Exemption Evaluation under Directive 2000/53 EC

ACEA et al. Answers to Stakeholder Consultation Questionnaires

of Bio Innovation Service
and The United Nations Institute for Training & Research (UNITAR)
and Fraunhofer Institute for Reliability and Microintegration (IZM) dates 08.02.2024

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)
- CLEPA, the European Association of Automotive Suppliers, Brussels
  (transparency registration ID number 91408765797-03)
- 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 & Mobility Association (KAMA), Seoul

This document consists of following two elements:

PART A Background and technical information
PART B Answers to the questionnaire

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PART A Background and technical information

Acronyms and definitions

Bi	Bismuth
CRM	Critical Raw Material
Cu	Copper
Mn	Manganese
ICE	Internal Combustion Engine
Pb	Lead
Si	Silicon
Sn	Tin
Te	Tellurium
VDA	Verband der Deutschen Automobilindustrie
Zn	Zinc

1. Introduction

With Commission Directive (EU) 2017/2096 from 17. November 2017, the Commission decided to extent the exemption 3 as the use of Lead remains unavoidable for the materials and components covered by exemption 3. This exemption was set to be reviewed in 2021. The review procedure started on 15. September 2020 with a stakeholder consultation ending on 8. December 2020 (12 weeks). The consultants published their report (in the following OEKO Report) on November 5th 2021. Based on the consultant recommendations and consultation with Member States, the Commission adopted Annex II with Commission delegated Directive (EU) 2023/544 of 16 December 2022.

Concerning ELV Annex II exemption 3, OEKO Report of 5. Nov. 2021 gives following recommendation:

> *´… For the validity period, the consultants suggest three years. The Commission might consider four years to enable the review of this exemption in parallel to the corresponding RoHS exemption III-6(c). Eight years as requested by ACEA et al. in the consultants' view cannot be justified in line with Art. 5(2)(b)(2) taking into account the proven cases where lead could be avoided in copper alloys, and that in the consultant's opinion there is potential for substitution in more applications. This should allow sufficient time for application-centred and specific assessments of substitution possibilities or, in case, impossibilities, so that in the next review, applicants can provide substantiated, sound and transparent evidence where the use of lead may still be unavoidable….`*

In Directive (EU) 2023/544 the Commission decided a further review for entry 3 in 2025 (see ibd. Note(3) to table *´This exemption shall be reviewed in 2025´*) .

In the RoHS Directive, the exemption 6(c) covers the use of Copper alloys with a Lead content up to 4% by weight. Stakeholders applied a renewal request on 03.01.2020 (same wording as in ELV Annex II entry 3). The COMM decision is still pending. A consultant report from 15. Feb. 2022, elaborated by the OEKO Institute Freiburg, recommends extending the exemption and, according RoHS decision rules, to set the expiry date to 21. July 2026 for all RoHS product categories.

For the automotive industry, it was surprising, that the Commission initiated an early review date for the review of entry 3 in February 2024. The review of Entry 3 is part of a stakeholder consultation for the 12th adaptation to scientific and technical progress of exemptions of Annex II. The consultation is open from 8th February 2024 to 18th April 2024 (10 weeks).

2. Markets

2.1 Global and European Copper market

The Copper market is global for refined primary Copper as well as for Copper containing scrap. There is no vehicle specific Copper material route known, nor for primary material nor for scrap.

According the ICSG Copper fact book 2023[1], page 40, the total global Copper usage in 2022 was around 32 million metric tonnes. Building and construction have a share of 26,2 %. Around 8,4 % of the global Copper demand are allocated to automotive applications[2,3,4].

Another Cu-uses estimation for the EU is given in the JRC critical raw material report 2023 Annex 6 [5].

Material	Application	Share	NACE sector	VA in million €
Copper	Building construction, Electrical power	21%	C27 - Manufacture of electrical equipment	89 422
Copper	Manufacture, other, diverse	13%	C32 - Other manufacturing	45 912
Copper	Building construction, plumbing	10%	C28 - Manufacture of machinery and equipment n.e.c.	204 200
Copper	Manufacture, Transport, Automotive, **Electrical**	10%	C29 - **Manufacture of motor vehicles**, trailers and semi-trailers	194 448
Copper	Manufacture, Industrial, non-electrical	10%	C28 - Manufacture of machinery and equipment n.e.c.	204 200
Copper	Manufacture, other, Consumer & general products	8%	C32 - Other manufacturing	45 912
Copper	Infrastructure, Power utility	7%	C27 - Manufacture of electrical equipment	89 422
Copper	Manufacture, Industrial, Electrical	6%	C27 - Manufacture of electrical equipment	89 422
Copper	Manufacture, Transport, **other transport**	4%	C30 - Manufacture of other transport equipment	55 777
Copper	Manufacture, other, cooling	3%	C28 - Manufacture of machinery and equipment n.e.c.	204 200
Copper	Infrastructure, Telecommunications	3%	C27 - Manufacture of electrical equipment	89 422
Copper	Manufacture, other, electronic	2%	C26 - Manufacture of computer, electronic and optical products	77 000
Copper	Building construction, Architecture	2%	C28 - Manufacture of machinery and equipment n.e.c.	204 200
Copper	Building construction, Communications	1%	C27 - Manufacture of electrical equipment	89 422
Copper	Manufacture, Transport, Automotive, **non-electrical**	1%	C29 **- Manufacture of motor vehicles**, trailers and semi-trailers	194 448
Copper	Building construction, building plant	> 0%	C32 - Other manufacturing	45 912

Table 2.1 *Copper applications in the EU per NACE sector; data taken from [4]*
(G) VA : (Gross) Value Added NACE: Nomenclature statistique des activités économiques dans la Communauté européenne

[1] https://icsg.org/copper-factbook/ last accessed 25.03.2024.

[2] https://www.coppercouncil.org/iwcc-statistics-and-data; last accessed 14.11.2023.

[3] https://www.coppercouncil.org/iwcc-statistics-and-data; last accessed 23.02.2024.

[4] https://www.iea.org/data-and-statistics/charts/total-copper-demand-by-sector-and-scenario-2020-2040; last accessed 23.02.2024.

[5] [European Commission DG GROW 2023] Study on the Critical Raw Materials for the EU - Final Report (2023), page 67 doi: 10.2873/725585 Annex 6 Material uses share (Copper), NACE 2 sectors assignment and Value added.

The data in the table 2.1, above, reflect the estimated share of Copper uses in different European end-user application categories, per application and NACE Code. The automotive industry is the estimated as the fifth most important Copper user in the EU. The EU CRM 2023 report estimates the total 2022 demand for Copper in the automotive sector with around 11 %.

For 2022 the EU market (EU27+UK) for total Copper *alloys* is estimated with a production volume of around 1, 4 Mio. tonnes [6] . Major uses are plumbing/sanitary [7] and infrastructure applications.

According Welter [Welter 2014] it is estimated that the brass mills fabricate some 30 000 t of brass rods for the automotive market.

2.2. Global and European vehicle market

The European vehicle market currently is 19 % of the global market. So less than, or around **2 %** of the global refined Copper produced in 2022 may be allocated to EU vehicles new registered in EU in the year 2022. Leaded Copper alloys are a small part thereof.

3. Use of Copper in vehicles

Copper and Copper alloys have unique properties and are essential materials for the automotive industry. 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[8] 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.

Around 1/5 of the Copper use can be allocated to the motor of an internal combustion engine (ICE) vehicle. This includes among other applications generator, starter, pumps, ventilator-/cooling system, injection systems, electric and control units and engine specific harness components. Due to specific requirements like elevated temperatures, impact of automotive fluids, conductivity and corrosion resistance, the use of Copper materials is necessary.

With EU decision in Regulation (EU) 2023/851 [9], new registered passenger vehicles with fossil-fuel powered internal combustion engine from 2035 onwards will be banned. It can be assumed that within a decade the volume of corresponding Copper applications in ICE´s and the number of annually new registered ICE powered vehicles will decrease significantly.

This traffic turnaround in combination with the numbers reported in 3.1 above will cause a change in the number of parts currently made of Leaded Copper alloys.

Cables, Copper windings in electrical engines and generators, are not made of Leaded Copper alloys.

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[6] https://www.coppercouncil.org/wp-content/uploads/2023/08/Semis-production-and-demand.xlsx; last accessed 11.03.2024.

[7] Factsheet Messing, (FKZ 3716 35 3230) Umweltbundesamt Dessau www.umweltbundesamt.de last accessed 9.11.2022.

[8] LME copper price per 11.4.2024 was 9374.00 USD per Tonne; source https://www.lme.com

[9] Regulation (EU) 2023/851 of the European Parliament and of the Council of 19 April 2023 amending Regulation (EU) 2019/631 as regards strengthening the CO2 emission performance standards for new passenger cars and new light commercial vehicles in line with the Union's increased climate ambition (http://data.europa.eu/eli/reg/2023/851/oj; OJ L 110, 25.4.2023, p. 5–20

So, most of the around 30 kg (see 3.1 below) of Copper per vehicle is used in Lead-free Copper based materials. Electrical driven vehicles will usually not have a starter motor but will have more connectors and similar components in the power train and to the battery. In combination with the increasing digitalisation up to autonomous driving, the number of specialized small components made of Leaded Copper alloys can increase.

