LIGHTINGEUROPE
THE VOICE OF THE LIGHTING INDUSTRY

Request to renew Exemption 4(e)

under the RoHS Directive 2011/65/EU

Mercury in metal halide lamps (MH)

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Contents

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2 Reason for application

LightingEurope submits this application to:	*request for extension of existing exemption **no. 4(e)in Annex III***
LightingEurope proposes to continue using the existing wording which is:	*Mercury in metal halide lamps (MH)*
LightingEurope requests a duration of	*Maximum validity period required*

3 Summary of the exemption request

Per DIRECTIVE 2011/65/EU Article 5(2) Annex III Exemption 4(e) will expire automatically per 21/07/2016, unless an application for renewal has been made to the Commission in accordance with Annex V.

With reference to the above, this request concerns the extension of the current Annex III exemption 4(e) regarding mercury in metal halide lamps (MH).

Since the lamps from exemption 4(e) have no LED replacement and the usable lifetime of the professional luminaires designed for Metal halide lamps is long (15-25 years). Customers expect to be able to continue to buy the efficient bright metal halide lamps. There will be no LED alternative that can replace the metal halide lamp in existing luminaires. The first reason is that because of the extreme compactness of these lamps the temperature is so high that no LED replacement can be made the in the outline of the existing lamp. The second reason is that the lamps are used in (parabolic) reflectors where the compact light source needs to be at the exact position in the focal point to get the right light beam. The last reason is that the existing drivers in luminaires that are suited for metal halide lamps have starters that generate pulses of 2500-5000V and even higher, these will damage the LED if not taken out: this will mean that the luminiare needs to be rewired by a professional to ensure a safe solution when a LED lamp solution would exist.

The metal halide family will slowly disappear, since part of the new luminaires will be designed with adequate measures to cool the LED’s with special designed optical systems.

Because of the very good light quality, the long lifetime and the high light fluxes and the high efficacy, metal halide lamps will be needed for a long time. The light colour, and the brightness is highly appreciated so also in the market for new luminaires, metal halide lamps will be looked for as a very efficient, high quality light source.

The general the LED lighting solution becomes more complicated for higher luminous fluxes and for more compact luminaires.

For this reason an exemption for mercury in metal halide lamps covered by the exemption 4(e) is required with a maximum validity period and with no expiry date.

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4 Technical description of the exemption request

4.1 Description of the lamps and their applications

4.1.1 Lamps covered by this exemption

This exemption covers High Intensity Discharge Lamps (HID) containing metal halides. The metal halide family is a diverse family with lamps designed for different purposes in the professional market. Since the lamps are very compact, the light can be focussed in a light beam. These lamps are handled by technically skilled installers and sold by specialized distributors or as part of lighting equipment. The installation of the lamps requires knowledge how to handle these lamps that require special driving gear including igniters that generating high voltage pulses. These lamps can produce UV radiation and the lamps will become very hot during operation.

Figure 1: Metal Halide lamps

The customers are for example institutions, governmental projects, municipalities, retail chains, sports facilities, designers of lighting equipment etc.

Lamp type (Application)	Metal halide salt fill	power range [W]	η (lm/W)	Ra	T_c (K) [K]	lamp life [kHr]
Shop lighting Ceramic Discharge tube	Na–Tl–(Ca,Ce)–Dy–Ho–Tm iodide	20 – 400	90-120	>85	3000-4200	12 – 20
Shop lighting Quartz Discharge tube	Na–Tl–Dy–Ho–Tm iodide	70 – 250	80	85	3000-4200	10
Outdoor Lighting HPI	Na–Tl–In iodide	250 – 2000-45kW *	80	67	4500	20
Outdoor Lighting Sodium Scandium	Na–Sc iodide	70 – 2000	85	65	4000	20
Entertainment Quartz Discharge tube	Dy–Ho–Tm–Cs iodide & bromide	400 – 2500-25kW	85-90	>90	5500	0.75-1.5
* Chemical industry						

Table 1 Lamp types and properties

The different lamp manufacturers use slightly different technologies to realize optimised lamp designs. Some properties of the lamps like lifetime, efficiency and colour temperatures are indicated in table 1. The names of the lamps of these lamp families are indicated in table 2. The acronyms are different between the manufacturers. In the table above a description of the different families is given together with an indication of the efficiency of the lamps, the range of lamp powers available the efficiency and colour properties and the lifetimes. The metal halide salts used by different manufacturers differ, so table entrances in column 2 serve as an indication of the relevant materials.

In Figure 1 indicative pictures can be found of the different lamp types.

Metal halide lamp	Names used:
Ceramic discharge tube (low-medium power)	CMH CDM HCI
Quartz discharge tube (Low power)	MHN ARC HQI MH
Quartz discharge tube (Medium-high power)	MVR MH HPI

Table 2 Abbreviations

The metal halide lamps can only operate on designated control gear that switch the lamp on, and regulate its power. Lamps of different metal halide families preferably operate in their own, dedicated control gear.

HID lamps generate light in a plasma arc. The compact arc has a high brightness. It is this brightness that enables the luminaire to gather the generated light efficiently into a broad or narrow beam of light with only a small reflector. The light in the HID lamp is generated by metal atoms, in HPS lamps they evaporate from the liquid metal in the discharge tube, in metal halide lamps the metal atoms are transported into the arc as metal halide molecules. The name metal halide lamp refers to these molecules. Since sodium atoms evaporate easily high pressure sodium lamps do not use metal halides they use sodium metal and mercury.

4.1.2 Applications covered by this exemption

The family of HID lamps consists of a diverse group of lamps based on different technologies each addressing their own application niche. We find in this group different families of metal halide lamps they are used light our cities, shops, roads, theatres, disco's and enable sporting outside in the evening. Metal halide lamps are designed for each application and the shape and size varies from the lowest power 20 Watt in shop lighting to above 2000 W sports lighting and lighting stages for concerts. The efficiency metal halide light source varies from good (80 lm/W) to highly efficient (120 lm /W). The

Figure 2 Pictures of typical applications of Metal Halide lamps

atmosphere they create varies from a bright daylight to a warm cosy evening light. The ability to render colours ranges from good enough in street lighting, to excellent for lighting fashion shops or TV broadcasting. This broad range of lamp powers, spectral demands has led to a wide range of lamps each designed of its own field of use.

