Exemption Request Form – Exemption #4(f)

Date of submission:

1. Name and contact details

(A) Name and contact details of applicant:

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On behalf of the Company/Business organisations/Business associations listed below participants in the **RoHS Umbrella Industry Project ("the Umbrella Project")**:

We will be inserting in this table endorsing Associations: (i) names, (ii) EU Transparency Register IDs (where applicable) and (iii) Logos.			

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2. Reason for application:

Please indicate where relevant:

☐ Request for new exemption in:

☐ Request for amendment of existing exemption in

☒ Request for extension of existing exemption in

☐ Request for deletion of existing exemption in:

☐ Provision of information referring to an existing specific exemption in:

☒ Annex III ☐ Annex IV

No. of exemption in Annex III or IV where applicable: **4(f)**

Proposed or existing wording: existing wording below:

We submit this application to request for an extension of the existing exemption no. 4(f) of Annex III and proposes to use the existing wording:

4(f) Mercury in other discharge lamps for special purpose not specifically mentioned in this annex

Duration where applicable:

We apply for renewal of this exemption for the categories marked in section 4 further below for the respective maximum validity periods foreseen in the RoHS2 Directive, as amended. For these categories, the validity of this exemption may be required beyond those timeframes. Although applications in this exemption renewal request may be relevant to other categories not marked in section 4 further below, this renewal request does not address those categories.

☐ Other: _____

3. Summary of the exemption request / revocation request

The scope of exemption 4(f) currently covers all the lamps for special lighting purposes, which do not belong to any of the groups identified in the exemptions 1(a)-4(e) by technology and application in Annex III of RoHS Directive 2011/65/EU (4g is not considered as it expired).

Neither mercury in these lamps can be substituted nor are replacement lamps available using a different technology. The exemptions for the use of mercury for these lamps are essential for huge variety of uses in nearly exclusively commercial, public or professional applications performing essential tasks for the EU community. Only some projector lamps are used in households. Discharge lamps need mercury for the generation of high power light in the visual and non-visual range.

There is a small but growing development of mercury-free technologies for some applications, e.g. in low power projectors, stage lighting, horticultural lighting or UV applications. In all of these cases the new light source does not replace the mercury containing lamp but requires design of new equipment. These new applications can cover and replace some of the existing solutions and they offer also new innovative applications and products. Nevertheless, a high number of applications is dependent on mercury containing lamps covered by exemption 4(f) and will be dependent for years.

If 4f lamps would no longer be allowed, many users especially of higher wattage lamps would have to stop required business processes including for example the whole European semiconductor industry. Technologies such as communications, computing, health care, military systems, transportation, clean energy, and countless other applications rely on semiconductors. Semiconductors are enabling most enabling technologies including virtual reality, the Internet of Things, energy-efficient sensing, automated devices, robotics, and artificial intelligence. The modern world is based on the enabling capabilities of semiconductor technology across many sectors of activity. Semiconductors enable the more efficient use of electrical energy in lighting, computing, data storage centres, intelligent transport systems, electric vehicles and in industrial manufacturing systems. Innovations in semiconductor devices enable sustainable developments in automotive safety, more secure communications and banking payments systems, improving medical devices and they play a key role in the realisation of the smart grid.

Furthermore, we will not be able to produce medicines, clean drinking water and wastewater, harden the coatings that make our products last longer and project images in our offices without 4f lamps. In addition, valuable electrical and electronic equipment would become premature waste. Many jobs all over the EU are dependent on the availability of the products.

Lamps covered by this exemption renewal request:
Exemption 4f so far covers a group of lamps which have not been further specified like exemptions 1 a-g, 2a-b, 3a-c, 4a-e, g of Annex III but can be identified uniquely.

Following an exclusion principle lamps covered by 4(f) are not belonging to the family of Low Pressure Discharge lamps for general and special lighting purposes which are covered by the exemptions 1-4(a), such as:

- Compact fluorescent lamps (CFLi and CFLni),
- Fluorescent lamps (linear and non-linear FL),
- Cold cathode fluorescent lamps and
- Low pressure UV lamps without phosphor coating operating at the same pressure compared to FL and CFL.

Within the High Pressure discharge lamps (i.e. other than low pressure lamps) the following lamp families are defined in exemptions 4(b, c, e):

- High Pressure Sodium (vapour) lamps (HPS) for general lighting
- Metal Halide lamps (MH)

The lamps and UV light sources contained in exemption 4(f) are:

- High Pressure Sodium (vapour) lamps (HPS) for horticulture lighting
- High pressure lamps for projection, studio and stage lighting
- Medium and high-pressure UV lamps

The proposal from the OEKO report Pack 9 (2016) is to split exemption 4(f) further and to identify the most important lamp types in this group[1]. However several uses and applications would not be covered by this wording with very high negative socio-economic impact for the users of these lamps in the EU.

Our proposal is to keep this diverse group of lamps together in exemption 4(f) but to describe the technical type of lamps more accurately and summarize their applications. The more accurate technical description allows the surveillance authorities to check whether the claimed exemption 4(f) is rightfully used, based objective measurements. This description found below, is essentially in line with the approach taken in the EU Ecodesign Regulation 2019/2020[2]. It should be noted that the definitions below are only a reference to the definitions in the Ecodesign Regulation 2019/2020 and are not valid for category 8 and 9 products, as they are exempted from the Regulation.

The light sources of exemption 4(f) can only be handled by professionals because they emit dangerous UV light, are in many cases too bright for human eyes and they require special control gear to operate them.

The light sources covered by exemption 4(f) are:

High pressure sodium lamps[3]:

Specified as:	"*light sources with a photosynthetic efficacy >1.2 µmol/J, and/or emitting 25 % or more of total radiation power of the range 250-800 nm in the range of 700-800 nm, and intended for use in horticulture*"

Application:

- Used in greenhouses for stimulating plant growth

[1] https://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_9/RoHS-Pack_9_Part_LAMPS_06-2016.pdf

[2] Commission Regulation (EU) 2019/2020 of 1 October 2019 laying down ecodesign requirements for light sources and separate control gears pursuant to Directive 2009/125/EC of the European Parliament and of the Council and repealing Commission Regulations (EC) No 244/2009, (EC) No 245/2009 and (EU) No 1194/2012 (Text with EEA relevance.)

[3] Page 25, Ibid

Short arc mercury lamps[4]:

Specified as: "*high pressure mercury lamps with a luminous flux > 500 lumen per mm² of projected light-emitting surface area defined as the area of the largest circle that fits between the electrodes of the high pressure lamp*"

Applications:

- Lamps for projection purposes (being part of projectors)
- Lamps for entertainment, cultural and stage lighting purposes
- Short-arc lamps for microlithography (essential for semiconductor production) boroscopy, microscopy, fiber-optic lighting

Medium and high pressure mercury lamps[5]:

Specified as *"light sources with specific effective ultraviolet power >2 mW/klm and intended for use in applications requiring high UV-content"*

Applications:

- Medium and high-pressure UV lamps for curing, disinfection, sterilization and other photochemical and photobiological purposes
- High Pressure Electrodeless Ultra-Violet Light Sources for various applications
- High pressure lamps for treatment of zoo mammals and birds, daylight simulation and other applications
- Curing of inks in printing systems, hardening of adhesives and silicones
- Disinfection of surfaces, water and air
- UV curing of composites, automotive coatings, glass and plastic decoration
- Wood treatment
- Electronic components and printed board production
- Medical, industrial, research and development applications including testing, inspection, measurements, qualitative and quantitative analysis utilizing specific wavelength

Figure 1 describes the lamp technologies covered by RoHS Annex III exemptions 1-4 as valid in January 2020.

[4] Page 4, see footnote 4
[5] Page 25, see footnote 4

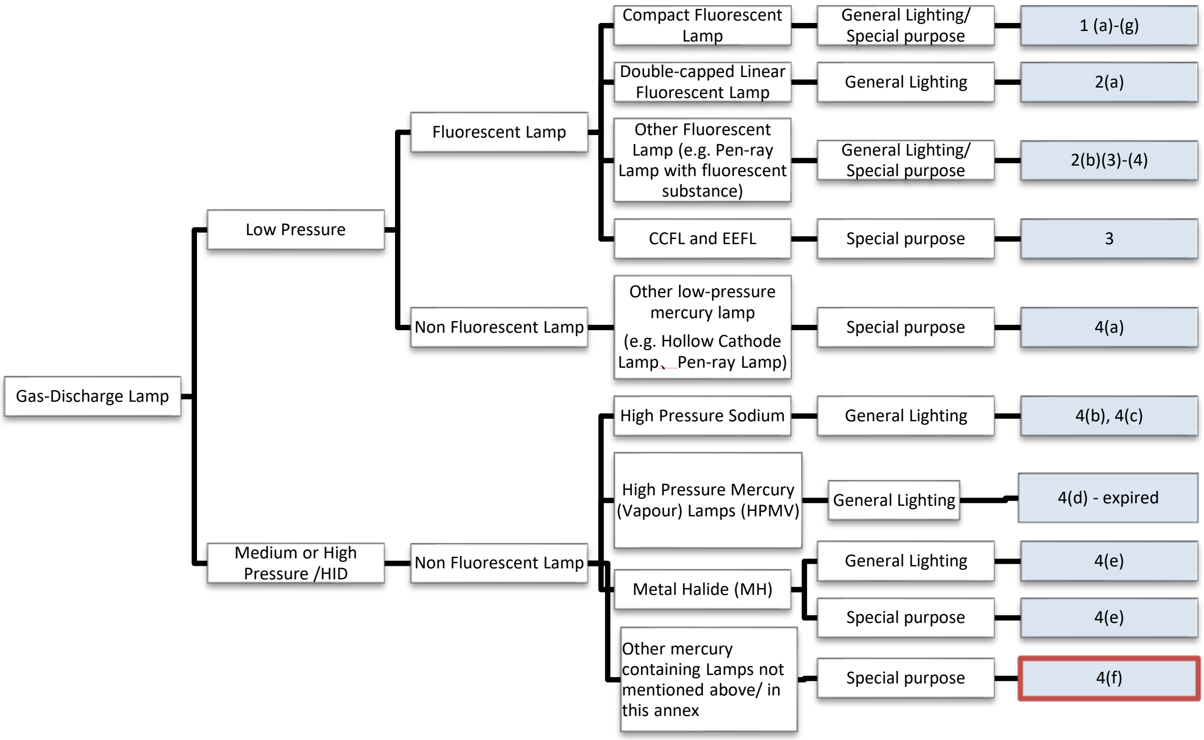

Figure 1: Chart on the hierarchy of lamps and exemptions

We would like to stress that Exemption 4(f) and the belonging lamp types represent a small market share and are responsible for a small part of mercury use compared to the other lighting exemptions.