3.1 Literature data

On global level, there are public available figures for Copper use in vehicles on the webpages[10] of the Copper Alliance in 2022. For Copper in today´s conventional ICE car they specify following uses:

Wiring	85 %
Alternator	5 %
Starter motor	3,7 %
Small motors	3,5 %
Non PT other	1,8 %
PT other	1,0 %

PT: Power train

This sums up to an estimated quantity of 29,4 kg per current vehicle on average.

3.2 Figures determined by the automotive industry

Our conclusions are based on current data samples provided by our members. The data were anonymized.

In line with literature, we state that the total amount of Copper materials per vehicle has increased.

EV need more Copper than ICE vehicles; EV have more electronics and electrical applications than ICE.

We note that the total Copper content and we note that the total Pb content covered by entry 3 are varying in a broad range of vehicle model.

We see the range for Cu uses varying between about 21 kg up to around 100 kg and we see the range for entry 3 related Pb weight share per vehicle varying between around 4 and 20 g.

As average value concerning entry 3 we estimate on average around 9 g Pb/vehicle. As the total Copper share per vehicle increased and the number of electric and electronic systems increased, a slight further decrease compared to 2019 may be assumed.

As there is no unified naming of components and because of the high amounts of part numbers, a listing of examples for specific uses would always be incomplete. Instead, reference is made to the previous contributions of ACEA et al where application groups and use examples for components produced with Lead-containing Copper alloys are outlined.

[10] https://copperalliance.org/wp-content/uploads/2022/03/Automotive.pdf; last accessed 12.03.2024

4. Function of Lead in Copper alloys

Lead is present in the microstructure of some Copper alloys in the form of finely dispersed particles, located at the grain boundaries of the alloy matrix. In addition, it has a grain fining impact. Lead because of its low melting point, is able to fill any casting porosities that may arise due to volume deficit that occurs during solidification[11]. This increases the pressure tightness of casted parts. Lead concentration above 1,5 % slightly reduces strength and elongation. Among other parameters, the Lead influences stress relaxation behaviour or mechanical deformation. Lead as alloying element has no interference with other alloying elements. This reduces complexity in alloy production and gives some robustness in alloy production.

4.1 Emergency Lubrication, Sliding Characteristics

The ability of the Lead particles decreases the coefficient of friction. In the Copper matrix, embedded Lead particles give excellent sliding characteristics and can prevent fretting of sliding elements e.g. in gear units and act as emergency lubricant, which is considered as important safety advantage viewed from engineering perspective.

4.2 Enhanced Machinability

Lead enhances the machinability of Copper alloys[12]. The most used free cutting Copper alloy is C36000 with the nominal composition 61,5% Cu, 3% Pb, and 35,5 % Zn [13]. It is considered as a kind of reference standard material, if maximum machinability is desired. A good machinability is not only economically relevant, but also important from an environmental point of view as a reduced machinability may increase the energy demand during the production process and increase the need for additional lubricant. Lead acts as a chip breaker and lubricant which provides manufacturing and performance benefits[14]. The Lead particles enable superior machinability required to achieve precise tolerances in tiny components. So miniaturisation of components and less material use is supported in addition by lower specific cutting forces level e.g. for the alloy CuZn39Pb3. Moreover, the achievable resulting surface quality is excellent with low surface roughness values.

Adding Lead to the alloy effects the formation of short chips[15], instead of long ribbon and whirling chips, which often occur in machining of Lead-free Copper alloys. The short chips support efficient production procedures and minimize challenges of safety and production interrupts which may be associated with the formation of whirling chips.

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[11] https://kupfer.de/kupferwerkstoffe/kupfer-legierungen/kupfer-blei-zinn-legierungen/?lang=en; last accessed 12.03.2024.

[12] Klocke F Nobel C. : Entwicklung einer Hochleistungszerspanung für schwerzerspanbare bleifreie Kupferknet- und –Gusslegierungen Final Report AIF IGF16867 N; https://publications.rwth-aachen.de/record/230384; last accessed 12.03.2024.

[13] [ASM 2001] ASM Specialty Handbook: Copper and Copper Alloys; ASM International 2001

[14] 2022_copper_alliance_EU_a7037_ELV_Directive_FAQ-1.pdf Copper Development Association, Inc. 2022 https://copper.org/publications/pub_list/pdf/a7037_ELV_Directive_FAQ.pdf; last accessed 12.03.2024.

[15] Tönshoff H.K., Denkena B.: VDI Buch Spanen Grundlagen, 2. Auflage, Springer-Vieweg Verlag Heidelberg S.48

´ The smearing property of the Lead nodules and the surface film allows minimising the use of lubricants. Indeed, the presence of lead strongly facilitated the occurrence of micro-lubricated and lubrication free machining without a real loss in performance. On the other hand, as it will be shown below, acceptable machining of lead-free alloys can require complex lubrication systems.´ [Welter 2014]

Workability (machining and milling) of Lead-free alloys is still in scope of research projects. The industry, with more than 20 industry partners, initiated further basic studies for the milling of Lead-free Copper alloys [16] at Aachen University. The research was supported with public founding.

4.3 Better Corrosion Resistance

As outlined in the Welter report from 2014 [17] (page 8 figure 3), increasing Lead content contributes to higher material corrosion resistance especially against sulphuric acids as well as for chlorine environment.

The Copper alloys used for vehicles need to be, dependant from each application and their location, resistant against additives in lubricants, vehicle operating fluids and additives therein. Any change will require validation test on component and system level.

4.4 Lower Impact on Electrical Conductivity and Aspects of Contacts Relaxation

Adding additional elements in pure Copper, in general, decreases the electrical conductivity and increases the electrical resistivity. The impact is element specific. Compared to Lead, the conductivity decrease impact of the chemical elements Si, Fe or Al as alloying element in Copper is higher. Higher resistivity values mean more energy losses by heat.

Element	Resistivity increase per 1 wt. % addition; [µ Ω · cm]
Au	0,185
Ag	0,355
Zn	0,286
Pb	**1,02**
Al	2,22
Mn	3,37
Te	4
Si	7
Fe	10,6
P	14,3
S	18,6

Table 4.4.1: *Resistivity increase per added element; data source ASM copper Handbook 2001*

[16] Bergs T., Schraknepper D., Baier S.: Entwicklung angepasster Werkzeuge u. Prozesse zur Steigerung der Produktivität und Prozesssicherheit beim Fräsen innovativer bleifreier Kupferwerkstoffe; AIF Research Report, IGF-Vorhaben Nr. 20029 N RWTH Aachen University Werkzeugmaschinenlabor WZL Lehrstuhl für Technologie der Fertigungsverfahren; Aachen 16.06.2021; https://www.wvmetalle.de/index.php?eID=dumpFile&t=f&f=323697&token=dec537d866eb1656c2b97462d7cea8ff21a212b5 last accessed 12.03.2024 .

[17] [Welter 2014] Welter, J.-M.: Leaded copper alloys for automotive applications: a scrutiny; report mandated by European Copper Institute Brussels Nov. 20; https://elv.exemptions.oeko.info/fileadmin/user_upload/Consultation_2014_1/Ex_3/E3__02__Welter_2014_leaded_copper_alloys_for_automotive_applications-a_scrutiny.pdf;

In Jan 2024, a research paper was published on increasing the conductivity of Copper[18] by adding small amounts of graphene. As this is in laboratory stage, a future use in Lead-free Copper alloys to increase their conductivity cannot be assessed today.

Long-term reliability of electrical contacts under mechanical dynamic load in a wide temperature range is important. This was outlined yet in the Welter report 2014. ´… *Long-term reliability of contacts surface connecting area but also the contact resistance should not increase significantly during service-life. It is well known that the electrical current flows through surface contact spots. The better these can be deformed, the higher the true contact surface is. Softer material like CuZn39Pb3 is therefore advantageous. Furthermore, the Lead segregated on the surface fills partially the inter-spot regions. Tests with terminals made with CuZn39Pb3 and CuZn42 at 125 °C have shown that even after 5000 hours the Leaded alloy relaxes less than the maximal allowed design value (figure 13). For the design of connecting elements, especially for spring-loaded terminals, high mechanical relaxation is a drawback. It reflects the reduction of internal stress when the material is deformed elastically through an imposed strain. The elastic stresses are needed to insure that the female element, acting as a spring, closes well the connector*.´ [Welter 2014]

4.5 Robustness Increase

Leaded Copper alloys have a set of unique specific physical properties. So Leaded Cu alloys, having somewhat lower strength than the non-Leaded Cu-Tin alloys, and much lower strength than Cu -Al or Cu-Zinc alloys, exhibit high degrees of conformability. That is, e.g. why bearings are getting more robust, as they may adjust its shape to allow for poor alignment or for vibration[19].