The market for HID lamps is slowly shrinking due to the fact that LED solutions are replacing HID lamps. The biggest part if the market is however the replacement of failed lamps. The installed park of luminaires is big and the lifetime of these professional

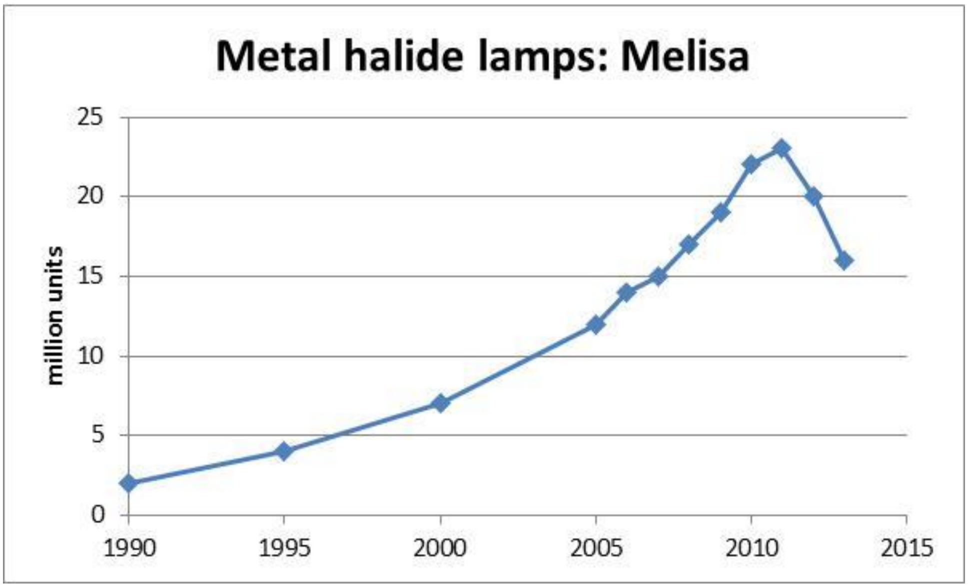

Figure 3 Historical sales of metal halide lamps, EU28 all sectors

luminaires is long. An indication of the European market size and the historical sales can be found in figure 3 obtained from data in reference[1]. The graph indicates that the fast growth of metal halide lamps is levelling off and even decreasing. On the basis of the McKinsey report the same team comes to the conclusion that in 2020 the market for HID is half of the market in 2012.This study assumes a lamp sales in 2012 that is much higher than the result of the Melisa study[2].

[1] From “Preparatory Study on Light Sources for Ecodesign and/or Energy Labelling Requirements” Draft Interim Report, Task 2 Markets, pag. 2-14, 19-November-2014.

http://ecodesign-lightsources.eu/sites/ecodesign-lightsources.eu/files/attachments/LightSources_Task2_nov2014_Draft.pdf

[2] Same study page 2-51

4.1.3 Annex I category covered by this exemption

List of relevant Annex I categories for this exemption

☐ 1	☐ 2	☐ 3	☐ 4	☒ 5	
☐ 6	☐ 7	☐ 8	☐ 9	☐ 10	☐ 11

Application in other categories, which the exemption request does not refer to: N/A

Equipment of category 8 and 9: N/A

The requested exemption will be applied in

☐ monitoring and control instruments in industry

☐ in-vitro diagnostics

☐ other medical devices or other monitoring and control instruments than those in industry

LightingEurope is of the opinion that lamps in general are category 5 because the most are used for general illumination. However, they have some of the characteristics of components (used in luminaires), consumables (finite lifetime and regularly replaced) and spare parts, lamps in luminaires have to be replaced when they cease functioning). Some manufacturers of electrical equipment in other RoHS categories may install fluorescent lamps into their equipment for general illumination purposes and so they will need to use lamps that comply with the RoHS directive, however the products that they place on the market are not category 5 but may be household appliances, medical devices or potentially in any RoHS category 1 - 11.

LightingEurope is aware of the difficulty to unambiguously classify certain lamps in the category set out by RoHS legislation. For lamp manufacturers it is essential to have legal certainty regarding the possibility to put the products on the market irrespective of the planned application as manufacturers are not able to control the use of the lamps in products falling in other categories in or out of the RoHS scope. In practice, most lamps are installed in buildings for lighting applications (category 5) but some are used in other types of equipment in all other RoHS categories. The way that lamps are used has no effect on lamp design so will not affect this exemption request.

Therefore lamp manufacturers do consider the lamps in scope of this document to belong to category 5 as individual products.

4.2 Description of the substance

4.2.1 Substance covered by this exemption

LightingEurope is asking for exempting

☐ Pb ☐ Cd ☒ Hg ☐ Cr-VI ☐ PBB ☐ PBDE

4.2.2 Function of mercury in lamps

The main role of mercury is to make sure the lamp operates at the right power and to optimize the efficiency of the combination lamp and driver.

High Intensity Discharge lamps generate light in a compact plasma arc with a high brightness. After the lamp has started by a voltage pulse the initial noble gas discharge heats the lamp and evaporates the condensed mercury. The increasing mercury vapour pressure increases the electrical resistance in the discharge which allows for putting more power into the discharge. As a consequence of more power coupled into the discharge, the discharge tube wall will heat up and the metal halide salts are evaporated. Once all mercury has been evaporated and the metal halides have entered the discharge, a state of equilibrium is established between the power entering the discharge and the light emitted from the discharge. The optimal efficiency is reached at this equilibrium. The mercury is not consumed over life. Its initial amount is instrumental over life.

4.2.3 More functions of mercury

Next to ensuring the lamp operates, efficiently at the right power, the mercury has a number of essential functions to fulfil:

Warm colour: Due to the broadening process of the atomic sodium radiation by mercury atoms the yellow sodium line is broadened towards the red part of the spectrum. This red radiation is responsible for the good colour rendering in many metal halide lamps, but also for the low correlated colour temperature, for instance in 3000K ceramic metal halide lamps. Without mercury this warm colour is not possible. This property is not valid for the high colour temperature lamps (>5000K) they don't have a warm colour and don't have sodium in the discharge.

