead in copper alloys. As extensively described in the ACEA et al. contribution for the last revision of the ELV Exemption 3 in 2014[26] and in that of 2010, different chemical elements have been evaluated for substituting lead in copper alloys. In particular, copper alloys based on silicon and bismuth, relatively close to lead in the periodic table of elements, have been abundantly studied and characterized but in most of the cases they demonstrated to be not suitable for substituting leaded-copper alloys. The inadequacy of silicon and bismuth to substitute lead in copper alloys goes beyond the production and the use of the components made of alloys based on them. Bismuth, for example, highly damages the recyclability of copper. Even if present in traces, bismuth tends to segregate at the copper grain boundaries increasing the sensitivity of the metal to the cold and the hot cracking[2]. Analogously, silicon-based copper alloys cannot be mixed with other copper alloys and their recycling shall be conducted through an independent recycling stream[27].

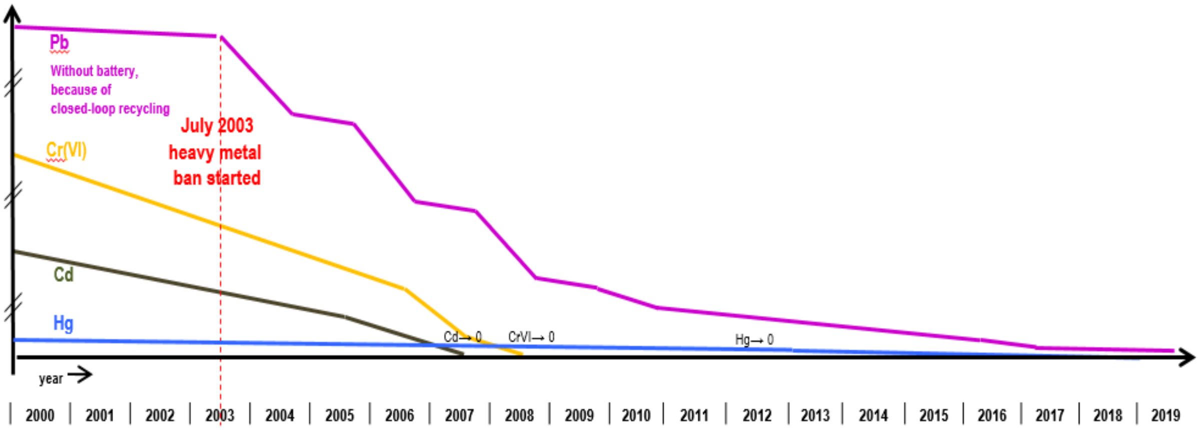


Figure 25. Qualitative trend for the content of the four heavy metals regulated by the EU ELV Directive in new vehicles from 2000 to 2019[28].

Other elements such as selenium, titanium, phosphorous and graphite have also been evaluated as potential substitutes of lead in copper alloys. Alloys based on these “new” elements were primarily developed as substitutes for casting yellow and red brasses used for plumbing devices. Thus, their microstructure was optimized mainly for maximizing their ability to be cast rather than their machinability. Furthermore, the corrosion resistance of these alloys was evaluated in drinking water.
As the leaded-copper alloys used in the automotive industry are mainly wrought alloys and as they are in contact with many other fluids besides water, most of the findings associated with these “new” alloys are not relevant for the products used in vehicles and their parts[2].

As already mentioned in the answer to Question 3 and in the chart of Figure 15, in the last ten years vehicle manufacturers and several automotive stakeholders performed vehicle dismantling studies, literature studies and test on materials and components aiming to increase the know-how on leaded-copper alloys and to find potential substitutes. In particular, these activities allowed ACEA et al. to get a better understanding of the uses of leaded-copper alloys, their technical and technological properties and the requirements of all the components made of these alloys. Differently from years ago, it is now clearer that the technical properties of lead as an alloy element in copper can be only partially taken over by other elements and that it is currently not possible to obtain the same mix of properties by simply substituting lead with another element or with a combination of more elements[29].

The revised leaded-copper alloy inventory showed that relatively high amount of lead are still needed mainly for very small components with a weight lower than 10 g. However, it also showed that the average number of automotive components made of leaded-copper alloys has significantly decreased in the last six years, as well as the total amount of lead per vehicle brought in through leaded-copper alloys. This demonstrates once again this type of copper alloys are used only when it is strictly necessary.