4.6 Circularity and Environmental Aspects

Green Deal [20]

The green deal strategy of the European Commission calls for the reduction of CO2 resp. greenhouse gas emissions and enhancing the circularity of the automotive sector. Use of Copper alloys resp. brass materials based on secondary raw materials contribute to this goal. The machining of Lead-containing Copper alloys allows lower cutting forces and therefore less production expenditures.

Recycling

There is a functioning recycling system with around a 90 % efficiency. Welter[2014] reports in page 5 that ´ *Leaded brass rods for free machining and hot forging are fabricated almost exclusively with recycled brass (either old scrap coming from end of life systems or new scrap occurring during the manufacturing of components), low quality Copper and zinc scrap. The intensive use of scrap has both financial and sustainable advantages within a circular economy. However, nobody can guarantee that all the scrap batches have similar qualities*.´

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[18] Gwalani, B., Li X., Nittala A., Choi W. et al : Unprecedented electrical performance of friction-extruded copper-graphene composites; Materials & Design, Volume 237, 2024, 112555, https://doi.org/10.1016/j.matdes.2023.112555.
last accessed 14.03.2024.

[19] Nielsen, W.D. Jr.: Metallurgy of Copper-Base Alloys; Western Reserve Manufacturing Co., Inc.
https://copper.org/resources/properties/703_5/ ; last accessed 11.02.2024.

[20] https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal_en last accessed 21.03.2024.

The direct use of scrap reduces the amount of energy needed for the production of alloys compared to production via primary material.

If Lead-containing scrap could not be processed directly, than an energy intensive metallurgical procedure needs to be applied to separate Lead and Zinc in order to obtain pure Copper. This causes energy demand and related emissions.

All Copper materials in a vehicle have an excellent recyclability. End-of-life vehicles within the EU have defined end-points (authorized treatment facilities). After pre-treatment, the remaining scrap vehicles go to shredders for material recovery. New developed shredder scrap separation technologies[21] like TSR40 (REDERS Project) are able to reduce Copper content in steel (e.g. < 0,1%) and Aluminium scrap and extracting even small Copper particles for subsequent separate Copper recycling. In addition, the efficiency to recover small Copper particles increases and dissipation losses decrease. Such technologies however could not extract Bismuth or Silicon containing alloys. Bismuth especially is challenging the recycling of brass and production of pure Copper.

5. Demands to automotive parts made from Lead containing Copper alloys

In the industry contribution from ACEA et al (Answers to Stakeholder Consultation Questionnaire of Bio Innovation Service, UNITAR and Fraunhofer IZM dates 15.9.2020) to the 11. Adaptation to scientific and technical progress of exemption 3 of Annex II to Directive 2000/53/EC (ELV) the different requirements were outlined in detail.

We consider this information and the expertise from Welter [Welter 2014] still as valid, refrain from mirroring or duplication all these justifications in this contribution, and limit this to a summary.

The fundamentals characterized in the Welter report [Welter 2014] are still unchallenged. The findings of Welter are reflected in the 2017 publication [22] of Haberling and Schwimmer on materials for automotive applications – Limits and Consequences of material restrictions. They give details on the comprehensive requirements and their complexity to Copper materials use in the automotive sector.

Along with fatigue resistance, strength, and ability to take a good finish, the main selection criteria for Copper and Copper alloys are:

- Material costs
- Ease of fabrication
- Electrical conductivity
- Thermal (heat) conductivity
- Corrosion resistance
- Sliding behaviour, low wearing
- Service life
- Weight
- (non)--magnetic properties

[21] e.g. TSR products TSR 40 (Fe), TSR130 (Al), TSR136 (Al); https://www.tsr.eu/metallrecycling-und-recyclingrohstoffe/; last accessed 12.3.2024

[22] Haberling, C. Schwimmer D. Werkstoffe für die Automobilanwendung –Grenzen und Folgen der Stoffverbote; Metall Jg. 71 11/2017 Page 425 -427

The Pb-containing Cu-alloys have a proper balance between crack toughness, machinability, malleability, relaxation and strength (Young´s modulus). There is a broad long-term field experience with their use in automotive applications.

The complexity of automotive requirements to the Copper materials and components produced thereof is outlined in figure 5.1. This graphics visualizes the manifold of demands, which need to be addressed and considered in the development of components including scrutinizing the interaction with neighboured parts on system level.

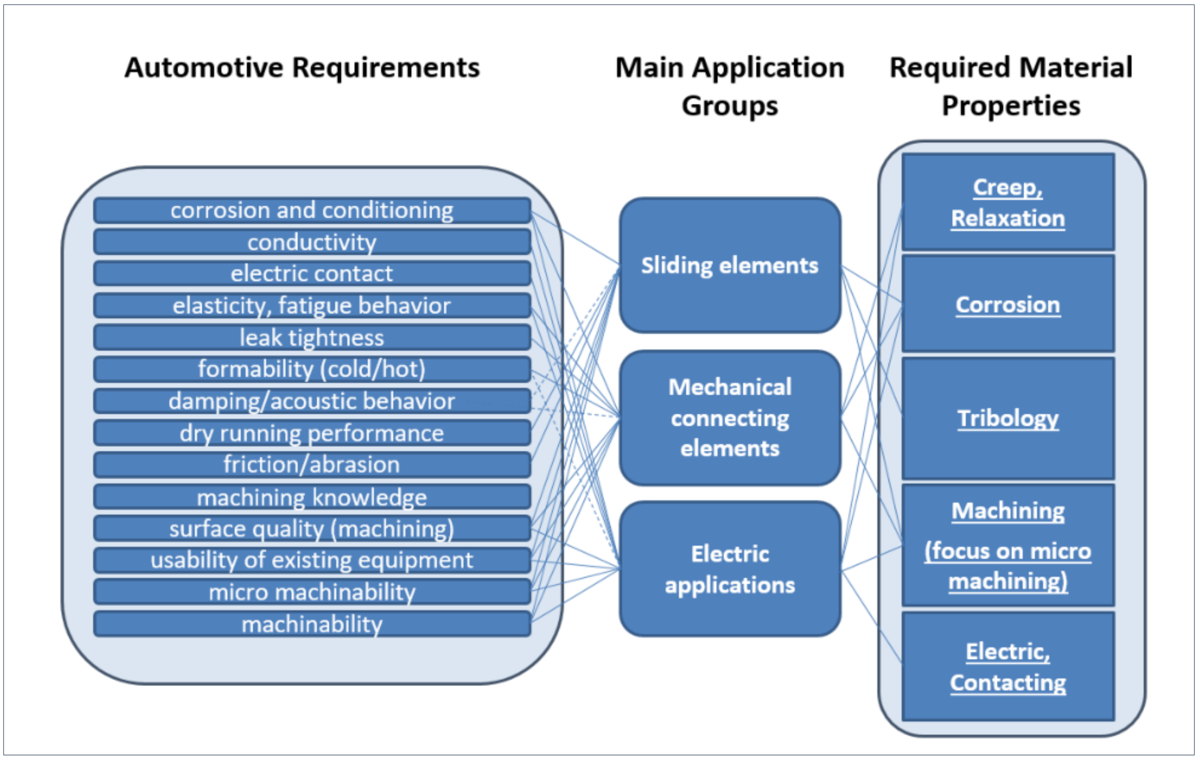

Figure 5.1 *Correlation between main application groups of Lead Copper brasses and automotive material requirements (source ACEA et al contribution Pb in Cu Figure 6 cited in OEKO 2021 report as Figure 5.1)*

The requirements for automotive applications are in general more challenging than applications for conventional plumbing or fitting applications, as more parameters have to be considered.

6. Substitution challenges

As the demands to components made of Lead-containing Copper alloys are multi-dimensional, a generic substitution would fail. Instead, a step-by-step, resp. part per part, approach is essential. Due to different material properties, it may be necessary to change the part geometry. Therefore, also, the system partners may need to be modified and the interferences between different components need to be tested. This causes high efforts.

In early stage of construction and design of new parts and systems, it is assessed if economic and also more environmental compatible materials can replace the expensive material, where possible and feasible.

As an outcome of this approach, the quantity of Lead in Copper alloys per vehicle decreased, but there are still many small applications, where the use of Lead-containing Copper alloys is still required due to technical reasons.

A new vehicle, in general, consists to a higher degree of well-known and intensively tested standard components (construction kits) and larger aggregates. These are applied in different vehicles and e.g. like plugs and connectors applied all over the automotive industry and beyond. Changing such industry standard components is more demanding than individual component design and a very complex and long-term task.