Efficiency: The most efficient radiating atom in the HID lamp is sodium: it radiates two yellow lines close to maximum the eye sensitivity. However this radiation will be absorbed in the colder regions of the plasma. Collisions of the radiating atom with other sodium atoms and mercury will broaden the emission lines allowing the light to escape from the plasma. The efficiency of the lamp would be lower if no mercury would be present. Mercury is very important for the lamp efficiency not only for lamps with sodium but also for other radiating atoms like rare earth atoms. This property is not valid for the small group of high colour temperature lamps (>5000K) they don't have a warm colour and don't have sodium in the discharge.

Lifetime: The heavy mercury atoms move only slowly in the high temperature plasma. Therefore the heat flux lost from the centre of the arc tube by thermal convection and conduction is low. Much of the power remains inside the plasma and can only escape as visible radiation or as IR radiation. This improves the efficiency of the plasma in generating visible light. The reduced conduction of heat also protects the material of the discharge tube from overheating. The high pressure of mercury limits evaporation of the hot Tungsten electrode. The low evaporation helps to maintain the light flux over lifetime, a high evaporation rate of tungsten will lead to blackening of the arc tube and a reduced transmission of light. Replacement by a noble gas could help limiting the diffusion, but will increase the demands on the igniter.

Switch on: Ignition of high pressure lamps is enabled by a short pulsed voltage of 3-5 kV. This is possible because the high pressure of mercury is absent when the cold lamp starts. Upon replacement of mercury by other gases for instance Xenon the high buffer gas pressure is already present in a cold lamp. This makes the lamp difficult to ignite and pulses certainly over 10 kV but more typically 25-60 kV are needed. These high voltages require special electrical isolation measures and new lamp holder lamp base designs to prevent discharges outside the lamp. These measures prohibit the use of the lamps in existing installations.

In metal halide lamps the salts react with the oxygen impurities that are inevitable in the lamp production process. This reaction results in the formation of iodine molecules. These are volatile at room temperature and effectively prohibit the lamp igniting (the molecules bind the mobile free electrons). When mercury is present in the lamp the iodine will react with mercury to the much less volatile mercury iodide that does not hinder ignition.

Stable operation: The HID lamps are operated on an alternating current. Each period when the current becomes zero, the radiation plasma cools down and the charge carriers disappear. The electrical resistance increases and the driver will encounter difficulties in keeping the lamp burning. The high density of mercury has enough heat capacity to keep the plasma warm enough for a short time. Eliminating the mercury makes the plasma extremely difficult to operate. The driver would need to supply very high voltage just after the current zero moment. The need for such a new driver effectively prevents the lamp to be used as a replacement in an existing luminaire. Again a high noble gas pressure can have the same function, but these lamps cannot be started with the current igniters in the market.

4.2.4 Location of mercury in lamps

Mercury is present in the so-called discharge tube. The discharge tube is itself contained in a closed (quartz)-glass outer bulb. Main function of the discharge tube is efficient light generation over life. Further elaboration on the function of mercury has been given in section 4.2.2.and 4.2.3.

4.2.5 Amount of mercury

Mercury is dosed in the discharge tube during lamp manufacturing as liquid metal. The amount of mercury dosed per lamp depends on aspects like lamp power and optical performance. For metal halide lamps in the scope of the Exemptions 4(e) the dosed mercury amounts in majority vary between 3 and 30 mg. Since the dosing determines the lamp voltage and the colour properties the dosing process is accurate.

The amount of mercury for the different lamp types differs. For higher power lamps with a discharge tube with a larger volume the amount of mercury needed to realise the same pressure increases.

The amount of mercury used for the different metal halide lamps is different for different lamp power, lamp types, colour temperatures etc. The distribution of mercury dose is not Gaussian: the 10% lower boundary is at 3 mg, the median dose is 4.7 mg the mean dose at 11 mg and the 90% upper bound is at 28 mg.

The lowest amount of mercury is used in low power lamps that have a discharge tube with a small volume. The higher power lamps used for instance in soccer stadia use almost 200 mg. These lamps have an operating power of 1.8 kW and generate 155000 lumen, more light than 60 T8 32W fluorescent lamps (60*2550 = 153000lm and the mercury use is limited by RoHS to 210 mg Hg). If a stadium would be lit with these fluorescent lamps a lot of luminaires are needed, and to support these in the wind, a large and strong construction is needed.

Very high power lamps, designed for projection equipment, enabling extremely high lumen flux of daylight, essential for Studio, Theatre, Movie industry more mercury is used. These lamps need a certain lamp volume to prevent that the heat generated in the discharge melts the wall of the discharge vessel. If the same high power lamp is used for projection the arc must be very compact. This requires a very high mercury pressure. The combination of a very high pressure and a large discharge volume leads to the necessity of a large amount of mercury (up to 2 gram). These high power lamps for entertainment consist of less than 0.05 % of the total market.

The total amount of mercury brought to the European market in the metal halide lamps is calculated in the following way: The database of one of the manufacturers is used to find the number of lamps sold in 2013 and the used mercury amount per lamp produced. Based on the estimated market share of this manufacturer in the different lamp families the total amount of mercury entering the European market is estimated to be around 16 Million lamps*11mg mean dose= 176 kg.

According to the UNEP document[3] the total amount of mercury used in the EU in 2005 was 492 tonnes, of which the mercury in lighting contributed 25 tonnes, and within this group the metal halide lamps of exemption 4(e) contribute 0.2 tonnes this is less than 2 % of the total use of mercury in lighting.

4.2.6 Environmental assessments, LCAs

There are several external LCA's performed regarding lighting. There is general agreement, that the main environmental impact is created during the use phase, meaning through electricity consumption when burning the lamp.[4] Since all attempts to remove mercury have led to a reduced efficiency[5], the effect of removing mercury worsens the LCA in the current state of technology.