Replacement of mercury and mercury containing lamps is impracticable:

The lamps covered by exemption 4(f) must remain available on the EU market:

- For new equipment for certain applications where no functionally suitable alternatives are available
- As spare part for equipment in the field to replace end of life lamps in order to avoid that the equipment turns into electronic waste before due time.

The requirements according RoHS Art. 5(a) are given:

- Substitution of mercury in the lamps is not possible.
- There are no or nearly no mercury free replacement lamps available for the electrical and electronic equipment in which they are used in.
- In those cases where a different technical solution is already or in the future available (e.g. for smaller wattage projector lamps, certain UV applications) a complete redesign of the equipment is required in which the light source is in use.

- These alternative solutions require, like all electrical and electronic equipment, additional use of lead in materials and electronic components currently exempted according to Annex III of RoHS Directive.
- The negative socio-economic impact would not be calculable if the 4(f) lamps would no longer be available. It would have huge consequences on commercial and industrial processes, health of people, availability of clean drinking water, availability of electrical and electronic equipment for cultural and entertainment purposes and many other areas.
- Accidental prohibition of certain lamps can have high socio-economic impact for the customer and user of the lamp as well as for the producer of the equipment in which the lamp is in use. For example the 4(f) proposal of the OEKO report (2016) does not cover certain stage lighting lamps and not UV lamps for microlithography which are essential for semiconductor production in EU.
- Potential misuse and difficult market surveillance as argued in the OEKO Institute Report 2016 [6] as main reason to exclude important lamps from the scope of 4f, is in practice very unlikely and easy to detect by market players. Market surveillance is an essential interest of lamp producers as well as of manufacturers of potential Hg-free alternatives, misuse would be notified to authorities in case of detection.

In the following Table 1 a summary is given why exemption 4(f) is still needed:

6 Assistance to the Commission on Technological Socio-Economic and Cost-Benefit Assessment Related to Exemptions from the Substance Restrictions in Electrical and Electronic Equipment, :2016 (OER)

Requirement according RoHS Article 5(a)	Status for Mercury in other discharge lamps for special purposes not specifically mentioned in this Annex
their elimination or substitution via design changes or materials and components which do not require any of the materials or substances listed in Annex II is scientifically or technically impracticable,	Substitution of mercury in the lamps covered by this exemption is scientifically and technically impracticable. In addition, retrofit replacement lamps using a different technology such as Light Emitting Diodes (LED) are not available. In those cases where a different technical solution is available a complete redesign of the equipment is required in which the lamp is in use. These solutions require the use of lead in materials and electronic components currently exempted according to Annex III of RoHS Directive.
the reliability of substitutes is not ensured,	In those cases where a different technical solution based on LED, Laser or other technology is available the reliability of the products has to be ensured and documented in the CE Declaration of Conformity. While for the existing technologies enough experience on the reliability is available for new product technologies long term reliability needs to be demonstrated in practice.
the total negative environmental, health and consumer safety impacts caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof.	LED-based replacement lamps are currently not available for lamps covered by this exemption. The existing technologies have a negative impact coming from mercury use. In those cases where alternative technologies are available usually these are less material efficient. Example: HPS lamp for horticulture lighting need by far less material compared to batteries of horticulture LED modules needed for the same plant area. At the same time the conventional lamp is highly energy efficient. In cases where the lamps would no longer be available even for existing equipment a high amount of waste would be generated. Detailed information on environmental impacts can only be evaluated by the producers and users of the equipment in which the lamps are used.

Table :1 summary justifying renewal of exemption 4(f)

4. Technical description of the exemption request / revocation request

(A) Description of the concerned application:

1. To which EEE is the exemption request/information relevant?

   Name of applications or products:

The scope of exemption 4(f) is thus covering those lamps, which

- are non-fluorescent,
- and have higher internal pressure compared to fluorescent lamps
- and are not covered by exemptions 4(b), 4(c) and 4(e)
- and are used for special purposes.

These lamps are used in a wide area of applications as described below.

a. List of relevant categories: (mark more than one where applicable)

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

b. Please specify if application is in use in other categories to which the exemption request does not refer:

Applications in this exemption renewal request may be relevant to categories not marked above and below.

We are of the opinion that lamps in general are category 5 because the majority 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.

c. Please specify for equipment of category 8 and 9:

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

2. Which of the six substances is in use in the application/product?

   (Indicate more than one where applicable)

   ☐ Pb ☐ Cd ☒ Hg ☐ Cr-VI ☐ PBB ☐ PBDE

3. Function of the substance:

The function of Hg in gas discharge lamps lies within the light generating process to convert electricity into light. Electrons are emitted from a heated electrode colliding with mercury atoms which elevates their electrons to an excited state. When these fall back to their original energy state, they emit photons either in the ultraviolet (UVC, UVB, UVA & UVV) or in the visible light wavelength range, depending on the technology.

By using a mix of different element atoms in the hot gas plasma, each emitting at specific wavelengths, the spectral distribution of the lamp as a whole as well as the quality of colour rendition properties can be controlled.

The use of mercury allows these needed properties to be achieved.

Mercury has been used for many decades because it has a unique combination of properties that no alternative has been found to provide. Mercury has a relatively low boiling temperature, so it is readily able to produce a vapour of suitable pressure. The heavy mercury atom slows down the fast electrons on their track though the plasma. Upon collisions of the electrons with the mercury atom UV light is generated very efficiently.

The mercury vapour is essential: all of the mercury is evaporated and the resulting pressure is chosen in such a way that

- the system can provide the exact power to the lamp,
- the discharge radiates as effective as possible,
- generates the required wavelengths for the desired application and finally,
- with a brightness that allows the most effective collection of the light.

Since the applications for 4(f) differ, the designs and the amount of mercury also differs widely. For example, very high power lamps, need a certain lamp volume to prevent the heat generated in the discharge melting 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 100 gram), e.g. in short arc mercury lamps. Other lamps require very efficient UV generation for instance for water purification. Here the generated UV must escape from the discharge without radiation trapping. These lamps have a medium mercury pressure (below 1 bar).

Mercury in High Pressure Sodium lamps:

The main role of mercury is different in HPS lamps. It is to tune the resistance of the plasma in such a way that the efficiency of the combination lamp and driver functions in an optimal way.

High Intensity Discharge lamps generate light in a compact plasma arc with a high brightness. After the lamp is started by a voltage pulse the initial noble gas discharge heats the lamp and evaporates part of the sodium/mercury amalgam pill. At first it is mainly the mercury that goes into the vapour phase. 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 sodium and mercury evaporate further until a state of thermal equilibrium is established between the electrical power supplied to the discharge, the heat conducted to the surroundings and the radiation emitted from the discharge. The lamps are designed in such a way that the optimal efficiency is reached at this equilibrium.

The mercury is not consumed over life. However, the sodium in the discharge tube does chemically react with the PCA wall (Polycrystalline alumina, ceramic discharge tube) and the electrode emitter [7,8]. As a consequence, the fraction of mercury in the amalgam becomes higher and this raises the lamp voltage. At a certain point in time the lamp voltage becomes so high that the mains voltage can no longer sustain the arc and the lamp extinguishes. This is the end of the lamp life. For a given sodium consumption, a certain amalgam dose is required to reach the specified life. If the dose is too small, the ratio of mercury in the amalgam rises rapidly and so does the lamp voltage, leading to a premature end of life.

The main role of mercury is to tune the resistance of the plasma in such a way that the efficiency of the combination lamp and driver is optimal. The mercury however has several additional essential functions to fulfil:

1. The mercury in the plasma of a High Pressure Sodium lamp does not directly contribute to the spectrum of the lamp because the arc temperature is too low to excite

[7] Luijks G.M.J.F., Sodium-PCA interaction in unsaturated HPS lamps, paper submitted for the LS6 conference in Budapest, Sept. 1992

8 Itoh, A. and Okamura, K., Evaluations of the sodium reduction in HPS lamps, paper submitted for the LS6 conference in Budapest, Sept. 1992

the interesting (optical) energy levels of the mercury atom. However, there is a very significant indirect contribution of the mercury atoms: the proximity of mercury atoms shifts the energy levels of sodium and creates a very large broadening of the sodium resonance line[9,10]. This broadening shifts the emission of the lamp to the red and by tuning the amalgam composition, the optimum radiation for growing plants can be obtained.

2. The presence of the mercury vapor also greatly reduces the thermal conduction of the sodium-mercury-xenon plasma[11] . Therefore, there is less heat loss from the plasma to the discharge tube wall. The efficiency of the lamp is thereby greatly improved by the presence of mercury[12].
3. 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 would lead to blackening of the arc tube and a reduced transmission of light and thus a lower lumen maintenance.