Introduction of new components or new materials are linked with missing related experience of vehicle service life. Therefore, OEM´s often start carefully with pilot applications in smaller volume models to validate the collected experiences from component testing and many km of tests on the road with prototype cars. Pilot applications may be screened over a complete vehicle cycle and if they performed well, they are an opener for large volume scale production. As this may be competitive sensitive information, it is very difficult to disclose such pilot applications within a stakeholder consultation.

In the last stakeholder consultation, some substitute applications were addressed to be in use since recently. There are no failures reported up to now, but they should not have passed a complete life cycle yet. Therefore, no final assessment or conclusions can be met.

We include following supplier opinion:

´ The more than 20 years of research done on Lead-free Copper alloys showed that up to now there is still a lack of drop-in replacement for Leaded Copper alloys, mainly CuZn39Pb3, with the same properties. So, a combination of adjustment of the production technology and perhaps of the products, as well as the development of materials with their critical properties at least similar to those of CuZn39Pb3 will be necessary.

Literature and patent studies as well as lab tests of new alloys are very useful instruments for the first steps in substitution. But the substitution of Leaded Copper alloys in relevant amounts, so in series production, is only possible when the alternative alloy and its supply chain is mature enough. Accordingly, besides the requirement that several batches of the alloy and the parts made from it show the required properties a number of further requirements have to be fulfilled as for example:

> *The availability of the alloy must be ensured. This includes that at least two reliable suppliers must exist, and the world market has to be able to provide the required amounts of material (e.g. not given for tellurium in 7.1.2.3). Also, as far as possible local sourcing has to be possible for robust supply and minimization of transport related emissions*
>
> *It has to be ensured that the material is available in relatively constant quality, so that production of safe and functioning products can be ensured. The about 3% lead in CuZn39Pb3 somehow smoothen the further properties meaning that small deviations in the other properties of a specific batch which can be caused by small changes in the composition, or the manufacturing are outweighed by the effects Lead gives to the alloy. It is an additional challenge in the substitution that this does usually not apply to the Lead free alloys (see chapter 4.5 in the 2015 renewal application for RoHS exemption 6 [23]).*

23 rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/Exemption_6_c_/Phoenix/6c_RoHS_Exemption_6c_Renewal_Dossier_16_JAN_2015.pdf

The products have to pass all tests etc., as was already described in the past and is referred in this document.

Accordingly, two strategies exist that are usually applied in combination: To try to use established Lead-free materials for new products and simultaneously to test upcoming new materials. The two existing families of alloys that are established at least in other industries (e.g. plumbing) are Copper-Zinc alloys with a higher Zinc content and no additional chip breaker, as well as Copper-Zinc-Silicon alloys. Both have been discussed in detail in the past contributions and are also addressed below. For these types of alloys the supply chain is usually developed, especially for industries that require higher amounts of brass as for example plumbing and construction. If substitution of Leaded Copper alloys is or will be possible in the nearer future for automotive parts, it is likely that it will happen via alloys of these two families. It is also very important to test and evaluate upcoming new alloys, but it is not likely that they can replace Leaded Copper alloys in the near future. ´

7. Industry activities and progress

As this stakeholder consultation for entry 3 comes early in 2024, information expected to be available in 2025 is missing and may not be used here, due to competition resp. antitrust guidelines to be met. We regret this situation.

The step-by-step procedure for minimizing the essential use of Lead in Copper materials is ongoing. The efforts concentrate for efficiency reasons mainly to new developments.

Developing, testing and validation of a new vehicle model takes around seven years, considered that yet existing parts can be applied and not every part needs to be new designed. The current progress status is detailed in chapter 7.2.

Furthermore, economic aspects of high Copper prices and machining costs and technological changes, as well, trigger efforts for substitutions. E.g., DVD or CD players, which contained a significant amount of tiny CuZnPb alloy based parts, disappeared in new registered vehicles, or a substitution with steel or other suitable materials was realized.

7.1 Industry activities

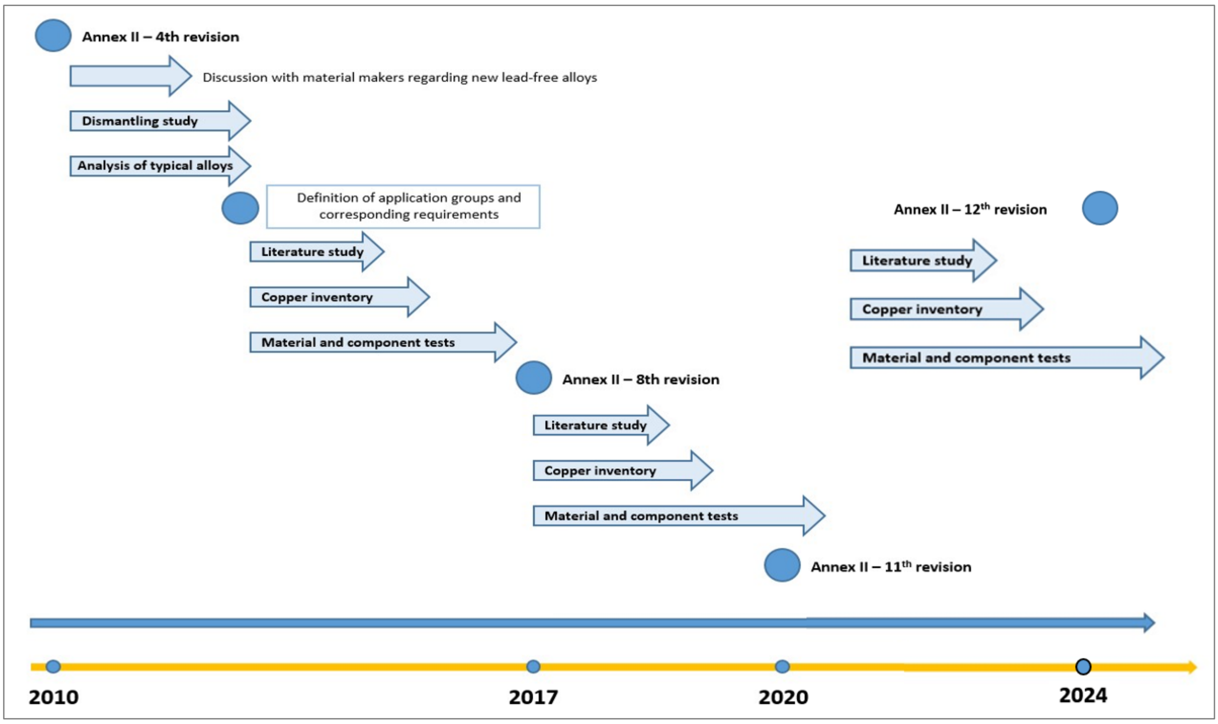

Figure 7.1: *Activity model 2010 to 2024*

The industry approach, yet described in previous consultations, in principle continues (see fig.7.1.).

7.1.1. Materials processability assessment (machining, milling)

In Germany a research project supported by more than 20 industry partners on improved milling parameters for new Lead-free Copper alloys was finished in June 2021.

The research was conducted at Aachen University, with having a long-term experience in production technologies and machining of materials. The project was supported with public research funding.

In the project, further Lead-free Copper alloys were assessed in continuation of a prior project (IGF 16867 N), which outcome was similarly described in previous contributions.

Assessing the machinability index (see figure 7.1), none of the tested up to now twenty different materials could demonstrate a better machining resp. milling performance than the reference alloy CuZn39Pb3.This alloy is still the benchmark with distance for machinability and for low cutting forces.