Apart from company internal LCA's two public LCA's have been published for HID lamps[6] [7]. In applications where directional lighting is involved a good LCA is difficult. Especially since both systems need to be compared at equal basis. In systems with directional lighting this is difficult. An example: in street lighting the amount of light reaching the street just below the pole is important for the drivers. But at the same time light reaching the footpath next to the pole where the pedestrians walk is also important how do you weigh these different application needs?

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[3] AMAP/UNEP: 2008,Technical background report to the global atmospheric mercury assessment. Arctic monitoring and assessment program /UNEP Chemicals branch. www.chem.unep.ch/mercury

[4] (see Enlighten report, Section 5, Ch. 3 fig. 4 & 5)

[5] Will be discussed and argumented in Chapter 6.1

[6] Department for Environment Food and Rural Affairs (DEFRA). Life Cycle Assessment of Ultra-Efficient Lamps. Navigant Consulting Europe Ltd. 2009

[7] AT. Dale.MM. Bilec,J. Marriott, D. Hartley,C.Jurgens,E. Zatcoff Preliminary comparative life-cycle impacts of streetlight technology. Journal of Infrastructure Systems193— 199,(2011).

In addition both the LED efficiency is improving but perhaps to a lesser extent the HID efficiency/maintenance has been improved in the time since the publication of the studies. The HID efficiency is improved to from 90 lm/W to over 115 lm/W and the light flux over life stays above 90% at the end of life for some families. A definitive conclusion of the relative weight of the LCA's cannot be made yet at this time, at least not on the basis of the information that is publicly available. The internal LCA's and certainly the extrapolation to the future are confidential. One general conclusion can be drawn however: clearly most potential to improve is in the LED systems where all global research effort is focussed on.

Since there is no direct replacement lamp for a failed metal halide lamp, the LCA should in fact be done by comparing the situation where a failed lamp can be replaced with a new metal halide lamp, with the alternative case where a failed lamp leads to replacement of the whole luminaire, including the lamp driver which is then replaced by a LED system + luminaire. This replacement system might include an active cooling fan to get rid of the excess heat from the compact luminaire.

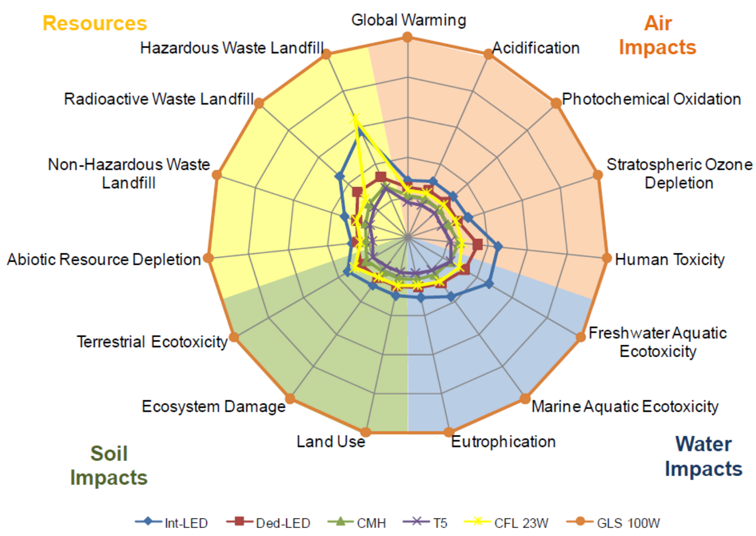

Figure 4: Figure from the Navigant report. LCA of different light sources

5 Waste management

5.1 Waste streams

☒ Article is collected and sent without dismantling for recycling

☐ Article is collected and completely refurbished for reuse

☐ Article is collected and dismantled:

☐ The following parts are refurbished for use as spare parts: _____

☐ The following parts are subsequently recycled: _____

☐ Article cannot be recycled and is therefore:

☐ Sent for energy return

☐ Landfilled

Metal Halide lamps are in the scope of EU Directives 2002/96/EC - WEEE and 2012/19/EU– WEEE Recast. Take back systems are installed in all EU Member States: end users and most commercial customers can bring back the lamps free of charge. Metal Halide lamps are collected separately from general household waste and separately from other WEEE waste.

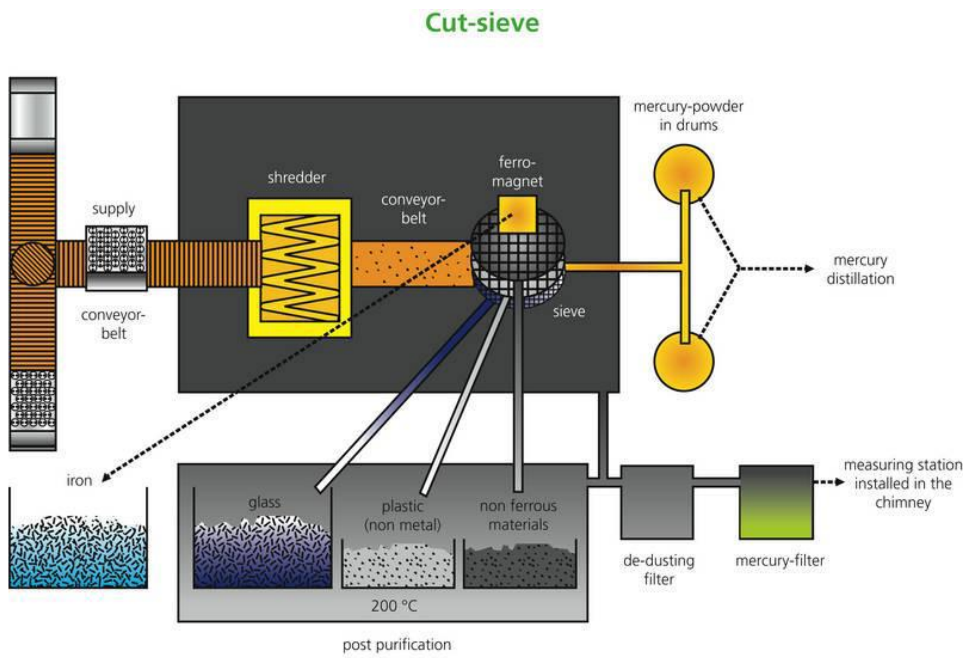

Figure 5: Recycling steps of fluorescent and HID lamps in Indaver (Belgium).
Source:www.indaver.be/waste-treatment/recycling/mercurial-waste.html

The collection efficiency with these professional customers is reasonably high. A dedicated recycling process exists for lamps because; according to legislation the mercury shall be removed from the gas discharge lamps. Mercury in treatment facilities is recovered by distillation or captured as Mercury Sulfide. In the installations CFL lamps and HID lamps are processed together (separating is difficult), this makes it impossible to report the recycle percentage for HID metal halide lamps separately. The process is running with the machine on under pressure to prevent exposure of the workforce to mercury. The recycling percentage for the combination of house hold and non-household waste combined is 45% and is audited each year.