To further improve the efficiency of these lamps a quite high Xenon pressure is used. This makes them even more distinct from ordinary high-pressure sodium lamps. As the broadening of the spectrum towards the red is essential, there are no mercury free alternatives for these lamps.

4. Content of substance in homogeneous material (%weight):

The RoHS Directive (2011/65/EU) defines homogenous material as a material which cannot be further mechanically disjointed. In the case of lamps, mercury is inserted or dosed into the burner in various forms, in medium or high pressure discharge lamps this is in most cases liquid mercury. Also, other forms are in use. In case of high pressure sodium lamps Mercury-Sodium amalgam is used.

Mercury is present in the so-called discharge tube or burner. In nearly all mercury discharge lamps for special purposes, a very specific amount of mercury is needed. Below, the most common dosing technologies are listed for lamps covered by this exemption:

- Manual pipetting or needle injection of liquid mercury (100% Hg)
- Semi- or fully automatic dosing, disc needle injection of liquid mercury (100% Hg)
- Mercury-Sodium amalgams Na-Hg (ca. 20% Hg)

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[9] Woerdman, J.P, Schleyen, J., Korving, J., Van Hemert, M.C, De Groot. J.J. and Van Hal, R.P.M., Analysis of satellite and undulation structure in the spectrum of Na+Hg continuum emission, J. Phys. B : At.Mol.Phys.,vol.18, pp4204-4221 (1985)

[10] J.de Groot and J. Van Vliet, The High Pressure sodium lamp, Kluwer Techische Boeken B.V. Deventer, ISBN 9020119028 (1986), p. 141 to 145

[11] J.de Groot and J. Van Vliet, The High Pressure sodium lamp, Kluwer Techische Boeken B.V. Deventer, ISBN 9020119028 (1986), p. 130 to 131

[12] J.de Groot and J. Van Vliet, The High Pressure sodium lamp, Kluwer Techische Boeken B.V. Deventer, ISBN 9020119028 (1986), p. 149 to 153

- Amalgam sticks (ca. 20-50% Hg)

5. Amount of substance entering the EU market annually through application for which the exemption is requested:
   Please supply information and calculations to support stated figure.

There is no single database or reliable evaluation that would give accurate data. The figures below are coming from different market studies or input from single companies to LightingEurope. The amount of mercury is the best estimation of LightingEurope.

Lamp type	***Mercury range per lamp***	***Mercury put on EU market***
High pressure sodium lamps for horticulture lighting	*19-40 mg, depending on type, Wattage*	*Data can be shared in confidentiality as part of a future consultation[13].*
Lamps for projection purposes	*10-48 mg depending on Wattage, average 20mg*	• *Ca. 22 kg maximum in new projector lamps* • *6 kg maximum in replacement/spare part lamps*
Lamps for studio and stage lighting	*10-40 mg depending on Wattage, average 30 mg*	*6 kg maximum*
Short arc mercury lamps	*20 mg – 8 g per lamp in EU (50 – 6.500 Watt)* *Medical, curing: 20 mg average* *Semiconductor production: 720mg average*	***6,1 kg total EU:*** *1,1 kg total EU medical EU* *5,0 kg total semiconductor production*
Medium pressure UV lamps	*Typical range 10-3000 mg*	• *Curing: 2018 - 108 kg ; 2021 - 158 kg* • *Disinfection: less than 100kg per year* • *Detailed data can be shared in confidentiality as part of a future consultation.[14]*
Other high pressure	*No information available*	*No information available*

Table 2: Estimation of the amount of mercury put on the market per year in lamps covered by exemption 4(f) of RoHS Annex III.

[13] Due to competition law, data can only be supplied under confidentiality as part of a future review of this exemption dossier.
[14] Ibid.

High Pressure Sodium Lamps:

Although the Melisa model established for the Ecodesign Regulation 2019/2020[15] gives a good estimate of the number of HPS lamps entering the market annually, the segment of lamps for Horticulture applications is narrow and has only a few players. Revealing the number of lamps put on the market is confidential competitive information and is not allowed within LightingEurope due to Competition Law. The amount of mercury can be estimated at best by LightingEurope. From the Melisa model it is expected that 7.1 Million HPS lamps are put on the market in 2019. A rough estimate (10% of these lamps are horticulture lamps, containing less than 40 mg of mercury) gives an estimate of 30 kg of mercury that is put on the market in 2019 in this application. The Melisa model estimates a general decline of 6% per year for all HPS lamps reducing the amount of mercury put on the market in this application to 22 kg per year after 5 years.

Lamps for Projection purposes:

According to a LightingEurope estimation in 2019, around 6.2 Mio new projectors of what 5.3 Mio contain mercury projection lamps are marketed worldwide per year. In addition, ca 1.5 Mio lamps are marketed separately for replacement (Aftermarket lamps). Lamps for projection purposes are mainly marketed by lamp manufacturers to producers of projectors outside the EU. Lamps are then reimported, contained in a projector, as a projector spare part. Calculating a market share of 20% for Europe will lead to approx. 1.36 Mio lamps (1,06 Mio in new projectors, 0.3 Mio replacement) containing around 28 kg mercury. Taking in account the yearly expected market decline the amount of mercury put on the market of this application will be reduced to 13 kg in 2023

Lamps for stage lighting, studio and entertainment

LightingEurope estimates around 1 million entertainment lamps are marketed worldwide per year. Around 80 % of them are used for new equipment, 20% as replacement lamps Calculating a market share of 20% for Europe will lead to 200.000 lamps containing in total about 6 kg mercury.

Medium Pressure UV lamps

We have made an estimate of the quantities used annually in Europe for lamp production in the areas of curing and disinfection. This is based on publicly available figures from Yole Development. For 2018, we arrive at a quantity of 108 kg for curing and 158 kg for 2021. However, we see a total amount of mercury in UV lamps for disinfection applications of less than 100 kg per year. From our point of view, approximately 200 kg of mercury are used in UV lamps for disinfection and curing annually in Europe. In addition, lamps from other regions are supplied to the European market.

15 Page 85 of “Melisa Model” Impact assessment - SWD(2019)357/996485 - Part 2 -available for download at the following link here: https://ec.europa.eu/info/law/better-regulation/initiatives/ares-2018-476175_en.

A big portion of the UV lamp producers are smaller producers, not members of LightingEurope, often located outside the EU. Their lamps are mainly imported as part of the system in which they are used as well as related spare parts.

High Pressure Short Arc mercury lamps:

The EU market for High Pressure Short Arc mercury lamps can be separated in the applications:

- Medical, Microscopy, Curing etc.: Ca. 55.000 lamps (mainly 50-200 Watt) per year;
- Industrial (Integrated Circuits) Ca. 7.000 lamps, (mainly 200-6.500 Watt) per year.

The total mercury content of these lamps is around 6 kg per year. Semiconductor production includes production of LED chips, other IC, memory, MEMs, sensors, ASICs etc..

6. Environmental Assessment:

☐ Yes

☒ No

For production, use and disposal of short arc mercury lamps an LCA was compiled. The Cumulative Energy Demand of this lamp, OSRAM HBO 12000 W/Chl, has been published under www.osram.com/lca.

(B) In which material and/or component is the RoHS-regulated substance used, for which you request the exemption or its revocation? What is the function of this material or component?

Mercury is inserted into the discharge tube or burner for converting electrical energy into light.

(C) **What are the particular characteristics and functions of the RoHS-regulated substance that require its use in this material or component?**

Lamps emitting light in the visible wavelength range

High pressure mercury gas discharge lamps can emit radiation directly as visible light. The use of mercury allows the needed properties to be achieved.

Lamps for projection

The lamps of exemption 4(f) are essential for the projection market, in commercial, medical or scientific environment, but can even be found in small quantities in private areas. They are used in equipment having a much longer life-time compared to the typical life of the lamps.

- For new equipment: only limited alternatives to mercury lamps exist in the projection market and only for specific applications. The vast majority of projectors still need mercury-based lamps, as explained in detail in the section on alternatives to mercury containing lamps for projection.
- Existing equipment in the European market: The mercury containing lamps used for projection are tailor made to the application/projector on form, fit and function. Consequently, no other replacement light source – aside from mercury-based lamps - can fit in the projector. This is in contrast to general lighting where LED replacement bulbs are widely available. This is explained in more in detail in the section on alternatives to mercury lamps. Out of pooling data (projector sales) provided by consultancy firm Futuresource (based on 2018 data), on average 7 mpcs projectors are being sold worldwide on a yearly basis of which approx. 25% sold to Europe. Assuming an average life of a projector of 10 years, the installed base in Europe is estimated on 17 million projectors. The continuation of mercury based lamps are needed to serve this base of existing projectors with spare parts and avoid turning it into electronic waste before due time.

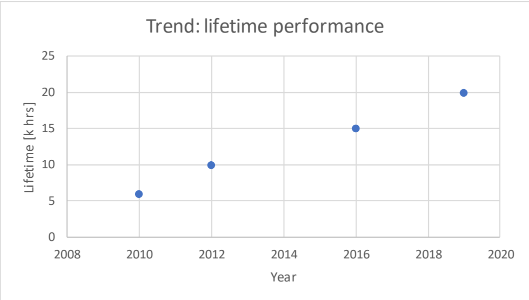
Based on the above, it should be concluded that for both the initial market and for the existing installed base of projectors, the continuation of mercury-based lamps for projection is needed.