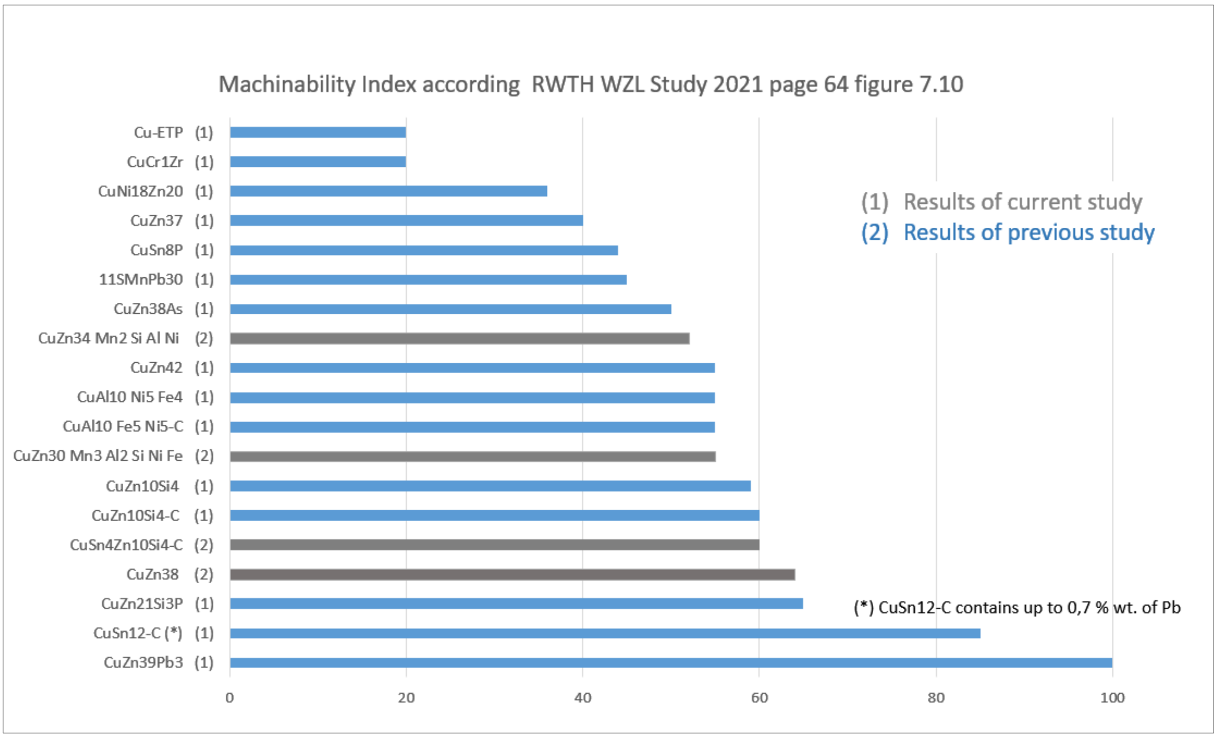

Figure 7.1: Results of machinability assessment of different Copper materials according RWTH WZL new assessed materials are coloured in grey and results from previous study are coloured in blue.

The findings of this report are considered resp. disseminated in an updated industry guideline from 2023 on machining of Copper and Copper alloys[24]. This will support well manufacturability tests for future component production and ease efforts to apply the most suitable parameters for each of listed alloys. The guideline is provided by the Copper industry as part of their engagement for Copper materials and gives evidence for efforts to support the application of new materials.

In addition the efforts for substitutions in the supply chain continue. This becomes evident by the constant amount of Lead for articles in scope of entry 3, despite of an increasing total Copper use and more installed electrical and electronic systems per new registered vehicle (see chapter 7.1.2.4).

7.1.2 Patent and Literature screening - Search for new Lead-free Copper materials

In material specific databases like total materia and patent databases like Espacenet and google patents, a search for new Copper materials was conducted. In addition, technical periodicals for metal materials were screened. There was a very limited number of hits on new Lead-free Copper materials.

The selection focused to patent activities from 2016 onwards. Results of the database queries provided mainly new patents or patents claims from the market China.

As an outcome, it could be summarized that there are attempts to invent and patent new alloys with up to eight different alloying elements in one Copper matrix with broader range of variation of single element share.

[24] Richtwerte für die spanende Bearbeitung von Kupfer und Kupferlegierungen; Informationsdruck i 18: edited by Kupferverband e.V. Düsseldorf 2023; www.kupfer.de last accessed 10.03.2024 .

Even supplements of Indium, Tellurium, Titanium and Bismuth and compounds thereof with interfering elements are listed in the described alloys.

The majority of new patents seems to be aiming uses in plumbing, heating and industrial fittings, valves and boilers.

A patent does not mean that a new material is available and suitable for large-scale production of automotive parts.

Some basics for CuZn alloys (brass) assessment:

mainly there are 3 phases in the matrix of the material to be discussed.
- α-phase brass with a Zn share <37,5 %,
- ($\alpha + \beta$)-phase brass with a Zn share from 37,5 % to 46 % and
- β-phase brass with 46 to 50 % Zn share.

α-brass can be processed well by cold-forming, is more difficult in hot forging and disadvantageous for machining.
Alloys with pure β-phase brass have gained only limited technical importance.
Cu-Zn alloys are not common to be hardened, as the achievable effects are low.
Higher strength and hardness values may be achieved by forming.

Most important alloys are CuZn30, CuZn37(α-brass), CuZn40, CuZn39Pb3 and CuZn40Pb2 (($\alpha + \beta$)-brass). The last two ones are the most important Cu machining alloys.

β-phase containing brass has a potential tendency for dezincification under certain corrosion conditions. Further alloying can minimize this; (e.g. alloy CuZn36Pb2As)

As machinability enhancer, Lead, Tellurium, Sulphur and recently Indium are applied.

7.1.2.1 Results of patent search

Patents found:

1) CN105274387 (2016) A Lead-free high-strength and corrosion-resistance silicon brass alloy easy to be cut and preparation method and application
(56 to 60 wt.% Cu, 1 to 1,5 wt.% Si, 0,5 to 0,9 wt.% Al, 38 to 42 wt.% Zn and small amounts of B and Ti.

remark: Si based alloys had been assessed in last contribution.

2) EP2913415A1 (CN) 2016 Bleifreies, Wismutfreies, Silikonfreies Messing
Cu Mg with Zn, Sb, Mn, Al , Sn added; originally CN patent; 8 different constituents;

remark: In patent claim the brass alloy is suitable for replacing the existing Lead-containing brass alloy and for producing parts like faucet and sanitary ware.

3) EP3360982A1 (CN) Aluminumoxid-dispersionsverstärktes (ODS) nicht bleifreies Schneidmessing und Herstellungsverfahren dafür (powder metallurgy and sintering)

remark: special alloys for cutting to be applied to the production of valve faucets

4) US9434005B2 (JP) (2016) Pb-free Copper alloy sliding material, and plain bearing
1 to 15 % Sn, 0,5, to 15 % of Bi and 0,05 to 5 % of Ag

remark 1: More particularly, the present invention relates to a Cu—Sn—Bi based sliding material and a plain bearing.

remark 2: challenges of Bi discussed in previous contributions

5) CN202010303203 (2020) A Copper alloy for electronic component and preparation method thereof

remark: Special alloy designed for leadframe application consisting of 6 main alloy elements;
high tensile strength material;

6) CN113430416A (2021/2024) Lead-free free-cutting high-conductivity tellurium Copper alloy material

Te and Bi, P and Mg, Se, Nb, La added

remark: New, not assessed yet; use of critical raw materials

7) US2016130685A1 (2016) EP3042971 (A1) Lead-free, high-sulphur and easy-cutting copper-manganese alloy AND PREPARATION METHOD THEREOF
Lead-free, high-sulphur and easy-cutting copper-manganese alloy; 6 alloying constituents

remark: New, not assessed yet

The patents, new available alloys and their usefulness will be discussed as part of ongoing work.

7.1.2.2 Literature and material related publication assessment

Technical papers found

Ramesh Chandra Singh (Dep.of Mech.Engineering, Delhi Technological University,) et al (2019) investigated the fabrication and sliding wear behaviour of some Lead-free bearing materials [25]

Cu-Ni Al and Cu P Al material were developed and first tested to sliding/ tribological properties. No component tests known.

remark: Early stage, new, not assessed yet;

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[25] Ramesh Chandra Singh et al 2019 Mater. Res. Express 6 066533
https://iopscience.iop.org/article/10.1088/2053-1591/ab0be4 last accessed 23.03.2024.

Results from Conference Proceedings

Kupfersymposium 2021 [26]

Tammen, N. Karabulut, F. Bolz, S. Weiß, S. Bleifreie Werkstoffe auf Basis der Legierungssysteme Cu-Sn und Cu-Sn-Zn zur Substitution von Rotguss und Zinn-Bronzen

The authors present investigations for replacing a Cu alloy with 7% Pb content with new Pb-free Cu casting alloy named EASECAST EC 7(CuSn7Zn3NiPS) whereas function of Pb was replaced by Sulphur. This alloy is designed as substitute for the Lead-containing alloys Rg7 (CC493K) Gbz12 (CC483K) Intended use is for larger casted parts.

copper-alloys 2022 conference

Haake M. and Hansen A. presented in 2022[27] a new alloy with sulphur added as chip breaker and to improve corrosion resistance. The focus of the new alloy CuSn4Zn2PS was on the ease of manufacturing fittings, suitable for the heating and plumbing industry and on achieving an excellent corrosion resistance.

Müller, M. S.; Tomovic Petrovic, S.and Sørby, K. investigated the potential to improve the machinability of the Lead free brass alloy CW511L. Investigated scope of this alloy was a drinking water application. The authors state that regarding the main cutting force, the heat treatment was not very beneficial. - Further assessment of heat treatment impact seems to be required.

Zachert C., Brans K., Schraknepper D. and Bergs T. published their findings for an assessment and comparison approach for the Machinability of Innovative Copper Alloys. The transparent and objective evaluation procedure allows the rating of the machinability of the investigated Copper alloys. They state that the method can also be used in the future to evaluate newly developed alloys in terms of machinability. They compare different Pb-free and Pb-containing alloys. As a reference, the index of 100 points was defined for the machinability of the Leaded Copper alloy CuZn39Pb3. None if the assessed materials achieved the same machinability of the reference material.- In the next step, further Copper alloys shall be ranked in relation to previous materials in terms of machinability.