5.2 Amount of mercury in WEEE

- ☐ In articles which are refurbished
- ☒ In articles which are recycled
- ☐ In articles which are sent for energy return
- ☐ In articles which are landfilled

To calculate the amount of mercury that is recovered by the recycling we do the following:

In the installation of the recycler CFL-integrated, CFL-non-integrated, LED lamps and HID are recycled together (household and non-household). The collection rate of lamps in Europe compared to the average amount of lamps put on the market during 2010 – 2013 is shown in below graph (Figure 10) based on Collection & Recycling Service Organization (CRSO) data consolidated by Philips Lighting. It also includes the targets set for 2016 and 2019. Please be aware that this graph includes all lamp types, not specifically the metal halide lamps. If we assume that the return percentage is the same for all categories, also for metal halide lamps, we estimate that 46% of 176 Kg this means 81 Kg is recovered, or about 100 kg enters the environment.

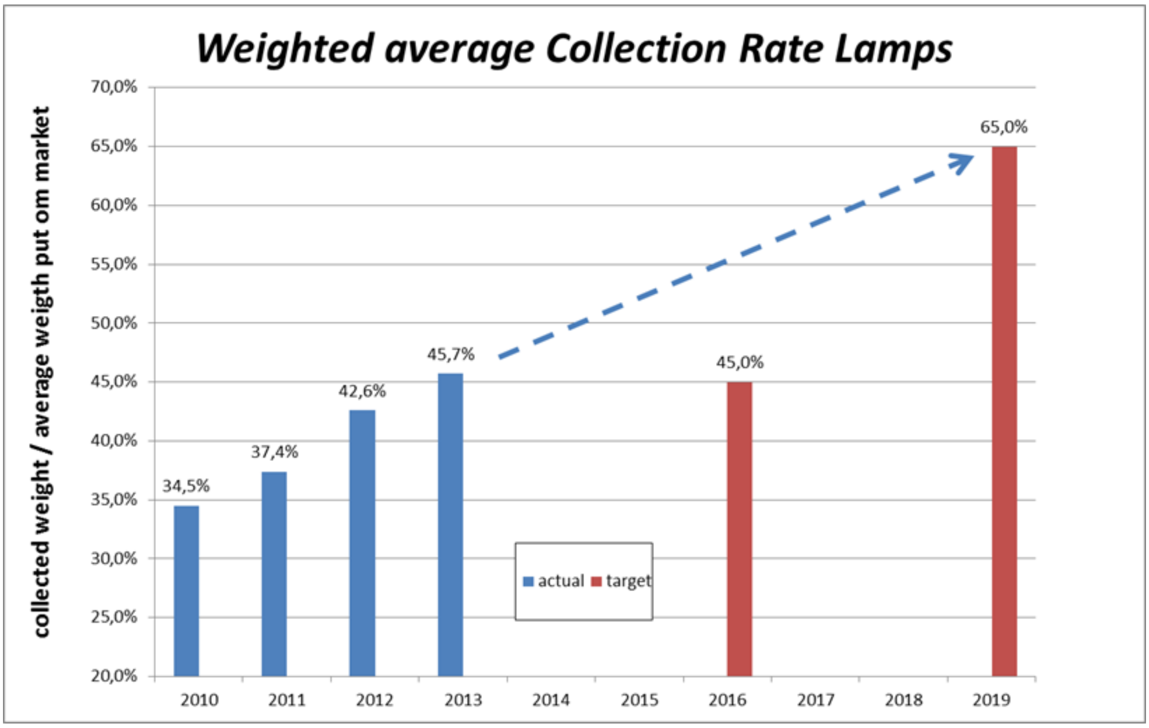

Figure 6: Recovery

How does the industry encourage an increase in recycling efficiency?

European legislation on Waste Electrical and Electronic Equipment makes producers responsible for end of life products within this category as from August 13th, 2005. European Lamp Companies have founded Collection & Recycling Organizations in the EU Member-States, with the objective to organize the collection and recycling of gas discharge lamps. Goal is to comply with present and probable future EU legislation and meet or exceed national targets.

In general however we can conclude that the following channels have been established in the respective member-states providing country wide coverage:

• Direct collection from large end users

Containers have been made available, ad hoc or permanently, and will be collected upon notification by the end user that the container is full.

• Collection through distribution

Wholesale and Retail place collection have collection means at their premises respectively in their shops. Collection upon notification.

• Collection through municipalities

Where infrastructure allows collection means are placed at municipality depots.

Campaigns are being executed or have been planned to re-enforce the role of the government to educate the population that gas-discharge lamps have to be disposed of in an environmentally friendly way.

6 Substitution

Can the substance of this exemption be substituted?

☐ Yes, by
- ☐ Design changes:
- ☐ Other materials:
- ☐ Other substance:

☒ No
Justification: see in below chapters

6.1 Substituting mercury in the discharge technology

For metal halide lamps several attempts were done to replace mercury. The alternatives used are

- Zinc but these lamps show severe loss of light over life[8],
- A high rare earth pressure but these lamps contain very narrow arcs due to arc contraction. This results in visual flicker of the light, due to movement of the arc and might lead to short lamp life when the hot arc touches the wall of the discharge vessel[9]
- Xenon that reduces the thermal losses but gives a very low lamp voltage needs a different operation mode[10] and the pressure makes the lamp difficult to ignite.