The recent literature survey performed by DKI in collaboration with ACEA et al. laid the foundations for the selection of two lead-free copper alloys, mentioned in the answer to Question 1, which already showed promising results and which will be further characterized.

As of today, it is still not possible to estimate a timeline for the elimination of lead in copper alloys. This is due to the fact that currently there are no available alloys able to ensure both machinability performances comparable of those of leaded copper alloys and comparable mechanical, chemical (e.g. corrosion resistance), conductivity (e.g. thermal and electrical), friction and wear properties.

Most likely, the future substitution of leaded-copper alloys will not be achievable through only a single type of lead-free copper alloys. Rather, different varieties of lead-free alloys will be likely needed to cover the whole spectrum of properties and possible applications that leaded-copper alloys are able to offer.

The challenges to face in the upcoming years to succeed in the complete substitution of leaded-copper alloys include the development of new alloys, their full characterization, as well as the deep study of the promising alternative alloys already available and the re-design, production and test of real components made of these new alloys. Additionally, as already mentioned, the recyclability aspects of the new developed alloys will need to be taken into account and especially the possibility to mix them with other copper-based products without “polluting” them and thus without the need to create and manage new recycling paths for each new alloy.

Another important challenge shall be focused on understanding how to deal with leaded-copper scrap that have been produced during the last years, that years ago were estimated to be in the range of ten to twenty thousand tons and that nowadays is considered a good quality scrap that can be directly melted in the foundry shops of the brass mills[2].

The overall environmental impact of new developed lead-free alloys shall be also be evaluated and compared with that of leaded-copper alloys. The production of leaded-copper alloys mostly involve secondary materials and involve an almost perfectly closed environmental loop and a relatively low energy consumption[32]. New lead-free copper alloys could then succeed only if their technological and technical properties will be associated with an overall environmental impact that is lower of that of the current leaded-copper alloys.

3.5. Question 5

What is the amount of lead that would be contained in vehicles

- **a. placed on the EU market**
- **b. worldwide**

in case the exemption is continued? Please provide at least a rough calculation or substantiated estimate.

In 2019, according to ACEA[33] and OICA[34], 18.003.571 new cars and light commercial vehicles (categories M1 and N1) were registered within the EU28+EFTA. 3.0 % of these vehicles were electric.
Taking into account the consumer demands per segment, a similarly to what was done in 2014[26], 80 % of these vehicles can be considered standard models, whereas 20 % can be assimilated into fully equipped models.
Combining the above mentioned vehicle market share with the outcome of the 2020 European copper inventory (see answer to Question 3), and considering the inventory to be representative for all the M1 and N1 vehicles registered in the EU28+EFTA, it can be assessed that 187 t of lead as constituent of leaded-copper alloys were contained in vehicles placed on the European market in 2019.
As showed in Figure 26, even if the number of vehicles sold in the EU in 2019 is higher than in 2013 and 2009, the corresponding total amount of lead brought on the market through the vehicles and included in copper alloys has significantly decreased in the last few years.
Unfortunately, detailed worldwide figures regarding the amount of lead in vehicles as part of copper alloys are not available. In particular, for many countries accurate date on that are missing (e.g. material break down of vehicles).

