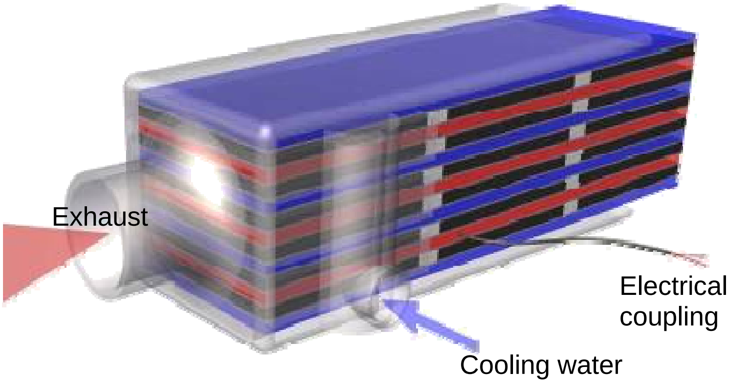
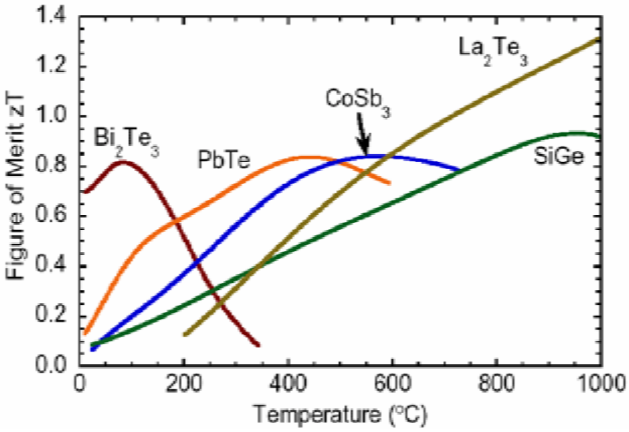
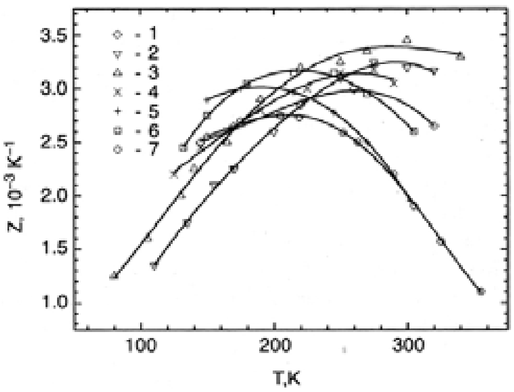
March 2009
ACEA JAMA KAMA CLEPA exemption request: Thermo-electric generator

No	Questions	Answers
1	Wording of the exemption	*Materials and components:* **Lead containing thermoelectric materials in automotive electrical applications to reduce CO_2 emissions by thermal recuperation of exhaust heat.** *Scope and expiry date of the exemption* **Vehicles type approved before 31. December 2018 and spare parts for these vehicles**
2	What is the application in which the substance/compound is used for and what is its specific technical function?	The thermoelectric material PbTe is used in an automotive thermal electric generator (TEG). With its overall energy efficiency the TEG converts the exhaust heat into electrical energy. As a result the load of the alternator in the ancillary belt drive of the engine can be reduced by the amount of thermal recuperated energy. This effect reduces the fuel consumption and thus CO2 emissions up to 1-3 % from vehicles depending on the driving profile and position in the exhaust system. The biggest yield is achieved in non-urban traffic profiles. This will be the first time that this technology will be used in the automotive sector In this manner as up till now these systems have only been used in aerospace applications only. The technology has a big potential for creating new jobs and competitive production technologies especially in Europe. It may contribute to a break through in heat recovery technology for broader use.
3	What is the specific (technical) function of the substance/compound in this application?	Due to the temperature difference between the hot exhaust stream and the cooling water (**Figure 1**) a thermal electrical potential is generated by thermoelectric modules. This thermo electrical potential is proportional to the temperature difference **ΔT** between the hot exhaust system and the cooling water side as well as to the material-dependent thermo power (Seebeck coefficient). The higher the Seebeck coefficient at a given temperature difference **ΔT** is, the greater is the recuperated performance and thus the CO_2 savings. It applies according to following equation: $S = \frac{U_{therm}}{\Delta T}$

		 ***Figure 1:*** *Thermo electrical generator with a slab-built exhaust gas heat exchanger structure.* The thermoelectric material must be able to resist the thermal boundary conditions in an exhaust stream and should not change physically or chemically over the entire lifetime of the vehicle to ensure reproducible electrical performance under given conditions. The exhaust gas temperatures in the entrance area of the thermo electric generator can be in the range between 250 °C and 600 °C. For automotive applications it is important to have materials which enable high efficiency of waste heat conversion per mass into power.
4	Please justify why this application falls under the scope of the ELV or the RoHS Directive (e.g. is it a finished product? is it a fixed installation? What category of the WEEE Directive does it belong to?).	Any automotive application falls under the EU ELV directive. As these lead containing thermoelectric materials are used in electrical applications of vehicles (e. g. thermo electrical generator) the ELV directive applies. In contrast to typical consumer electronics which are lead-free under ROHS regulation, the requirements for automotive electronics are significantly different and more demanding. The automotive applications are not covered by any category of the WEEE directive.
5	What is the amount (in absolute number and in percentage by weight) of the substance/compound in: i) the homogeneous material ii) the application and iii) total EU annually for relevant applications?	**i)** PbTe material containing 38 wt.% Pb. **ii)** Approximately 300 g PbTe material per vehicle. **iii)** Open issue.
6	Justification according to technical and scientific progress	The selection of a thermoelectric material for the utilisation of the exhaust heat in combustion engines is determined by following aspects with the dimensionless figure-of-merit $ZT = \frac{\sigma \cdot S^2}{\lambda} \cdot T$ and the electrical and thermal conductivity of the material σ, λ.