In the SCHELP project, co-funded by the Belgium government (IWT), Philips attempted to replace each function of mercury with a separate substance.[11] The project has led to reasonable efficacies for cool white light for the warmer colour impression no efficient solution was found. Apart from the problems mentioned, above several others occurred: problems occurred with ignition on existing driver systems due to the halogens[12] , and with severe chemical reactions occurred with the reactor vessel with new chemistries[13].

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[8] M. Born. Untersuchungen zum Ersatz des Quecksilbers in keramischen Hochdruckgasentladungen mit Hilfe von metallischem Zink. ISBN: 3-89653-788-1, 2000.
M. Born. Mercury free high pressure discharge lamps. In Proc. 9th Int. Symp. Sci. and Technol. of Light Sources, page 43, 2001.
M. Born, H. Giese, and I. Niemann. Abschlusbericht BMBF-Projekt 13N8264, 2005.

[9] M. Käning, L. Hitzschke, B. Schalk, M. Berger, St. Franke and R. Methling, Mercury-free high pressure discharge lamps dominated by molecular radiation, J. Phys. D: Appl. Phys. 44 (2011) 224005..

[10] C. Stewart, M. Duffy, J.Dakin, V. Roberts,S-A El-Hamamsy, H. Witting,
L. Inouye, K. Shimizu, K. Araki, Inductively Coupled HID Lighting System, The 6th International Symposium on the Science and Technology of Light Sources, Budapest, 1992

[11] Rijke, A.J. (2013, Oktober 16). The power balance of ceramic metal-halide high intensity discharge lamps. TUE : Technische Universiteit Eindhoven (235 pag.) (Eindhoven: Technische Universiteit Eindhoven). Prom./coprom.: prof.dr.ir. M. Haverlag, prof.dr.ir. G.M.W. Kroesen & dr.ir. S. Nijdam.

[12] E G Estupin´an, R Pereyra, Y-M Li and W P Lapatovich The effect of hydrogen iodide on the ignition of Hg-free metal–halide lamps,J. Phys. D: Appl. Phys. 44 (2011) 224004.

[13] R. Hilbig, A. Koerber, S. Schwan and D. Hayashi, Novel molecular discharge light sources, J. Phys. D: Appl. Phys. 44 (2011) 224009.

The study concluded that operation of the lamps on existing lamp driver systems was judged to be impossible if no concession could be done to the efficiency or lifetime of the mercury free lamps. The project did not lead to a mercury free lamp, or to an alternative lamp reduced in mercury, retrofit on existing lamp driver systems.

6.2 Substituting metal halide discharge technology by LED technology

6.2.1 Feasibility of the alternatives

6.2.1.1 Technical feasibility of substitutes

LED cannot replace Metal Halide lamps on a one to one replacement basis when a lamp has failed because of the following reasons:

High intensity discharge lamps are compact and are in general high power lamps. In the application it is required that HID lamps operate in closed luminaires. Since over 90% of the power supplied to the HID discharge vessel[14][15], leaves the discharge as radiation (visible light, infrared radiation and some UV) the luminaire and the lamp do not become too warm. Over 33% of the energy is transformed into visible light[16] far more than the 1.2 % for Incandescent lamps.

An LED replacement bulb will need to be operated in the existing luminaire and needs to get rid of the excess heat too just like the HID lamp. To judge the size of this thermal issue to be solved we can compare the current thermal loss of the HID lamp and the loss of an LED replacement lamp (if this will be developed in the coming years). The HID lamp envelope is heated by the non-radiative losses (10%) and by the UV and infrared radiation absorbed by the glass envelope. The total heat flux to the glass is about 40% of the power supplied to the HID lamp[17]. In efficient LED lamps over 35% of the power is transformed into light the other 65% is to be removed as heat. This means

[14] *See ref. 9*

[15] *Rijke, A.J., Nijdam, S., Haverlag, M. & Mullen, J.J.A.M. van der (2010). The energy balance of high intensity discharge lamps. In M. Haverlag, G.M.W. Kroesen & T. Tagushi (Eds.),* Proceedings of the 12th International Symposium on the Science and Technology of Light Sources and the 3rd International Conference on White LEDs and Solid State Lighting (LS-WLED 2010

[16] *A. G. Jack, M. Koedam, Energy Balances for Some High Pressure Gas Discharge Lamps, J. Ill. Eng. Soc. 1974, 323 – 329.*

[17] *Infra-red radiation above 5 micron wavelenght is absorbed by quartz glass. Ir-radiation measurements: Janssen, J.F.J., Rijke, A.J., Nijdam, S., Haverlag, M., Dijk, J. van, Mullen, J.J.A.M. van der & Kroesen, G.M.W. (2012). A comparison between simulated and experimentally determined energy balances for HID lamps. In R. Devonshire & G. Zissis (Eds.), Poster : Poster presented at the 13th International Symposium on the Science and Technology of Lighting (LS-13 2012), june 24-29, 2012, Troy, New York, USA, (pp. CP040-175/176). Sheffield: FAST LS ltd.*

that the heat flux from a current LED is 1.5 times the heat from an HID lamp. Modern LED's can operate at junction temperatures close to 100 °C, higher temperatures lead to reduced efficiency, shorter lifetimes and might even damage the device. At 100ºC a lifetime of close to 25000 hours is possible. Since the transport of heat from a lamp to the luminaire via the lamp base is limited, the only path for the heat to disappear is via conduction and convection to the air surrounding the lamp, and possibly by radiation if the lamp is hot. In a closed luminaire, warm air limits the transport, but even if the lamp would operate in open air, the compact size needed to fit as a retrofit lamp in other closed luminaires limits the cooling opportunities.

With a hypothetical LED that is even 25% more efficient than the HID lamp, the heat loss would not be 1.5 times higher than for HID lamps, but would about the same. The reduction is due in part because the LED uses now 25% less power, and furthermore the non-radiative losses decrease. The bulb temperature of the replacement LED lamps will then come close to the temperature of the metal halide lamps.