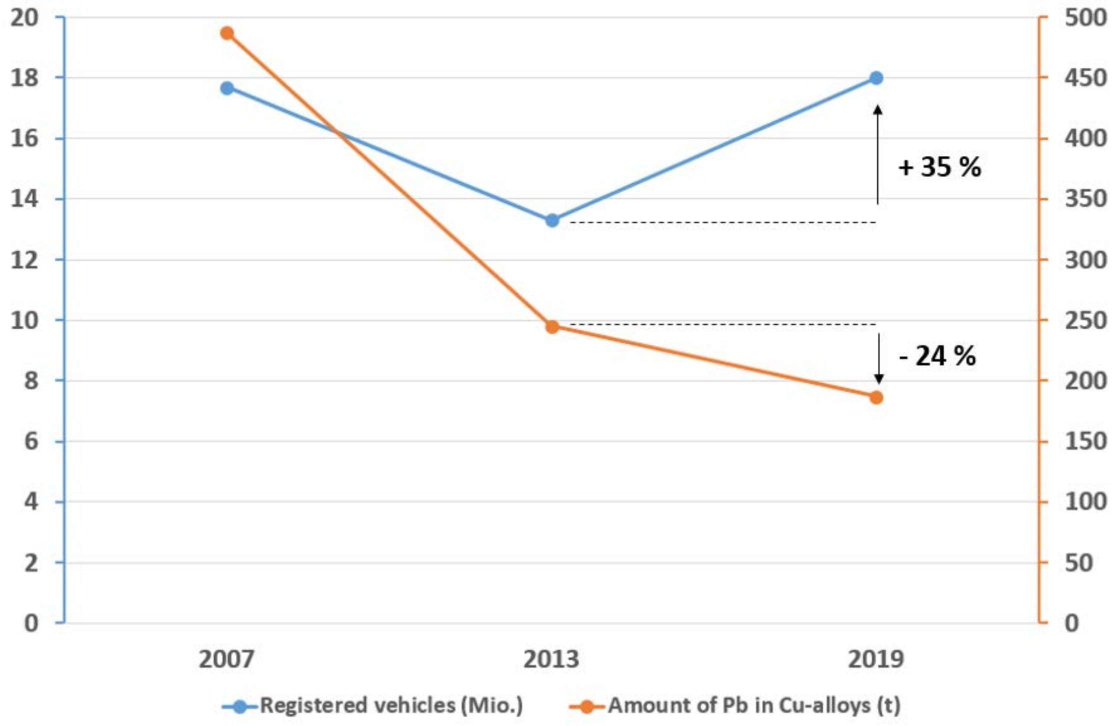


Figure 26. Number of vehicles (cars + LCV) registered in the EU and related total amount of lead in copper alloys that are part of these vehicles.

3.6. Question 6

Overall, please let us know whether you agree with the necessity to continue the exemption and sum up your arguments for or against the continuation.

As extensively described in the answers to the previous questions, leaded copper alloys are still widely used in the automotive industry, mainly for the manufacturing of very small parts (e.g. electrical and electronic equipment, valve elements, joint elements, bushing, etc.) that require very particular properties. In particular, the high machinability, associated to the optimal chip breaker effect of lead, the high conductivity and the intrinsic lubricant effect caused by lead, are some of the main reasons why leaded-copper alloys are used.

In the last years, the use of leaded copper alloys has been strictly limited to the applications where no other technical viable solution could be found. As demonstrated by the revised 2020 leaded-copper inventory, also the amount of automotive parts and the amount of lead per car included in copper alloys has appreciably decreased since 2014.

Several promising lead-free copper alloys have been recently developed and in some cases even commercialized. Based on the current knowledge, it is not possible to identify a lead-free copper alloy or a group of lead-free copper alloys that could potentially substitute leaded-brasses and copper alloys in all their applications fields. For example, some new alloys might be able in the future to substitute copper alloys with relatively low amount of lead (e.g. up to 0.8 % by weight) for what concerns the machinability and the mechanical and corrosion properties, but no alternative currently exists for emulating the internal lubricant effect of leaded alloys. Also, a very limited number of literature studies have so far taken into account the recyclability aspects of new-developed lead-free copper alloys and their overall environmental and circular economy-related impacts. From this point of view leaded-copper alloys, having a very good “acceptance” in the copper recycling loop, not requiring a dedicated recycling stream and being produced with very high fraction of secondary material, are difficult to replace obtaining lower environmental impacts.

Once and if new lead-free copper alloys able to fully substitute leaded-alloys will be available on the market, many years will still be needed by the automotive industry to re-design, test, validate and produce new components made of these alloys.

Therefore, the associations involved in answering this questionnaire, ACEA, JAMA, JAPIA, KAMA, CLEPA and the European Copper Institute, claim that the unlimited exemption concerning leaded copper alloys is still required and that the maximum lead content in these alloys must remain at 4 % by weight. Moreover, the joint associations propose a review time for this exemption of 8 years.