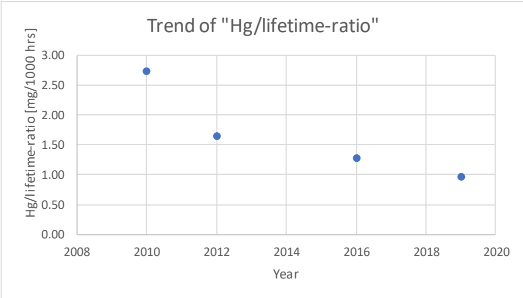
Projection applications are very demanding for the light source. In order to reach sufficient brightness, the light of the lamp has to be efficiently collected onto the imaging display. This can only be achieved with a lamp that resembles a point source, i.e. a lamp with a high luminance and a short arc.

For these UHP (Ultra High Pressure) lamps, the high luminance of the plasma is reached by using pure mercury (1) at a very high pressure (2).

(1) The fact that only mercury is used, results in the best luminance arc: compared to lamps with spectrum additives (high performance metal halides), the luminance is a factor of 2 higher[16]. Next to that, in a pure mercury gas it is possible to design a halogen cycle which keeps the wall clean. This is necessary to obtain long lifetimes with lamps of small sizes. Mainstream projector lamps currently have lifetimes of 5000 to 20000h, whereas typical high-performance metal halide lamps (with a lower pressure less mercury reach around 1000h.

Evolution of UHP lamps: UHP lamps are constantly being improved to reach longer lifetime to have less Hg consumption in the market, as shown in graphs below:





(2) The high pressure reduces the load on the electrodes by reducing the current and serves as a buffer gas to insulate the arc from heat losses. The high-pressure limits diffusion of tungsten atoms away from the hot electrode. Next to the halogen cycle, these properties are required to enable long lifetimes compared to other high luminance lamps. The high pressure also improves the spectrum of the lamp so that it matches the required output spectrum for good picture imaging (according REC709 standards). The good color quality is due to the

[16] New UHP Lamp Technologies for Video Projection, Holger Mönch, 2001, *SID-ME Meeting on display Materials and Components Fall 2001* LightingEurope

extreme pressure and the *Bremsstrahlung* (i.e. deceleration radiation) generated by collisions of electrons with mercury atoms[17].

Special application of projection lamps (rear projection)

The domain of projection lighting can be split in 2 technologies, both using the same lamp solution:

- Front Projection Applications
- Rear Projection Applications

Front projection application, typical called projector or beamers are already discussed above and proves that the front projection is predominantly using and requiring high pressure mercury short arc lamps. Both for new applications as well as for the replacement market.

However rear projection (solutions with integrated screens) differs from front projection applications. The rear projection market could be split up in 2 market segments:

- RP-TV: Rear Projection Television
- Video wall application (stacking of multiple RPTV engines)

Rear projection TV

Video wall

Difference between front and rear projection

Front projection is typically used to project content on a separate screen. Most of the time the projector is positioned in front of the screen (hence the name). Rear projection applications

[17] Bremsstrahlung radiation from electron–atom collisions in high pressure mercury lamps, J E Lawler 2004 *J. Phys. D: Appl. Phys.* **37** 1532
Infrared continuum radiation from high and ultra-high pressure mercury lamps, J E Lawler, A Koerber and U Weichmann ,2005 *J. Phys. D: Appl. Phys.* **38** 3071

typically projects on a built-in screen (in the application, comparable to televisions) and projection device is located behind the screen (rear).

Currently, the high majority of rear projection systems has been transitioned to LED based TVs. However the existing applications still require replacement lamps. Same as with front projection aftermarket there is no retrofit solution available with LED. Meaning if you want or have to upgrade your system to a SSL solution, the entire application needs to be replaced by a new equipment. This has high socioeconomic impact as unnecessary waste is created, new equipment has to be produced and also the new equipment will contain small amounts of hazardous substances, even RoHS regulated substances in exempted applications (technical reasons see front projection). As rear projection is more comparable with a television system, the brightness is also specified in a different way compared to front projection. The luminance of the application is used to specify the brightness output, candela per square metre (symbol: cd/m2) Most of the times nit (symbol: nt) is a non-SI name also used for this unit (1 nt = 1 cd/m2).

Example of control room

Lamps for stage lighting and other cultural and entertainment purposes:

Lamps for projection under exemption 4f include not only lamps used in projectors, but also for studio and stage lighting. They are essential in concerts, shows, theaters, studios and also film sets. Discharge lamps are used in the entertainment industry for high powered automated fixtures (moving lights) and follow spots (high powered lights specifically used for 'following' a performer from a long distance away operated by a human operator). For theatrical performances, there is an artistic requirement to have a very bright source. Touring shows use a lot of small discharge lamps which are very efficient.

An illustration of this lamp is shown in the picture below.

The lamp power of these kinds of lamps varies between 100W and 650W. Luminous flux goes up to 33000 lm (depending on lamp wattage and aperture size of the measurement device). The very small arc distance of 0.7mm towards 1.5mm enables a very high beam intensity.

The lamps are used in equipment that have a much longer lifetime than the lamps themselves have. Thus, the lamps must remain available on the market as spare parts:

- For new equipment as there are none or nearly no alternatives available in the EU market
- For equipment in the field to replace end of life lamps, in order to avoid unnecessary equipment turning into electronic waste before due time. The typical weight of an entertainment fixture varies between 20 and 35kg.

LightingEurope is aware of the difficulty to unambiguously classify certain lamps in the category set out by RoHS legislation. For lamp producers it is essential to have legal certainty regarding the possibility to put the products on the market irrespective of the planned application as we are not able to control the use of the lamps in products. While for general lighting it is more comprehensible that they cannot be considered as “spare parts of a luminaire”, application specific special purpose lamps indeed can be considered also as a spare part (or consumable) in certain applications such as entertainment fixtures.

The compact and lightweight design of the lamps provides OEMs the freedom to create small and light fixtures, which can be used at any location on stage. Although the lamps are small and light, they can create powerful light beams.

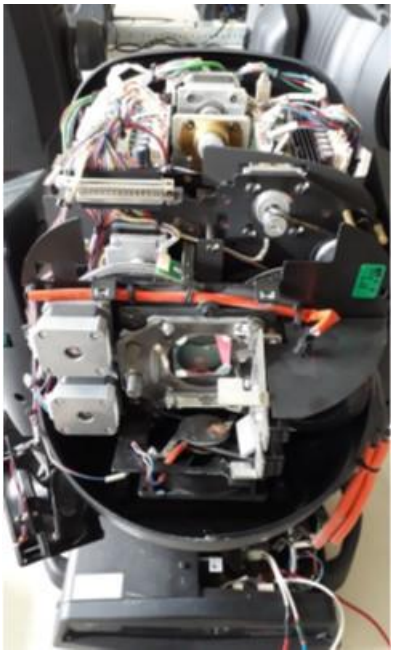
The combination of the short arc, a dedicated reflector and a high color temperature, produces a sparkling, high beam intensity. The lamps also offer long and reliable lifetime, high efficacy and fast replacement times.

The lamps are used in dedicated fixtures, developed specifically for these lamps.

The complexity of these fixtures is high, combining a dedicated lamp holder, dedicated cooling and dedicated optical system.

- Lamp holder: in order to get the best performance, it is very important that the lamp is aligned very well in the fixture. Therefore, the fixture has a dedicated lamp holder, depending on the reflector type that is used.
- Cooling: in order to reach optimal performance over life, the cooling of the lamp is very important. The requirements for the cooling design are dependent on the lamp design (lamp power, burner design, reflector).
- Optical system: the optical system is designed to achieve, in combination with the lamp design, optimal optical performance. Optical components as color wheels, gobo's etc. are used to create the desired optical effects.

An example of the complex inner design of a typical entertainment fixture is shown in the picture underneath. Because of the high complexity, the entertainment fixtures are quite expensive, typical prices are up to 14000€.



Within entertainment, 3 different fixture types can be distinguished: beam, spot and wash. Difference between these fixture types is the beam angle:

- Beam < 4°
- Spot between 5° and 50°
- Wash > 50°.

In reality, most OEMs make a combination of 2 or 3 types, the so-called hybrid fixtures: beam/wash (2-in-1) or beam/spot/wash (3-in-1).

Mainly in beam applications, the brightness level is extremely important. This high brightness (up to 28000 lm/mm²) can only be achieved by lamps with a very short arc.

In the most recent developments, there is a trend towards higher lifetimes (up to 6000h), resulting in a decrease of the Hg-consumption in the market (as lamps do not need to be replaced that often).

Lamps for Horticulture applications (High pressure Sodium lamps):

In horticulture lamps, the mercury broadens the sodium radiation from yellow light towards the red part of the spectrum and increases the efficiency of the lamp to stimulate the growth of plants and there is no available substitute technology that meets all the functional requirements of lamps in this application.

This exemption covers the High-Pressure Sodium (HPS) lamps for use in Horticulture, a member of the High Intensity Discharge Lamps (HID) group. The HPS lamps for Horticulture are designed to stimulate plant growth (examples are tomatoes, cucumbers, flowers). The lamps are illustrated below.

The efficiency of the lamps is not expressed in lumens/W, since the plant growth responds to the photons almost universally: each photon above a certain minimal energy is of about the same efficiency Research at universities and applied agricultural research stations has demonstrated that the rate of photosynthesis is related to the number of photons roughly between 400– 700 nm. This photosynthetic flux measures the total stream of light available for the plants: ‘Photosynthetic Photon Flux’ (PPF). This is expressed in micro mole of photons per second (μmol / s)18.