Figure 7 Typical compact metal halide luminaire with parabolic reflector

Measurements of the glass bulb of existing metal halide lamps (table 3) give a flavour of the temperatures we are talking about. The bulb is much warmer than the required temperature of the LED junction of retrofit lamps. (400ºC >> 100ºC). Therefore retrofit lamps of the same size as HID lamps cannot be made now, at least as long as the efficiency of the LED's is not much larger than that of the current metal halide lamps.

There is another design limitation. The optics in the luminaires (fig.7)is designed to operate efficient when the compact light source is in the optimal focal point. This limits the possibilities for creating retrofit LED lamps. They cannot be too big and the cooling fins cannot be in the optical path.

Lamp type	Bulb diameter [mm]	Power [W]	Twall [°C]	stdev [°C]
Ceramic metal halide	19.0	70	394	4
	19.0	150	525	5
	14.0	70	580	10
	13.3	50	490	10
Quartz metal halide	46.6	400	560	10
Studio Stage lamp	30	575	650	15

Table 3 Temperature measurement of common metal halide lamps

The last design obstacle is of electrical nature: Metal halide lamps are operated on electrical systems that generate high voltage pulses to ignite the lamps. These ignition pulses can are typical 3500V but can reach 5000V or even 60000 V in systems with a called hot-restrike facility. These igniters have to be taken out of the system (if not integrated in the electronic driver) and rewiring is in the luminaire is needed if LED's would be designed to replace the failed HID lamps. It is not clear who is responsible for the safety of the luminaire after the replacement.

To conclude there are no mercury free retrofit lamps available on the market. And we foresee no lamps appearing in the next years.

6.2.2 Availability of substitutes

☐ Yes ☒ No

There are no replacement lamps for the HID family available. On system level there are LED luminaires that can replace the HID system, examples are seen in luminaires for lighting fashion shops and even LED solutions are found for lighting tennis fields and soccer stadia.

6.2.3 Impacts of substitution

6.2.3.1 Environmental impact of substitutes

Since the HID luminaires can be very compact the replacement luminaries in many cases contain active cooling with a fan. For higher power systems solutions can be found that use the luminiare or the lamp pole in street lighting as a cooling device.

The environmental impact of the solutions with cooling fan is not quantified yet.

6.2.3.2 Health and safety impact of substitutes

6.2.3.3 Socio-economic impact of substitution

Economic effects related to substitution:

- ☐ Increase in direct production costs
- ☒ Increase in fixed costs
- ☐ Increase in overhead
- ☒ Possible social impacts within the EU
- ☒ Possible social impacts external to the EU
- ☒ Other:

Substitution of mercury would inevitably lead into the changeover to a new light source technology, like LED. Since there is no lamp replacement replacing HID lamps with LED lamps, as a consequence involved luminaires and drivers need to be replaced completely resulting in high investments for customers and governments while the installed equipment is still capable to be used for many years when replacement lamps would remain available (typical life cycle for professional luminaires is around 10-15 years for indoor use and 25-30 years in outdoor)[18]. As a consequence the society has the extra burden of the investment in new luminaires and the environment will be spoiled unnecessarily with additional waste. The waste typically consists of a conventional control gear (1 kg Iron and copper) and a luminaire (1 kg aluminium).

The total installed number of luminaires with metal halide lamps installed is estimated to be about 500 million globally or approximately 150 million in Europe. Although the lifetime of the lamps can be long 12,000-30,000 hours, the lamps need to be replaced every few years. LED solutions are entering the market rapidly, and are competing in the initial market of new luminaires. Not all owners of these professional lighting systems however are financially capable of investing in these new solutions when a lamp has failed and needs to be replaced. Such a change requires not only changing

[18] Lighting the way: Perspectives on the global lighting market. McKinsey 2011

Table 2

GENERAL LIGHTING APPLICATION – LIFETIME OF LUMINAIRE		Average	MIN	MAX
Residential	Years	10	8	12
Office	Years	12	10	14
Industrial	Years	14	13	15
Shop	Years	7	7	7
Hospitality	Years	8	8	8
Architectural	Years	10	10	10

Figure 8 Lighting the way: Perspectives on the global lighting market. McKinsey 2011

Note: Avg/Min/Max across regions, between 2010 - 2020

the light source but the whole lighting system including: luminaire, its optics and magnetic or electronic driver system. No one to one lamp replacement of HID lamps with LED's is possible in the foreseeable future.

An attempt to quantify this:

An example: The industry produces approximately 15 M ceramic discharge lamps per year. The biggest part of these lamps is nowadays replacement of lamps for existing luminaires. Since the lifetime is about three years the existing luminaire park can be estimated to be 45 M luminaires. The replacement of these luminaires by professional LED luminaires costing between 200 - 500€ to replace this is an investment of 9-23 Billion €. As stated above the disposal of one luminaire creates already about 2 Kg waste consisting of iron, copper and aluminium.

However due to the entrance of LED lighting in the initial luminaire market the replacement market for HID metal halide lamps will decrease in the long run[19]

Social impacts

Loss of jobs due to shut down of manufacturing sites for Metal Halide lamps in Belgium Hungary, Germany and Poland.

6.2.3.4 Impact of substitution on innovation

Focus of the current lighting industry is already on the further development of LED technology (paragraph 6.1). An extension of the exemption will have a positive effect on the efforts to further innovate in LED, as HID efficiency, colour quality and brightness is the benchmark to be outperformed by LED.

[19] Lighting the way: Perspectives on the global lighting market, McKinsey 2012 second edition

6.2.4 Future trends of substitution

The time frame for substitution of HID by LED solutions is set by the replacement cycle of the luminaires as discussed in chapter 6.2.3..3 and the desire to adhere to at least the high efficiency and colour performance of HID lamps.

6.3 Links to REACH, according to RoHS Directive Article 5(1)(a)

Do any of the following provisions apply to the application described?

no

☐ Authorisation
- ☐ SVHC
- ☐ Candidate list
- ☐ Proposal inclusion Annex XIV

☐ Restriction
- ☐ Annex XIV
- ☐ Annex XVII
- ☐ Registry of intentions

☐ Registration

Provide REACH-relevant information received through the supply chain.