Kupfer Symposium 2023[28]

Seuß, F.; Feldner, P.; Ricken, H.; Dehnelt, A.: eZeebrass - das neue bleifreie Standardmessing

The authors present a new developed Pb-free Cu alloy (CuZn41Mg) for machining. They provide first processing results from feasibility studies.

The available alloys and their usefulness will be discussed as part of ongoing work.

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[26] https://kupfer.de/wp-content/uploads/2021/11/Tagungsband-Kupfer-Symposium-2021.pdf; last accessed 26.03.2024

[27] Haake M., Hansen A.: CuSn4Zn2PS -Lead Free Gunmetal for drinking water applications;
Copper Alloys 2022 Conference Düsseldorf, 22. - 23. November 2022; Proceedings page 23; https://kupfer.de/wp-content/uploads/2022/11/Proceedings-Copper-Alloys-2022_.pdf last accessed 26.03.2024

[28] Proceedings of Kupfer Symposium 2023 Jena 29/30 November 2023 https://kupfer.de/wp-content/uploads/2023/12/Tagungsband-2023-klein.pdf last accessed 26.03.2024

7.1.2.3 Assessment of discussed substitutes / elements which shall replace Lead

Main driver for the substitution of Lead in Copper alloys are applications for drinking water, plumbing and sanitary industry. Disregarding potential interfering effects between different alloying elements, we conduct a generic assessment of the major elements proposed as Lead substitutes.

Bismuth

Bi as alloying element of Copper was yet assessed in 2008 by the consultants.

OEKO [2008] states:

„ *According to the Copper industry, among others bismuth has been considered as a potential substitute for lead in two-phase brass alloys. However, the use of bismuth significantly complicates the production of wrought alloys, i.e. rods, wires and profiles. This is due to the increased internal stress in the material caused by the expansion of bismuth during solidification. This is also the reason why these materials are far more susceptible to stress corrosion cracking. Furthermore, bismuth endangers the ability to produce so-called single-phase Copper wrought alloys. These are brass alloys with a Copper content of over 61% by weight. Bismuth contents down to 20 ppm already lead to premature material failure even during the production of wrought products.*

Alloys containing bismuth are also more difficult to recycle, because recycling is done unmixed and so far fully developed recycling does only exist for lead containing Copper alloys.

Explanations were also given as to why bismuth-containing alloys were not suitable alternatives. Embrittlement and lower strength and ductility at high temperatures were cited as some of the main issues. The other major disadvantage in bismuth-containing Copper alloys is the high internal stress responsible for frequent stress corrosion cracking. This is caused by the expansion of the bismuth during solidification and thus is fundamentally unavoidable.

Furthermore, machinability of bismuthed Coppers is also between 66% and 85% that of free- cutting, lead-containing brasses. In addition, the complete replacement of lead by bismuth would result in a tenfold increase in the demand of bismuth. For each tonne of bismuth, 30– 200 tonnes of lead would have to be produced.

Stakeholders further stated that alloys containing bismuth were also more difficult to recycle, because recycling must be done separately and so far fully developed recycling only exists for lead-containing Copper alloys.

The mixture of chemical composition in very different Copper based alloy scraps may end in difficult material recycling and the energy consumption for the recycling of these scrap mixtures will increase enormously. Current Copper based scraps derived from end-of-life-vehicles are a valuable resource for secondary Copper or brass applications. The discussed silicon or bismuth containing alloys are incompatible to be recycled into alloys, which are free of these elements. A mixture may end up in a loss of recyclability “

Bismuth contamination is as well unwanted in pure Copper production as its separation by pyrometallurgical or electrometallurgical methods is not possible. The tolerated Bi concentration limit is 5 ppm in pure Cu and 20 ppm in brass, as Bi effects unwanted brittleness.

The reported global primary production volume for Bismuth in 2021 was 11 000 tonnes (JRC RMIS [29]). Bismuth is classified as CRM in the EU.

Seen from ecotox perspective, there is insufficient data available on Bismuth.

(ECHA[30] Bi Hazard assessment conclusion: DNEL (Derived No Effect Level) Value: 13.3 mg/kg bw/da
GHS: data conclusive but not sufficient for classification/data lacking
Web search results: bismuth encephalopathy[31], genotoxicity[32])

Silicon

As well, Silicon as alloying element of Copper was yet assessed in 2008 and 2010 by the consultants.

OEKO [2008] states:

´Some progress has been made in the alloy system Cu-Zn-Si and Cu-Zn-Mn-Si—X. Here first products are in the process of sampling and approval. Silicon brasses have a high strength and moderately high corrosion resistance (e.g. "Ecobrass"). Chip forms are, however, less favourable than those of leaded Copper alloys.

Furthermore, the self-lubricating effect is missing resulting in a higher tool wear.

To overcome the existing difficulties in the production process of semi-finished products from silicon brass, further research and development work is necessary.

" The stakeholder Wieland-Werke AG provided a statement indicating that especially silicon brass (e.g. "Ecobrass") has got the potential to substitute leaded Copper alloys. However, they stress that there is still the need for the development of respective manufacturing technology to overcome the above mentioned existing disadvantages of this alloy type "

[OEKO 2010]

´Test data provided indicated that:

- *The electrical properties of two geometrically identical pieces of copper made from Ecobrass and standard leaded copper alloy were compared. It was observed that the electrical resistance (and therefore the voltage drop) was 2,7 times higher in Ecobrass than the standard leaded alloy.*
- *The machinability and surface finish of the alternative alloy "M37" 13 was also analysed, and proved to be far less satisfactory than standard leaded copper.*
- *Another study indicated that Ecobrass was 89% as machinable as the 1,6%–2,5% leaded copper, though only 80% as machinable as the 2,5%–3,5% leaded copper. The main disadvantages of Ecobrass compared to standard leaded copper appeared to be its smaller heat conduction capability and electrical properties, gas-shielded arc weldability and hard solderability.*
  These drawbacks were even more contrasted with the 2,5%–3,5% leaded alloy.

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[29] https://rmis.jrc.ec.europa.eu; last accessed 28.03.2024.

[30] ECHA https://echa.europa.eu/registration-dossier/-/registered-dossier/14679/2/1 last accessed 11.03.2024 .

[31] https://bmcneurol.biomedcentral.com/articles/10.1186/s12883-019-1437-9

[32] Recklinghausen, Ursula & Hartmann, Louise & Rabieh, Sasan & Hippler, Jörg & Hirner, Alfred & Rettenmeier, Albert & Dopp, Elke. (2008). Methylated bismuth, but not bismuth citrate or bismuth glutathione induces cyto- and genotoxic effects in human cells in vitro.

The lubricating effect of lead in copper alloys is also stressed by tribological tests. In contact with steel CuZn39Pb3 mostly shows a considerable lower friction coefficient than lead free alloys or Ecobrass.

- *Negative effect on formability and sealing (e.g. fittings in the fuel feed systems) showed a significant difference between the silicon-alloyed and the lead-alloyed brass.*

  Equally, assembled fittings with an approximate torque 25 Nm were tested under pressure and temperature. The residual torque after testing was about 1,3–1,6 times higher for a conventional alloy than for the Ecobrass fittings. Values under 10 Nm (e.g. Ecobrass) can not be accepted for this test

- *In a hot forging trial with lead free material (Ecobrass) on production process with varying electric current condition for electrical resistance heating it was not possible to reach proper forging results. This was allocated to the increased deformation resistance and to the higher hardness of silicon-alloyed compared to lead-alloyed brass. These tests revealed that the addition of silicon to copper, contrary to the addition of lead, affects the alloy's electrical properties significantly. Stakeholders thus conclude that Eco-brass can therefore not be used where electrical properties are of importance. Furthermore, the machinability of Ecobrass is worse than that of leaded copper alloys.* `

So Silicon reduces electrical conductivity and sliding properties.

In ecotox aspects, there are no concerns.

Tellurium

Tellurium is made as a by-product of Copper and nickel metallurgy. The global production volume was estimated with around 660 tonnes for the year 2021 (JRC RMIS].

According ECHA[33] the classification provided by companies to ECHA in REACH registrations identifies that this substance may damage fertility or the unborn child, is harmful if inhaled, may cause long lasting harmful effects to aquatic life and may cause an allergic skin reaction. (Classifications Danger; GHS07, GHS08 H360D, H317, H332, H413).

Due to properties of concern Tellurium and Tellurium scarcity, Tellurium is not favoured as substitute for Lead.

Indium

The new alloy NA 279 from Aurubis contains Indium as machining enhancer in a CuZn42 matrix.

Indium is a very expensive material and even that, obviously is does not achieve the same machining performance as Lead-containing alloys.

The Indium resources and refining capacities are dominated by China [34]. In the RMIS system, the global Indium production volume for the year 2021 was estimated with around 917 tonnes (JRC].