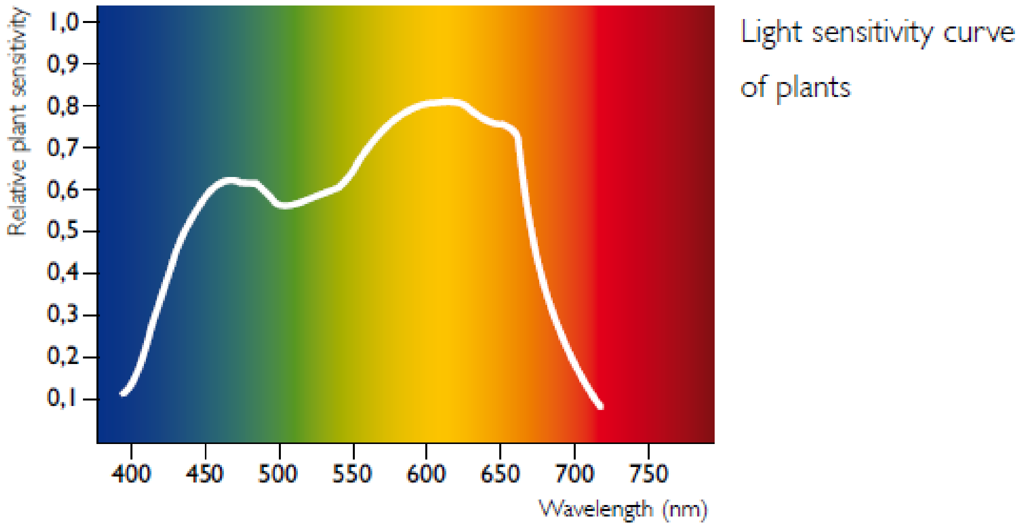


Figure 2: Light sensitivity curve of plants defining PPF

The efficiency of the system is measured as micromoles of photons per Joule electrical energy, which ranges from 2.1 (micro mole photons/Joule), for the most efficient 1000W lamp, to 1.6 (micro mole photons/Joule) for the 250W lamps.

Since plants are used to receive light from above, these lamps are mounted above the plants and should be as compact as possible. The small size is to avoid blocking the useful sunlight. The luminaire might block the light even when the growth light is not used, for instance during summer. The lamps are handled by technically skilled installers and sold by specialized distributors or as part of lighting equipment.

A recently found secondary effect, is the irradiation with infra-red light. Many crops benefit from infrared radiation from above (from the direction of the sun), especially during the winter. The flux depends on the plant, but for tomatoes it is about 25-30 W/m^2 which is easily provided by the HPS lighting. In LED lighting this radiation is absent. In modern greenhouses the HPS lamps are combined with LED lamps both for their own purpose[19].

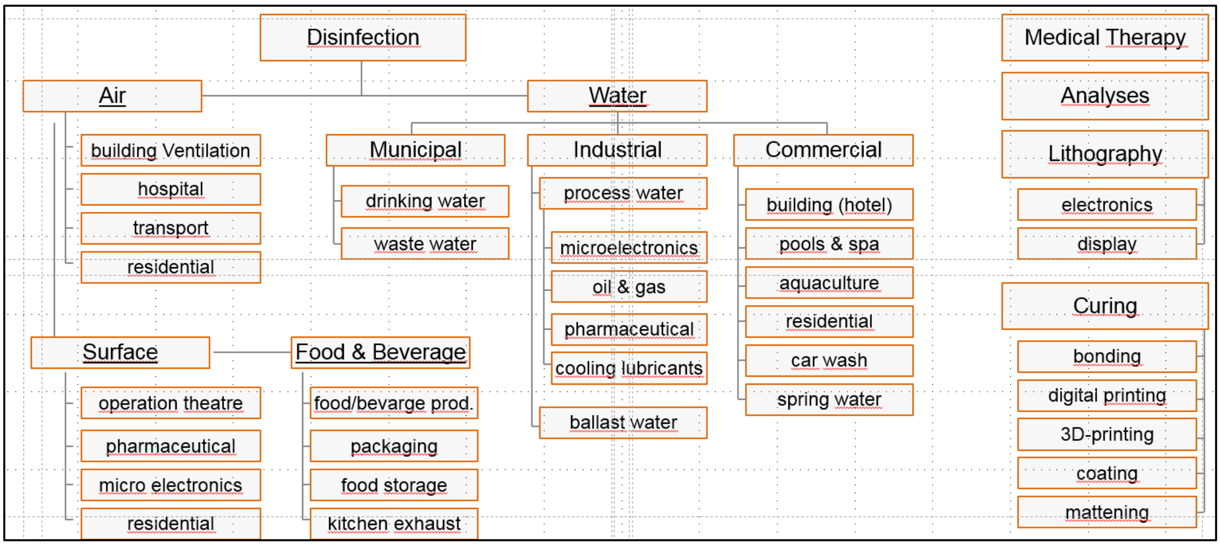
[18] Accuracy of quantum sensors measuring yield photon flux and photosynthetic photon flux. Barnes C[1], Tibbitts T, Sager J, Deitzer G, Bubenheim D, Koerner G, Bugbee B, HortScience. 1993 Dec 28 (12):1197-200.
[19] http://www.energiek2020.nu/fileadmin/user_upload/energiek2020/onderzoek/licht/docs/Warmtevraagstuk_led_in_tomaat.pdf http://www.energiek2020.nu/uploads/media/Stralingswarmte_en_led.pdf

The customers are farmers with greenhouses, especially greenhouses that are equipped with cogeneration equipment to generate their own electricity and use the CO_2 and heat produced in this process to stimulate growth of the crops.
De Groot and Van Vliet[20] give a comprehensive review of the operation principles of the HPS lamp. Further developments are discussed in a paper by Geens and Wyner[21].

High Pressure Sodium lamps are characterized by very long life (30,000 to 50,000 hours) and very high luminous efficiency (from 80 lm/W to 150 lm/W). HPS lamps can only operate on designated drivers that switch the lamp on and regulate the power. These drivers can be an electro-magnetic ballast (inductive/capacitive load) to stabilize the lamp current in combination with a high voltage pulse generator (ignitor) to ignite the lamp. Nowadays, also electronic drivers are used to stabilize the lamp at the correct power.

Lamps emitting light mainly in the ultraviolet wavelength range

UV lamps are required for many industrial and commercial processes and markets. The picture below gives an overview of different uses of low, medium and high pressure UV lamps.



Medium pressure UV lamps

Medium pressure ultraviolet curing lamps are utilised in special purpose industrial accelerated curing applications, disinfection and surface modification processes. Typical examples include, but are not limited to, sheet fed printing, digital inkjet printing, semiconductor, applications in wood, glass and plastic finishing, metal decorating, fiberoptics, CD manufacturing, electronics, and in water, air and packaging disinfection processes.

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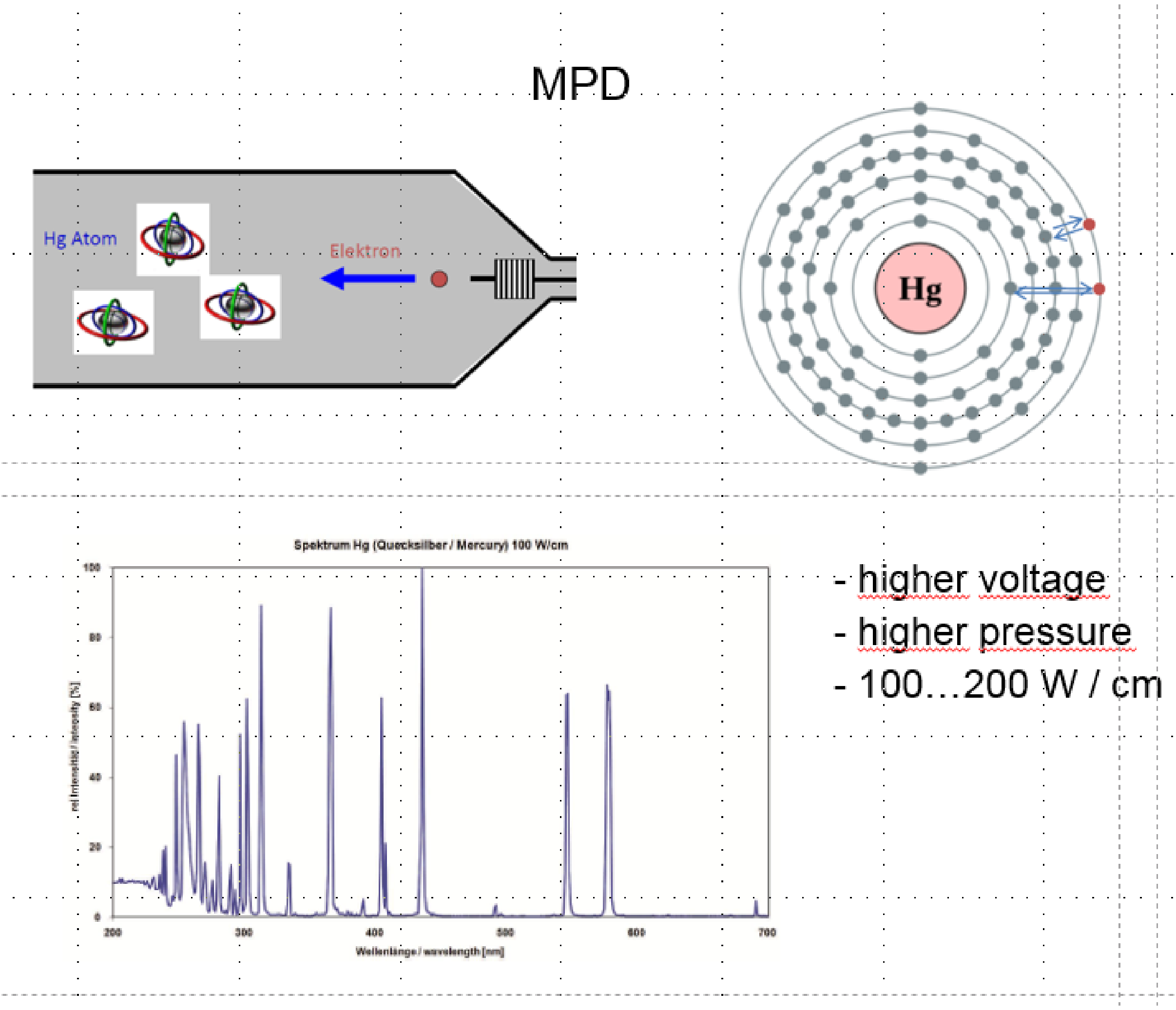
[20] J.de Groot and J. Van Vliet, The High Pressure sodium lamp, Kluwer Techische Boeken B.V. Deventer, ISBN 9020119028 (1986)

[21] R. Geens and E. Wyner, Progress in High Pressure Sodium Lamp Technology", IEE Proceedings-A Vol. 140 No. 6, November 1993

They contain a mixture of mercury and argon gas inside a sealed quartz tube. In operation, this mixture is heated to create a stable, mercury plasma which emits radiation at specific wavelengths within the UV range (100-400nm), and which are characteristic of mercury. UV curable inks, coatings and adhesives are formulated to absorb the UV light at specific wavelengths by selecting photo initiators whose absorption profiles match the emission spectrum as closely as possible. In germicidal applications, the spectra have to be optimized to match the wavelengths required for cell deactivation.