Not Applicable

7 Removal of mercury from lamps

Can mercury be eliminated?

- ☐ Yes.
- ☒ No.

This is discussed in the chapter on alternative substances. The elimination will reduce the light output, the quality of the light and the resulting lamp cannot operate on existing control gear in the market.

8 Reduction of mercury content of lamps

In High Intensity Discharge lamps all mercury is evaporated. Dosing less mercury will lead to lamps that will not perform the task they are designed for: Reduction of mercury first leads to a low lamp voltage. This will lower the power supplied by the driver to the lamp. This results in a lower light flux. As a secondary effect the lower power will reduce the temperature of the lamp causing reduced vapour pressure of the light emitting atoms in the discharge. This again leads to a change in light colour since not all metals have the same temperature dependence of the vapour pressure and in many cases a reduced colour rendering since part of the spectrum is not filled. An example of the effects on the spectrum is illustrated below in Figure 7. In this case the red radiation is dramatically reduced[20].

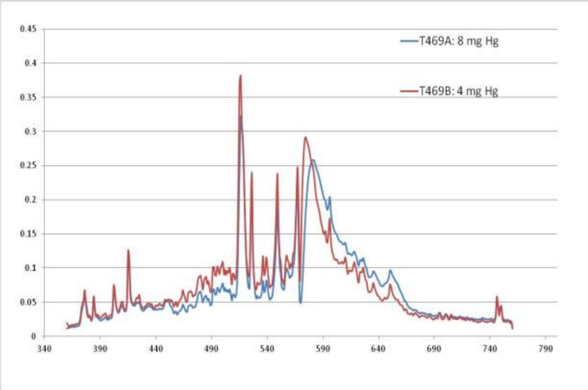


Figure 9 Spectrum change with mercury content

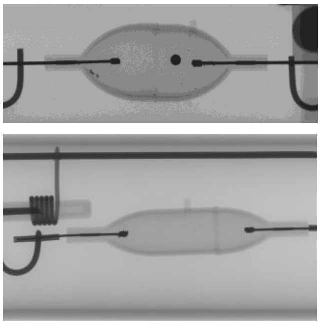
Figure 10 De-mixed lamp

This is not the only effect on the lamp. With the lower mercury dose the discharge tube needs to become longer to reach the same lamp voltage (see figure 10). This results in different colours when the lamp is used in different burning positions (for instance horizontal or vertical). To reduce this dependence, the physics of this process is studied in the space station. Gravity is the driving force for the de-mixing that occurs in the lamp resulting in colour differences in different operating positions. No technical solution was found for this issue[21] (figure 9).

20 Internal measurement of one of the LightingEurope companies.

21

Figure 11 Two discharge-tube designs, for high and low mercury pressure



Due to the nature of the lamp and driver combination a reduced lamp voltage leads to an increased current in the current limiting ballast. This will reduce the lifetime of the reactor ballast and can even lead to overheating. This limits the opportunity to design lamps with less mercury that can retrofit broken lamps in existing installations.

Although a reflector, designed for efficient collection of light, demands a short arc (and high mercury pressure), in some cases metal halide street lighting lamps the mercury dose is low. This is possible since the optical demands are such that a longer arc tube is not a disadvantage: the light has to be distributed over a long stretch of road and a longer arc is beneficial in this case. Moreover, these lamps are mainly used in horizontal burning position, such that the longer arc tube is no issue in this street lighting application. The colour rendering however falls below CRI 70, due to the low mercury dose, but for outdoor lighting this is good enough.

9 Other relevant information

NA

10 Information that should be regarded as proprietary

NA

List of abbreviations

ADCO	Administrative Cooperation Group
BASI	Bioanalytical Systems, Inc
BSP	Barium Synthetic (Pb^{2+}) phosphor
CCG	Conventional Control Gear
CDM	Ceramic Discharge Metal Halide
CDV	Committee Draft for Voting
CFL	Compact fluorescent lamp
CRI	Color rendering index
CRSO	Collection & Recycling Service Organization
DEFRA	Department for Environment Food and Rural Affairs
DOE	Department of Energy
ECG	Electronic Control Gear
EEE	Electrical and Electronic Equipment
ELC	European Lamp Companies Federation
EM	Electromagnetic: lamp control gear based on a magnetic coil (= CCG)
EMC	Electro Magnetic Compatibility
ERP	Energy related Products; Directive 2009/125/EC establishing a framework for the setting of eco design requirements for energy-related products
FTE	Full Time Equivalent, indicates the workload of an employed person
HF	High frequency: lamp control gear based on high frequency (= ECG)
HID	High intensity discharge lamps
HPS	High Pressure Sodium (vapor) lamps
Hz	Hertz
K	Kelvin: Unit of color temperature (2700 K warm color, 5600K cool daylight)
Lm	Lumen
LFL	Linear Fluorescent Lamps
LCA	Life cycle assessment

LED	Light Emitting Diode
LPD	Low Pressure Discharge lamp
LVD	Low Voltage Directive
mg	Milligram
MH	Metal halide lamps
OEM	Original equipment manufacturer
OLED	Organic Light-Emitting Diode
PCA	Poly-crystalline alumina
PLL	Pi shaped Long Length, compact fluorescent lamp
R&D	Research and Development department(s)
REACH	Regulation on Registration, Evaluation, Authorization and Restriction of Chemicals, 1907/2006/EC
RoHS	EU Directive 2011/65/EU on the Restriction of the Use of Certain Hazardous Substances in Electrical and Electronic Equipment
SSL	Solid State Lighting
SVHC	Substances of Very High Concern
TF	Task Force
UMICORE	global materials technology group which focuses on application areas where its expertise in materials science, chemistry and metallurgy makes a real difference.
UNEP	United Nations Environnent Programme
UV	Ultraviolet
VDE	German Association for Electrical, Electronic and Information Technologies
W	Watt unit of (electrical) power
WEEE	Waste Electrical and Electronic Equipment
ZVEI	German Electrical and Electronic Manufacturers´ Association