		i) The dimensionless figure-of-merit (ZT) of the thermoelectric material must have the best possible value in the temperature range of the exhaust gas between 200 °C and 650 °C at a certain distance from the manifold for using the thermoelectric system with a reasonable efficiency. **Figure 2** shows the thermoelectric figure-of-merit (ZT) of different materials. As shown the PbTe material has a reasonable figure-of-merit in the required temperature range.  ***Figure 2:*** *Temperature dependence of the thermoelectric figure-of-merit ZT.* **ii)** The thermoelectric material must meet the requirements for use in the automotive industry. This means that the material must have both a sufficiently high mechanical as well as temperature stability. **iii)** The thermoelectric material must be produced and available in sufficient quantities industrially.
7	Substitution of concerned hazardous substances via materials and components not containing these is technically or scientifically either practicable or impracticable	The use of BiTe instead of PbTe for the conversion of exhaust heat into electrical energy is only possible by an ineffective efficiency factor as shown in a previous study (1). Prototypes produced for technology potential investigation were made of BiTe. However this material works only at temperatures up to 250 °C. Depending on the doping level of BiTe the figure-of-merit ZT reaches a maximum between 200 °C and 250 °C only and falls with increasing temperature dramatically (Figure 3).

		 ***Figure 3:*** *Temperature dependence of Z for BiTe.* From 550 °C the material begins to liquefy. Commercially available modules achieve a maximum efficiency of 3-4% (1). PbTe is able to work up to 600 °C and generates more power. (1) Dr. Müller, Thermoelectric materials, DLR Cologne, 2009.
8	Elimination or substitution of concerned hazardous substances via design changes is technically or scientifically either practicable or impracticable	A design modification of components will not affect the basic thermoelectric effect of the material composition. The basic physical properties of this material can not be influenced by a change in the design or particular configuration.
9	Negative environmental, health and/or consumer safety impacts caused by substitution are either likely or unlikely to outweigh environmental, health and/or consumer safety benefits thereof (If existing, please refer to relevant studies on negative or positive impacts caused by substitution).	There were and are no substitutes available that are technically feasible in the temperature range of the exhaust heat from internal combustion engines. In addition the quantity of material available in industrial scale is limited. New lead free material developments in laboratory stage have to prove their suitability and need more than 10 years until they are available for major industrial application. As soon as these materials are ready for industrial use in automotive applications a changeover will be made.
10	Please provide sound data/evidence on why substitution / elimination is either practicable or impracticable (e.g. what research has been done, what was the outcome, is there a timeline for possible substitutes, why is the substance and its function in the application indispensable or not, is there available economic	BiTe has been used widespread in commercial compressor coolers. It has a limited scope in temperature range which excludes the use for application within exhaust system. So-called TAGS (Te-Ag-Ge-Sb) materials can only be used in stationary, high-temperature, environments (1). The material decomposes at room temperature and allows no cyclic thermal load. Any use in the automotive sector therefore is excluded. With respect to thermoelectric properties of PbTe the skutterudite, e. g. $CoSb_3$,

	data on the possible substitutes, where relevant, etc.).	show the closest behaviour (1). However, these materials are not commercially available yet and subject of material research programmes. Also other thermoelectric materials such as clathrates, magnesium silicides, Half-Heusler alloys, oxides or high temperature materials such as SiGe have been investigated. None of these materials show a comparable beh aviour such as PbTe in the relevant temperature range. In addition, either the materials are not yet commercially available or the materials have an inefficient efficiency factor in the required temperature range. Furthermore, the materials are not thermally stable or the manufacturing process is not yet available. Currently no time frame is known at which a certain material can replace PbTe. However according to experts a replacement or removal of Pb-containing materials based on activities in the field of material research will be realised in approximately 10 years. (1)
11	Please also indicate if feasible substitutes currently exist in an industrial and/or commercial scale for similar use.	Currently there is no application in the temperature range of the exhaust heat from internal combustion engines or other automotive applications.
12	Please indicate the possibilities and/or the status for the development of substitutes and indicate if these substitutes were available by 1 July 2003 (ELV) or by 1 July 2006 (RoHS) or at a later stage.	There were and are no substitutes available that are technically feasible and have comparable behaviour in the temperature range of the exhaust heat from internal combustion engines or other automotive applications. -> see entry 9
13	Please indicate if any current restrictions apply to such substitutes. If yes, please quote the exact title of the appropriate legislation/regulation.	Not known.
14	Please indicate benefits / advantages and disadvantages of such substitutes.	See above
15	Please state whether there are overlapping issues with other relevant legislation such as e.g. the Energy-using Products (EuP) - EuP Directive (2005/32/EC) that should be taken into account.	According to Art 1 (3) the EuP directive "shall not apply to means of transport for persons or goods". There is also no overlapping issues with the RoHS (see above) or the battery directive. However, there is a clear overlap with the REACH regulation and therefore, substance restrictions should be excluded from the EU ELV directive in general. PbTe was pre-registered under REACH.
16	If a transition period between the publication of an amended exemption is needed or seems appropriate, please state how long this period should be for	Exemption for vehicles type approved before 31 December 2018 and spare parts for these vehicles. The use of the thermal electrical material will be done in a closed

	the specific application concerned.	system with the obligation of dismantling and separate recycling like catalytic converters or vehicle batteries. The high price of this material ensures that the nearly total recycling will take place. Under normal and foreseen use conditions there will be no release of lead because this is a solid state technology. The environmental benefits outweigh by far the potential negative impact.