Medium pressure discharge lamps use differs from low pressure discharge:



Medium pressure UV lamps – examples in pictures	Medium Pressure UV Lamps for Curing
 	These lamps are used in particular where fast and reliable curing of coatings, inks and adhesives is required and where a durable, scratch-resistant, abrasion-resistant and/or chemical-resistant surface is required. Examples of this are: • Curing of inks and coatings in printing processes • Curing of coatings on furniture, decors (floor coverings) and wood/MDF • Curing of coatings for other highly stressed products/components (e.g. lenses, fibre optic cables, parts in automotive, plastic housings) • Microlithography in semiconductor manufacturing These lamp types are also used for bonding processes, e.g. for displays or for medical products (e.g. syringes). Further application examples are the curing of encapsulated casting compounds for electronic components or the curing of silicone papers. Some of these UV lamps are doped (e.g. with iron) to adapt the radiation spectrum to the process. **Medium pressure UV lamps for disinfection** These lamp types do not differ in design significantly from the lamps used in UV curing. They are used to disinfect water, surfaces and air. Examples of this are:

 	• Disinfection of drinking water, process water, waste water or ballast water • Disinfection of machine surfaces and packaging materials/products in the pharmaceutical and food industries • Air disinfection in heavily frequented areas such as hospitals and airports

Short Arc mercury lamps

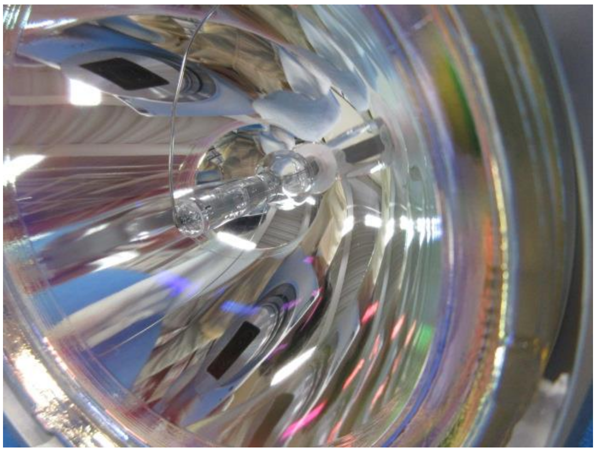
Short-arc lamps contain a mixture of mercury and xenon gas inside a sealed quartz tube. These discharge lamps are available in wattages from 50W to 35000W for dc or ac operation, depending on the type. When the high-wattage lamps are at room temperature the mercury is generally present in the form of small metallic droplets in the discharge vessel (bulb). When the lamp is started, the mercury vaporises as the temperature in the bulb rises and heats up in the arc between the electrodes to around 10,000 °C. The temperature on the inside wall of the bulb is around 800 °C. When thermal equilibrium is reached (which may take from 1 to 10 minutes after the lamp has been switched on, depending on the type of lamp) the mercury vapour exerts a pressure of about 30 to 70 bar on the bulb, depending on the type of lamp.

As with all short-arc lamps, material is lost from the tips of the electrodes during normal operation. This not only causes the bulb to blacken but also increases the gap between the electrodes and therefore increases the lamp voltage. To avoid overload operation, dc operated short arc lamps may only be used with constant output control gear (mains rectifiers); ac operated lamps may only be used with suitable reactors. High pressure mercury short arc lamps are used in medical as well as industrial applications such as:

- Microlithography (also known as photolithography) for producing among others integrated circuits on silicon wafers, ie, semiconductors including light emitting diodes (LED), liquid crystal displays (LCDs) and printed circuit boards (PCBs).
- Visual and fluorescence microscopy in medical, life science and industrial uses,
- Irradiation for photo polymerisation (used in manufacturing processes for, among other things, efficient printing ink, reliable adhesives and effective compound materials)
- Boroscopy (used in particular in the aviation industry as part of maintenance work on turbines, engines and other technical equipment)
- Curing of Adhesives and Composites e.g. if high irradiation level is required for short curing times in dental and industrial applications.
- Analytical and diagnostic processes
- Medical fiber optics for illumination of organs and tissues
- Dental curing

<u>Other High Pressure Mercury lamps for special purposes</u>

High pressure mercury lamp, high pressure mercury xenon lamp

Lamps and light sources for medical, industrial, research and development, are used for:

1. testing and qualitative and quantitative analysis with utilizing specific wavelength;
2. color comparison, observation, inspection with utilizing wavelength range from ultraviolet to infrared.

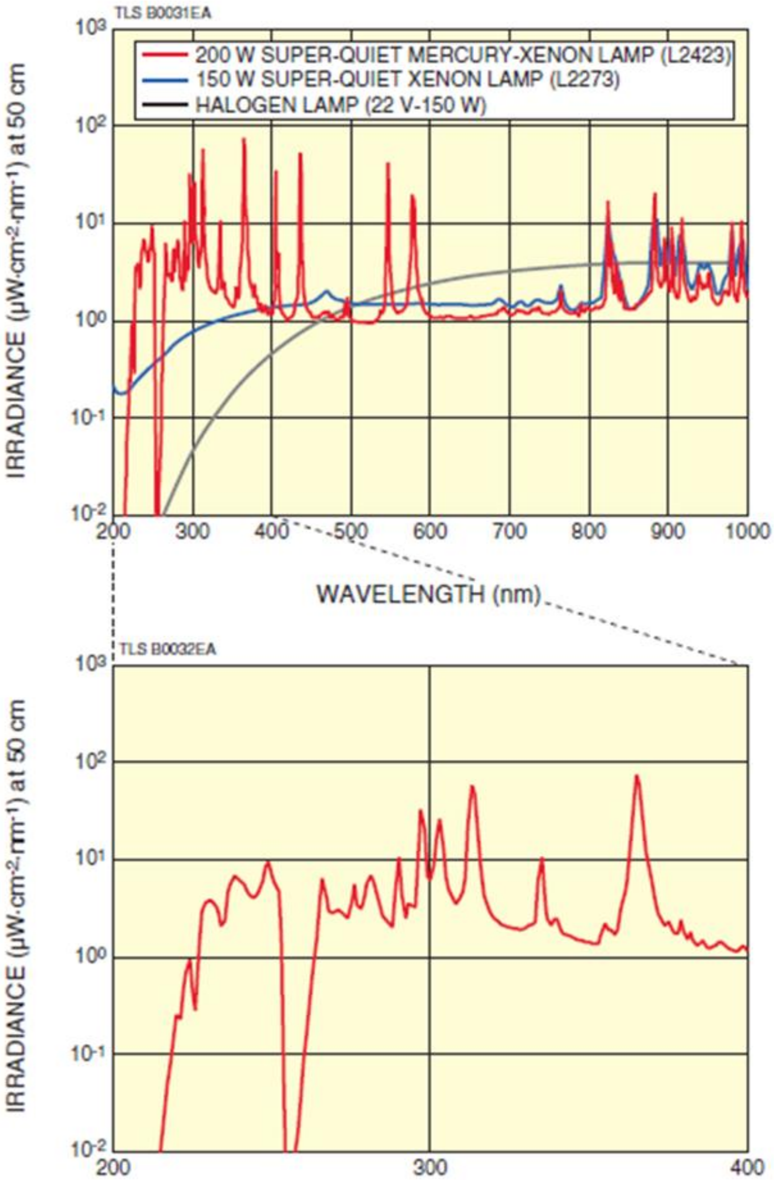
In order to carry out those applications, multiple specific wavelengths, high-intensity, and a spot light source are required.

At present, only mercury (or combinations of mercury and the other elements/substances) in a single light source achieves the applications of No.1 and No.2. As these lamps are manufactured in various sizes and power consumption corresponding to equipment, it is impossible to determine the definite amount of mercury limit value.

Unlike other lamps, a lamp is capable of emitting high-intensity light over a wide wavelength range with a very small bright spot size.