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[33] ECHA https://echa.europa.eu/substance-information/-/substanceinfo/100.033.452; last accessed 11.03.2024.

[34] https://rmis.jrc.ec.europa.eu/rmp/Indium; last accessed 25.03.2024.

- Indium is part of listed as EU Critical Raw Material (2020).

Ecotox assessment was not possible due to lacking data.

Sulphur

Alloying of Copper with sulphur reduces the conductivity significantly (see table 4.4.1). There are some new alloys with around 1 % S added mainly designed for plumbing applications

Sulphur, when present in Copper and Copper-based alloys, typically induces intergranular embrittlement, leading to a significant reduction in ductility[35]. The effect can be mitigated with additional allying elements like Yttrium, Cerium, Lanthanum, Calcium and others. They have additional impact on the electrical conductivity.

Ecotox assessment under ECHA CLP is skin irritation cat. 2.

Recycling aspects

EU Recycling Indicators according JRC RMIS System (https://rmis.jrc.ec.europa.eu/rmp/)

Element	EoL Recycling Input Rate	Recycling Input Rate	EU CRM
Lead	80 %	85%	no
Bismuth	0%	6%	Yes 2023
Indium	No data assumed 0%	No data	Yes 2020
Tellurium	1%	15%	no

Table 7.1.2.3: RMIS recycling indicator values for Pb, Bi, In and Te

Table 7.1.2.3 provides data on recycling values for Pb, Bi, In and Te. Pb has the highest recyclability performance of all elements in scope here. Pb will enter in existing recycling loops.

[35] Ahn, M.; Park, J.; Yu, G.; Kim, S.; Cho, D.-K.; Jin, H.-H.; Shin, C. Copper Alloy Design for Preventing Sulfur-Induced Embrittlement in Copper. Materials 2024, 17, 350. https://doi.org/10.3390/ma17020350

7.2 Activities of material producers

Several material producers have supported the machinability tests, outlined in 7.1.1.

7.2.1 Discussed Material in last OEKO report / ACEA contribution

Several alloys were yet addressed in the last contribution from 2020.

CW511L Aqua Nordic® - Rod (CuZn38As modified)

This material has a yet received a qualification of the Swedish certification body Kiwa. As intended use the certification states that, the alloy is for the manufacturing of components for fixtures, appliances, fittings and pumps in contact with drinking water.
In the RWTH study, CuZn38As was assessed. The state a machinability index of 50, whereas CuZn39Pb3 as reference has a machinability index of 100.

There are not yet test results for automotive application known.

CW510L Aqua Nordic® (CuZn42)

This material is specified according the data sheet of the producer as ´ *a free cutting and forging brass in the form of rod. The alloy is lead free and is approved according to the 4MS list, use for drinking water applications, product groups B-D. ´*

There is no information on added chip breakers to enhance the machinability.

In the RWTH study CuZn42 was assessed. The state a machinability index of 55, whereas CuZn39Pb3 as reference has a machinability index of 100.

Otto Fuchs alloy (2020)

Referring to the Otto Fuchs publication, ACEA et al noted, that the alloys described in the study aim to substitute Leaded-alloys with a relatively low Lead-content, at our understanding, not exceeding 0.8 % by weight.

Update (2024):

The Otto Fuchs Pb-content OF-alloys list contains around 100 entries. We assume the alloys OF 2299 (CuZn30Al2Mn2Ni1FeSiSn), OF 2297 (CuZn35Mn2Ni2FeSi) and the alloy OF 2290 CuZn28Al4Ni3Si1Mn) addressed in the current consultant questionnaire.

We noticed the corresponding paper [36] of Otto Fuchs available in the web, which was presented at the 12th International Fluid Power Conference, Dresden 2020. The assessed parts are bushings and slippers (OF 2299) in axial piston pumps and distributor plates.

Otto Fuchs is a supplier of the automotive industry and member of the VDA. The efforts of Otto Fuchs give evidence for the committed engagement of the automotive industry to find Lead-free solutions in a step-by-step approach.

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[36] https://tud.qucosa.de/api/qucosa%3A71055/attachment/ATT-0/ last accessed 20.03.2024;

Otto Fuchs conducted research as material producer and as component manufacturer and developed a promising Lead-free solution for applications in oil-hydraulics systems. We have no information if the release for volume production for this material and in this application was yet given.

The alloy CuZn34Mn2SiAlNi was in scope of RWTH 2021 machinability assessment. The machinability index was determined with around 52. The alloy CuZn28Al4Ni3Si1Mn and the alloy CuZn35Mn2Ni2FeSi were not part of the RWTH study 2021.

Aviva alloy model 3 (Cu Zn14,5 Te)

The Aviva Model 3 TM free machining alloy was mentioned also in the last contribution of ACEA et al.

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.

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 in the meantime.

The assessment of Tellurium as alloying element was given in chapter 7.1.2.3 with Tellurium being a quite limited resource and being associated with health risks.

7.3.3 Other new Pb-free Cu alloys

The development of new Lead-free Cu alloys is ongoing and material producers e.g. like Wieland (eco GS1 CuSn4Zn2PS-C-GC), Mitsubishi Materials (Glo Brass, Si based) and Diehl (ezee brass CuZn41Mg) have presented new developments. The engagement of the material producers is much acknowledged.

Main drivers are company related targets for reduction of Lead and the offering a product portfolio for Lead-free or Lead-reduced alloys in plumbing and infrastructure applications as main market. The requirements are different from automotive applications.

One approach we notice is a trend to complex micro alloying. This sets very high demands to alloy production to ensure a consistent composition and microstructure.

The challenge to achieve substitutions in a step-by-step approach remains, as there are part specific demands like hot /cold formability, precise machinability, conductivity over service life etc. to consider, in principle for each component.

Once and if new Lead-free alternatives, able to effectively substitute Leaded-Copper alloys for all their current automotive 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**.**

Acknowledgments.

The report benefits from the scientific technical support of the German Copper institute and the Copper Alliance and their engagement in Copper materials research and result dissemination.

In previous contributions, the submissions were based on the expertise from Dr. Jean-Marie Welter as outstanding and experienced expert for copper materials. Dr. Welter passed away in July 2022. In memory to him, this report intentionally several times refers to his reports for doing honour to his merits in material science and to an outstanding person we miss.

Thanks also go the material producers to tirelessly efforts in material research for substitutes and the colleagues from the automotive industry and in the supply chain for their great support.

PART B Answers to Questionnaire

Information from Consultant Consortium

1. Background

Bio Innovation Service, UNITAR and Fraunhofer IZM have been appointed[37] by the European Commission for the evaluation of applications for new exemptions and the renewal/continuation of exemptions currently listed in Annex II of the ELV Directive 2000/53/EC. [38]

This questionnaire has been prepared for the stakeholder consultation held as part of the evaluation. The objective of this consultation is to collect information and evidence for subsequent review to assess whether the exemption is still justified according to the criteria listed in Art. (4)(2)(b)(ii) of Directive 2000/53/EC (ELV Directive)[39].

Additional background information can be found on the exemption review page accessible through the following link: www.elv.biois.eu

We welcome your contribution to this stakeholder consultation. We recommend reading the below section before you answer the questions.

2. Main Observations in the Previous Review

The above exemption was reviewed by Deubzer et al. (2021) last time under the ELV Directive, and the consultants concluded that the use of lead was avoidable for certain applications but that overall, the scope of the exemption could not be narrowed to reflect this substitution successes in the exemption wording.

The available information at that time suggested that the current maximum lead content of 4 % should be maintained. As to the substitution of lead, valves in variable capacity air conditioners operating with steel shafts, and two insert nuts could be demonstrated to be cases where a lead-free copper alloy (EcoBrass) successfully replaced a standard copper alloy with 3 % of lead content. For technical reasons, these substitution successes could not be reflected in the exemption scope.

Around 20 lead-free alloys were reported by applicants in 2020 to be available, including new ones just having entered the market which should have offered potential for further substitutions if application-specific and systematic tests are applied. Next to the above EcoBrass and others, the below lead-free copper alloys were explicitly classified as new and for further assessment:

- AquaNordic lead-free copper alloy that might be a substitute of leaded brass from machinability point of view.
- Novel lead-free copper alloys for oil-hydraulic applications as bushings, slippers or distributor plates, by the company Otto-Fuchs[40] aimed to substitute leaded-alloys with a lead-content not exceeding 0.8 % by weight.

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[37] It is implemented through the specific contract 070201/2020/832829/ENV.B.3 under the Framework contract ENV.B.3/FRA/2019/0017

[38] ELV Directive, http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0053

[39] C.f. EUR-Lex, http://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32000L0053

[40] Reetz B., Münch T., Challenges for novel lead-free alloys in hydraulics, 12th Internat. Fluid Power Conference, Dresden, 2020.