4. Description of the associations supporting this application

ABOUT ACEA

The European Automobile Manufacturers' Association (ACEA) represents the 16 major Europe-based car, van, truck and bus makers:
BMW Group, CNH Industrial, DAF Trucks, Daimler, Ferrari, Fiat Chrysler Automobiles, Ford of Europe, Honda Motor Europe, Hyundai Motor Europe, Jaguar Land Rover, PSA Group, Renault Group, Toyota Motor Europe, Volkswagen Group, Volvo Cars, and Volvo Group.

ACEA works with a variety of institutional, non-governmental, research and civil society partners - as well as with a number of industry associations with related interests.

ACEA has permanent cooperation with the European Council for Automotive R&D (EUCAR), which is the industry body for collaborative research and development.

ACEA has close relations with the 29 national automobile manufacturers' associations in Europe, and maintains a dialogue on international issues with automobile associations around the world.

- 14.6 million Europeans work in the auto industry (directly and indirectly), accounting for 6.7% of all EU jobs.
- 11.5% of EU manufacturing jobs–some 3.7 million–are in the automotive sector.
- Motor vehicles account for €440.4 billion in taxes in major European markets.
- The automobile industry generates a trade surplus of €74 billion for the EU.
- The turnover generated by the auto industry represents over 7% of EU GDP.
- Investing €60.9 billion in R&D annually, the automotive sector is Europe’s largest private contributor to innovation, accounting for 29% of total EU spending.

ABOUT CLEPA

CLEPA, the European Association of Automotive Suppliers, represents over 3,000 companies supplying state-of-the-art components and innovative technologies for safe, smart, and sustainable mobility.

CLEPA brings together over 120 global suppliers of car parts, systems, and modules and more than 20 national trade associations and European sector associations. CLEPA is the voice of the EU automotive supplier industry linking the sector to policy makers.

- The automotive sector accounts for 30% of R&D in the EU, making it the number one investor.
- European automotive suppliers invest over €30 billion yearly in research and development.
- Automotive suppliers register over 9,000 new patents each year.
- Automotive suppliers in Europe generate close to five million direct and indirect jobs.

ABOUT The European Copper Institute (ECI)

The European Copper Institute (ECI) is the voice of the International Copper Association (ICA) in Europe. The International Copper Association, with its 35 members, represents a majority of the world's primary copper producers, and some of the largest mid-stream smelters/refiners, and 10 of the world's largest copper fabricators. It aims to bring together the global copper industry to develop and defend markets for copper and to make a positive contribution to society's sustainable development goals.

ABOUT JAMA

Japan Automobile Manufacturers Association, Inc. (JAMA) is a non-profit industry association which comprises Japan's fourteen manufacturers of passenger cars, trucks, buses and motorcycles. JAMA works to support the sound development of Japan's automobile industry and to contribute to social and economic welfare.

ABOUT JAPIA

The Japan Auto Parts Industries Association (JAPIA) is an industry organization that was established in August 1969, when its predecessor, the Auto Parts Industries Association was reorganized as an incorporated association with a higher level of public interest. Today, the value of shipments of auto parts from member companies has reached approximately 20 trillion yen, supporting the manufacture of automobiles not only in Japan but also around the world.
Each and every one of these high-quality parts makes a significant contribution to the safety and comfort of automobiles. The environment surrounding the automotive parts industry is becoming more and more severe, and the industry is facing many challenges such as responding to structural changes, dealing with environmental issues, and promoting international cooperation.
JAPIA will continue to develop proactive business activities to contribute to the growth of the Japanese economy and society while promoting the sound progress of the "motorized society" through the automotive industry.

In 2018 (FY), the automotive related shipments was 60 trillion yen (19% of all manufacturing), of which 26trill. yen (8%) was for automobiles and 35trill. yen (11%) was for auto parts. In terms of employment, the automotive industry as a whole employed 900 thousand people in JAPAN, which accounts for 12% of the total employment in the manufacturing industry, of which 700,000 were in the auto parts industry, accounting for 9% of the total.

There are approximately 6,800 companies in the auto parts industry in Japan, and the number of JAPIA member companies (434), most of which are in Tier 1, accounted for 6% of the industry but about 60% of the value of shipments.

About KAMA

KAMA is a non-profit organization representing the interests of automakers in Korea. We are promoting the sound growth of the automobile industry and also the development of the national economy.

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