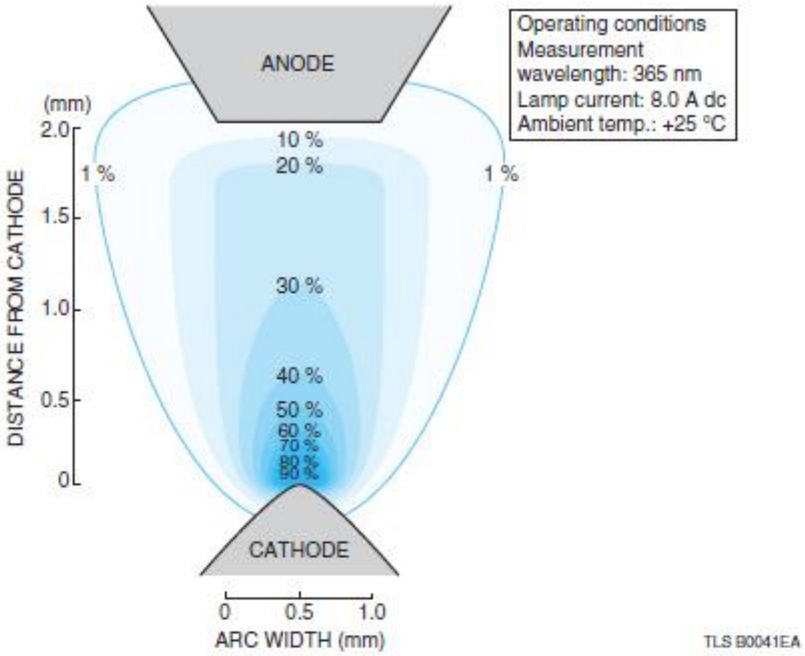
Mercury lamps have several strong bright line spectrums from ultraviolet to visible light wavelength caused by mercury. In addition, mercury-xenon lamp which contains xenon gas into mercury lamp has continuous spectrums from ultraviolet to infrared caused by xenon gas. For these reasons, mercury containing lamps can have sufficient high intensity which are required for variety of applications in broad wavelengths. Moreover, mercury containing lamps has a feature of high intensity point source. As physics law, the intensity of light from a light source is inversely proportional to the square of the distance from the source. Thus, if it needs sufficient intensity of light, the distance from a light source to object must be shorten. It is impossible to close the distance from light source to object in certain applications mentioned above. In consequence, point source of light by mercury containing lamp is the best way for those applications.

Spectral irradiance:



Point source of light output distribution

Note: Maximum light output intensity is more intense around the cathode and decrease towards the anode.



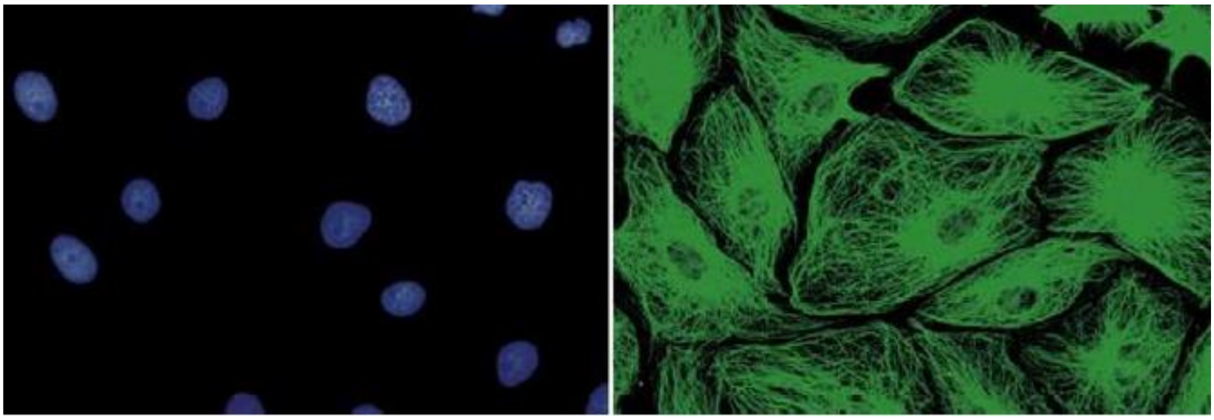
Examples:

Microscope

Semiconductor Inspection Devices

microsurgical systems

Fluorescence Microscopy (observation of fluorescence and capturing of image),



Liquid Chromatograph Detectors

(OR Detector, CD Detector)

Optical and spectrophotometric products

(Polarimeter)

Genomic Research equipment

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5. Information on possible preparation for reuse or recycling of waste from EEE and on provisions for appropriate treatment of waste

(A) Please indicate if a closed loop system exist for EEE waste of application exists and provide information of its characteristics (method of collection to ensure closed loop, method of treatment, etc.)

In the EU all lamps (and equipment in which they are installed) are subject to Directive 2012/19/EU (WEEE) and the respective country specific implementation of the Directive. Products using Mercury containing lamps have to be dismantled, the lamp has to be removed for separate treatment according the mentioned legislation, e.g. projector lamps have to be removed from projectors prior to further recycling or shredder processes.

The lamps covered by exemption 4(f) are used in a wide variety of applications which have different waste routes. By far most of these lamps are in use by professional/commercial customers in industry, municipalities, authorities etc.. This equipment is usually not disposed of in household waste, due to its large size, but is collected mainly by business-to-business collection schemes set up according to WEEE legislation. Only a small portion could end in private households in projectors. Projectors in private households have been widely replaced by big TV screens.

Lamp type	Field of use (industrial, commerce, domestic etc.)	Collection scheme
High Pressure Short Arc Mercury lamps	Industry, scientific institutes, hospitals	National collection schemes according WEEE legislation, contractual recyclers of commercial customers
Lamps for projection, studio and stage lighting purposes	Commercial public and private customers	National collection schemes according WEEE legislation
High Pressure Sodium lamps for horticulture lighting	Industrial, commercial customers	National collection schemes according WEEE legislation, contractual recyclers of commercial customers
Medium pressure UV lamps	Industrial, commercial customers	National collection schemes according WEEE legislation, contractual recyclers of commercial customers
Other medium and high pressure lamps for special purposes	Industrial, commercial customers	National collection schemes according WEEE legislation, contractual recyclers of commercial customers

Table 3: All lamps covered by exemption 4f are in the scope of the WEEE directive 2012/19/EU.

All lamps are covered by the scope of WEEE. Therefore for all lamps there is a commitment to a closed loop recycling process. Lamp manufacturers within Europe describe the procedure for disposal of these lamps within their product manuals and state that only certified organizations have permission for recycling. This will ensure the recycling process.

<u>Statistics for recycling of lamps used in electronic equipment</u>

With reference to question no. 3 of this section on the quantity of RoHS substance in EEE waste we would like to note the following:

- Lamp producers have little influence on the actual disposal route OEMs of lighting equipment promote end users select for products containing lamps. PLamp producers finance and partially steer collection schemes and such schemes typically contract recyclers to perform the treatment. Alternatively, equipment producer directly contract recyclers e.g. in the B2B take-back. This is especially the case if lamps are imported by equipment producers.
- Recyclers are mandated to remove any gas discharge lamps from products (WEEE Annex VII requirement). Recyclers collect such removed lamps, combine them with

other lamps and hand them over to lamp recyclers. No statistics on the origin of the lamps is made[22].

- Equipment producers are required to provide treatment relevant information to recyclers (WEEE Art 15 & Annex VII) to facilitate environmentally sound treatment.
- Statistics on the type of equipment collected and treated, partially backed up by sampling, are not detailed enough to break down specific electrical and electronic equipment and estimate this on a European basis[23].
- Therefore, equipment producers do not have European data on end of life statistics on electrical and electronic equipment becoming WEEE and in particular on lamp treatment and their final disposal.
- Lamps which have to be replaced become waste during equipment can be brought free of charge to the respective WEEE collection points

(B) Please indicate where relevant:

☒ 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

This statement only refers to the lamps used in electrical or electronic equipment, not to the EEE. Recyclers are mandated to remove any gas discharge lamps from products.

(C) Please provide information concerning the amount (weight) of RoHS substance present in EEE waste accumulates per annum:

☐ In articles which are refurbished
☒ In articles which are recycled < 250 kg
☐ In articles which are sent for energy return
☐ In articles which are landfilled

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[22] Information from recyclers on recycled weight of products containing mercury is that the data is not split down by the brand of the product or even the compliance scheme. They recycle mercury in large batches that are mixed from different sources; the majority of mercury comes from public street lighting.

[23] Reports from compliance collections schemes only details the amount of mercury in total collected from WEEE. See example compliance scheme report from Switzerland http://www.google.co.uk/url?url=http://www.swicorecycling.ch/downloads/dokumente/technical-report-swico-sens-slrs-2013.pdf/1400&rct=j&frm=1&q=&esrc=s&sa=U&ei=0kgAVP7uOcjcPYbrgcAH&ved=0CBQQFjAA&usg=AFQjCNGVOdg1ECkVykqDSTAYOAszUgPSAA page 15 showing less than 0.00% mercury collected from all WEEE

As stated above, there is no suitable statistical data available. All products come under the regime of WEEE take back obligations. With reference to table 2 above and according the information and data available for LightingEurope 240 kg mercury might be put on the market in lamps falling in this exemption. As the lamps covered by exemption 4f are nearly exclusively in commercial, industrial and professional uses a high collection rate for these lamps is assumed.

6. Analysis of possible alternative substances

(A) Please provide information if possible alternative applications or alternatives for use of RoHS substances in application exist. Please elaborate analysis on a life-cycle basis, including where available information about independent research, peer-review studies development activities undertaken

Substitution of mercury in lamps

Alternative chemical elements for mercury either lack the required vapour pressure at a low enough temperature, or do not radiate efficiently upon collisions with electrons or react violently with the transparent quartz wall and block the light when the lamp becomes older.

All single elements, stable combinations of elements and stable compounds with suitable vapour pressure, have been evaluated as possible alternatives to mercury and none give either the same broad UV spectrum nor the required wavelengths with sufficient intensity to perform the necessary functions. Therefore, the only potential future alternatives to use of mercury could be from different technologies.