- The Aviva Model 3 alloy offering very good machinability, high conductivity and excellent dezincification-resistance properties.
- CuSi4Zn9MnP (wrought alloy) and CuSn4Zn2PS-C (casting alloy)

In the light of the above developments, Deubzer et al. (2021) deemed appropriate a validity period which is long enough for application-centred and specific assessments of substitution possibilities or, in case, the impossibility of substitution in certain applications, so that applicants will be able to provide substantiated, sound and transparent evidence where the use of lead may still be unavoidable.

Questions of the consultants - Answers in blue colour

Question 1.

As to the above-mentioned alloys:
Where they tested as to where/in which applications they can substitute leaded copper alloys? If so, please let us know how they were tested generally and application-specific. Please also provide the results concerning their potential to substitute leaded copper alloys in general or in specific uses taking into account the specific properties of the respective lead-free alloys and the requirements of specific applications which they can match.

Please see chapter 7.3.1 (discussed Materials in last OEKO report / ACEA contribution). We refer to alloys, which may have different brand names.

We cannot provide test results for these addressed materials.

The alloy with 4% Silicon has not an elevated level of properties suitable for automotive applications, as this alloy was not necessarily developed for automotive Lead-free applications, at our opinion. In the last contribution of ACEA et al from 2020 there was yet a pre-assessment given.

The alloys of AquaNordic are according to chapter 7.3.1 modifications of existing CuZn alloys that have been discussed in the past. These are reliable alloys and it is known that they can be used to replace Leaded Copper alloys in very specific cases for applications with simple geometries (see Oeko report on RoHS Pack 22, page 108). So far we are not aware of a part with electrical function and such simple geometry. The example refers to a household connector where the part made of Lead-free brass is mostly a cylinder without additional complications. Unfortunately the time given to prepare the answer to this questionnaire was too short to fully evaluate if similar parts are used in the automotive industry and if or when substitution will already be possible.

The alloy Aviva Model 3 was also discussed in the working groups in the automotive and electrical industry. It is less promising due to the low availability of tellurium and its toxicity.

The alloys CuSi4Zn9MnP and CuSn4Zn2PS-C have a much higher Cu content then CuZn39Pb3. As the price of Cu is more than three times the one of Zinc both alloys are economically less favourable than CuZn39Pb3 and also than CuZn42 and similar alloys. A significant difference in technical properties is assumed.

Question 2.

Do you know of other promising lead-free copper alloys besides the ones mentioned above?

Please see Part A, chapter 7.3.3 other new Pb-free Cu alloys

In addition we received following two statements:

OEM x: A significant reduction in the proportion of Lead in the vehicle resulting from Lead-containing Copper alloys would be achieved primarily by replacing Lead-containing cutting brass (CuZnXXPbY). Here, there is still only the variant of Lead reduction (up to 0) at the expense of machinability – e.g. Aqua Nordic, CW511, CW510, or the replacement of Lead with another chip breaker such as Bismuth or Tellurium (e.g. Aviva Model 3). In that case, problems arise with the existing single-origin recycling cycles, which play a major role, especially in the case of cutting brass. The other option, CuZn21S3P, (Ecobrass ™) has been known for years. The machinability is slightly lower than that of free-cutting brass containing Lead. However, due to its higher strength and poorer electrical and thermal conductivity, the alloy is not a 1:1 substitute and would more or less be suitable depending on the application.

Supplier x: As explained in 7.1.4 further promising Lead-free alloys for a substitution in the nearer future cannot exist as first the supply had to be established. For the nearer future, it is rather more likely to see substitutions using the existing alloy families sometimes with small modifications. This may be especially the case for parts with less requirements, e.g. no electrical/electronic function, easier geometry, no safety relevance, or similar characteristics that make the substitution easier.

Question 3.

Are tests available that demonstrate which applications of leaded copper alloys they can replace in automotive applications?

As the requirements are component individual, a grouping in application schemes is inappropriate and might be inaccurate (see paper from Haberling et al referenced in chapter 5).

The achieved reductions in use of Lead since 2003 give evidence that replacement is done on part individual level in a step-by-step approach.

Due to the large number of applications, each with specific requirements, a large number of specific tests are required.

Question 4.

Are there any leaded copper alloys with significantly reduced lead contents that could replace other leaded alloys with high lead content?

This question is difficult to answer. We addressed this question, but assumedly, due to the time constraints, we have not yet received much answers.

In general we have the opinion that the potentials of "one size fits for all purposes" substitution approaches are consumed. Over the last years, significant reductions of the required Lead quantity for this exemption had been realized.

Based on the experiences and test results of the last years, we are sceptical to a further success of generic substitution approaches.

From current view such replacing would be possible only at the expense of machinability (cost-effectiveness, possible geometries, surface quality)

There are very new Lead-free alloys presented, as mentioned in chapter 7.3.3, but it is too early to draw any conclusions.

Question 5.

In the last review by Deubzer et al. (2021), ACEA et al. stated that 3D-printing of parts using or replacing lead-copper was not yet sufficiently mature. Have 3D-printed parts meanwhile become available that could be a reliable substitute for parts produced from leaded copper alloys?

A German study on additive processing of Copper materials with material jetting technology was published in 2023[41]. This additive manufacturing procedure for Copper materials still remains more in scope of basic research and is an early stage. They have not yet reached the maturity for economic volume scale production.

More progress was in additive processing of Copper materials with selective laser melting (SLM) technology [42] [43]. A density of 95% for produced parts made from pure Copper was achieved. However, this very interesting manufacturing method has not yet reached the maturity for economic volume scale production. For prototype or small volume components it becomes more and more interesting. A continuous production with pore-free microstructure represents a challenge[44]. The applicable choice of materials is limited. 3D printing of brass is not established (zinc evaporates in the process).

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[41] AIF Schlussberichts zu IGF-Vorhaben 21553N/1 TU München Lehrstuhl für Umformtechnik und Gießereiwesen 2023; https://www.wvmetalle.de/index.php?eID=dumpFile&t=f&f=444940&token=3d8de226495d02bb6d0021153a9cf58a31b2fe4a; last accessed 12.03.2024.

[42] Loic Constantin, Zhipeng Wu, Nan Li, Lisha Fan, Jean-François Silvain, Yong Feng Lu,: Laser 3D printing of complex copper structures, Additive Manufacturing, Volume 35, 2020, https://doi.org/10.1016/j.addma.2020.101268. last accessed 12.03.2024.

[43] Heine L.M et al Efficient processing of copper and its alloys with blue diode laser Copper Alloys 2022 Conference Düsseldorf, 22. - 23. November 2022; Proceedings page 24 to 27

[44] Tran, T.Q.; Chinnappan, A.; Lee, J.K.Y.; Loc, N.H.; Tran, L.T.; Wang, G.; Kumar, V.V.; Jayathilaka, W.A.D.M.; Ji, D.; Doddamani, M.; et al. 3D Printing of Highly Pure Copper. Metals 2019, 9, 756. https://doi.org/10.3390/met9070756

Therefore, we see that technology mainly applicable to parts that made of pure copper. 3D printing is still far from being able to replace machining (number of pieces and properties).

In October 2022, a German press publication[45] informed about start of SLM metal 3 D printing of Copper parts at company FKM additive manufacturing. As materials, they use metal powders of pure Copper or CuNi2SiCr. The focus is more on rapid prototyping and small series production.

As of today and according our opinion, this production method (3D printing) is not yet sufficient mature, to substitute the volume production of parts produced from Leaded Copper alloys.

Question 6.

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.

We have received one feedback. In the area of aggregates, components have been converted to Lead-free with a high level of testing.

In general, please see Part A, chapter 7 and figure 15 of last ACEA et al contribution.

Question 7.

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

The industry is continuously working on that topic (see Part A). However as general solutions for substitution are still missing or not finally found, providing a general reliable roadmap including all stakeholders is excluded.

The generic approach of the last years is continued. See and figure 15 of last ACEA et al contribution

We estimate that new developments will more concentrate on EV´s rather than ICE vehicles.

[45] VDI z 10/2022 S. 13 Nachhaltiges Wirtschaften – vom Land unterstützt.

Question 8.

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.

Please see Part A, current uses; (chapter 3.2)

For the reference year 2022 we estimate an annual volume of about 120 t/a Pb uses covered by exemption 3 for vehicles put on the EU market annually. With an average copper share of around 30 kg per vehicle this figure needs to be understood in relation of a used Copper volume of around 400 000 t Cu/a and EU and a global Copper demand of 32 million metric tonnes (see Part A Chapter 2.1). The Pb-containing Cu-alloys are entering the utilization path for Copper alloys together with recovered Copper alloys from other industry sectors. The Copper remains in the loop.

As machining is an expensive production technology, we estimate that in combination of future production methods and new materials the trend to substitution will continue.

A long-term estimation is not possible, as it depends on market development.

Question 9.

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

Yes, at our opinion this exemption is still required.

Please see also Part A of this submission and our previous submissions.

Question 10.

Is there any other information you would like to provide?

There is no further input.

Contact details

For contact details, please see the additional frame document.