The suitability of alternative technologies, as far as available, differs per application. Alternatives for horticulture lighting differ from alternatives for water purification and projection lamps.

Application with alternative technology

Equipment using lamps covered by exemption 4f are increasingly replaced by alternative technologies, mainly based on LEDs and laser technology. On the other side for still many 4(f) applications there is no alternative technology with the same performance characteristics as those mercury containing lamps provide. Whenever mercury free technology is introduced this is done with completely new or redesigned equipment. Retrofit solutions based on LED or laser technology are currently not possible as described below.

Horticulture lighting alternatives:

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 lamp leaves the burner as radiation (visible light, infrared radiation and some UV) the temperature of the luminaire and the lamp is stabilized without the need for heat sinking.

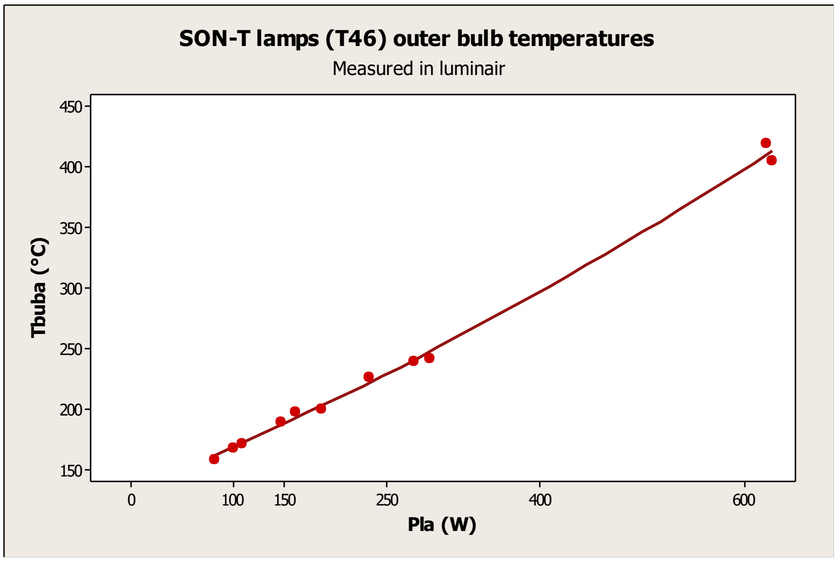

Figure 3: Measured temperatures of the outer bulb of HPS lamps of various power.

The glass surface of the outer bulb of the lamp is heated by conduction of the heat generated in the burner (10% of the supplied power) and by absorption of half of the infrared radiation from the burner. In total the glass envelope is heated by approximately 40% of the lamp power[24 25].

As argued in the introduction, the infrared radiation generated by the hot HPS lamp is not lost, but is beneficial to the plants too. The heat stimulates plant growth during the cold winter season.

For the currently available most efficient LED lamps, the power that is transformed into light is about 40% and there is no IR or UV. 60% of the electrical power is transformed into heat and has to be removed by convection/radiation to the surrounding air in the closed luminaire. This makes the design of the luminaire difficult especially since the environment temperature in the greenhouse is high and the size of the luminaire is limited because of the demand to minimize blocking of direct sunlight.

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24 Jack, A.G. and Koedam, M., "Energy Balances For Some High Pressure Gas Discharge Lamps," Ilium. Eng. Soc., July 1974 (other reference needed: Thesis A. Rijke)

25 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.

The heat loss of the most efficient LED's is higher than of HPS lamps. So measurement of the envelope temperature of the HPS lamps in a luminaire will predict the temperature of the envelope of the future LED lamp with the same size. Since the transport of heat in a lamp via the lamp base is limited, the only path for the heat to disappear is via conduction to the air surrounding the lamp. 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 the closed luminaire limits the cooling opportunities.

Figure 3 gives an indication of the measured surface temperature of HPS lamps of different power. The 1000W lamp is even warmer and is measured around 700°C.The LED retrofit lamps will reach at least the same temperature. This surface temperature from 400-700°C is much higher than the optimal LED junction temperature of 100°C. This means that LED replacement lamps with the same size as the current HPS lamps cannot exist in the coming decades or that the emitted light flux is lower and/or the lifetime is limited.

Moreover, there is an issue with safety and responsibility of a luminaire where the HPS lamp is "retrofitted" with an LED lamp. HPS lamps are operated on electrical systems that generate high voltage pulses to ignite the lamps. These ignition pulses are typically 1800V-3300V. The igniters must be taken out of the system (if not integrated in the electronic driver) and rewiring in the luminaire is needed if LED's would be designed to replace the HID lamps. The installer needs to take the responsibility for safe replacement and needs to label the luminaire accordingly. For the moment, this replacement scheme is hypothetical as no LED replacements are available for the high-power horticulture lamps.

Suitability of alternative technology as spare part

It is not possible to replace the mercury containing lamps in existing equipment by alternative technology. Lamps must be replaced almost each year in the greenhouses. The replacement lamps must fit into the existing fixture, and must deliver the same performance, safety and reliability, which the equipment was designed and tested for.

It should also be recognized that lamps are consumable items that are mainly utilized in high value equipment which is already in service. The systems were designed for mercury lamps and there is no alternative chemistry that will produce a suitable spectral output that will operate with the power electronics contained within the existing luminaire.

Hence, even if a new technology becomes available in the future, there will be a requirement for sodium/mercury lamps as replacement spare parts for existing installations for a considerable period.

As luminaires LED solutions are now entering the market in 2019 also for top lighting, this demonstrates that this industry is working on alternatives for HPS systems. These are in an early stage and require adequate budgets at the growers.

Figure 4 LED luminaire for horticulture lighting

Mercury-free lamps for projection purposes:

Replacement of mercury

Hg free discharge technology based on Zn has been developed[26]. For projection applications, this technology is not suitable, due to a too low metal gas pressure which leads to a low lamp voltage. This results in low energy efficiency. Efforts have been made to develop a high pressure Zn discharge lamp, in order to reach reasonable energy efficiency in a projection application. These efforts have been stopped because there was no technical solution to cope with the required extreme high operating temperatures.

Furthermore, the zinc atoms violently react with the quartz, damaging the transparency. The loss in transparency reduces the brightness of the source and makes the lamp unfit for the application. This makes zinc no alternative for mercury.

[26] Patent WO2006046171

Xenon-lamps can offer the required high luminance for projection purposes, but they suffer from very low energy efficiency. Xenon-lamps are by about a factor of 4 less efficient than Ultra High Pressure-lamps, leading to much larger lamps. As a result, they are used in very limited projection applications[27].

Solid state technology

For projectors, the ANSI Lumen (Lm) level on the screen determines the market segments. It is regarded as a basic requirement for a projector to have at least 2000 ANSI Lm brightness level. There are multiple other values being used to compare screen brightness, but ANSI Lm[28] is considered the standard (eg. LEDlumen[29], marketing lumen, others[30]) For lit environments, a brightness minimum level of 3000 ANSI Lm is regarded as the standard. All projectors between 2000 and 5000 Lm are defined as mainstream projectors.

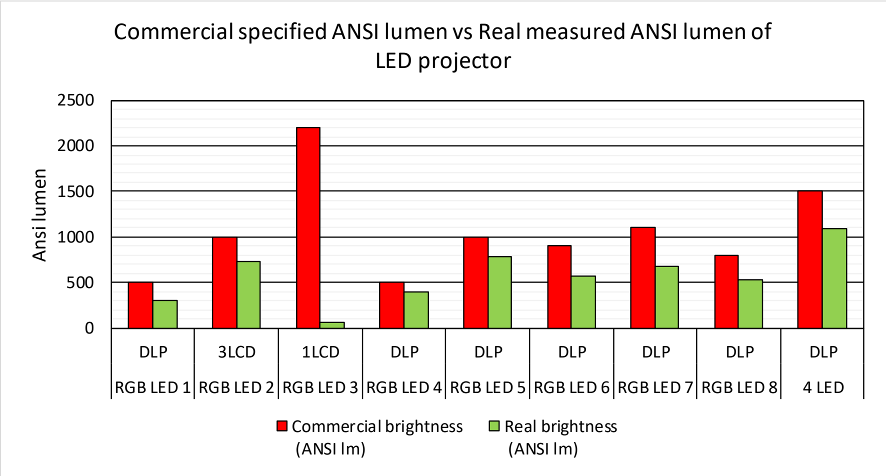
Some projector producers have started several years ago to use solid state light sources within a limited area. These can be categorized as: White LED (1), Scanning Laser (2), RGB LEDs (3), LED/Laser (-phosphor) Hybrid (4), Laser-phosphor (5) or RGB Laser (6), RGBB LEDs (7), HLD (LED) (8)

White LED (1) and Scanning Laser (2): these technologies will not be able to alternate the conventionally mainstream projectors mounted with mercury containing lamps. The luminance level of White LEDs (1) is too small to reach more than 500 Lm. For Scanning Lasers, safety requirements limit the scanning beam intensity. Usage of both White LED (1) and Scanning Laser (2) will be limited to the pico projector segment.

RGB LEDs (3) used for projectors are a surface light source and have a limitation in luminance level. High luminance is required for optical imaging. It does not add value to increase total light flux by increasing the light emitting area, which is a typical design choice for LED illumination. As a result, light intensity is limited when RGB LEDs (3) are used as a light source in projectors. The range of RGB LED projectors currently available on the market only covers lumen levels up to 1500 ANSI Lm (commercially specified). The measured brightness level is currently still limited to around 800 ANSI Lm[31]. This means that RGB LEDs (3) do not play a role in the mainstream segment. To get to higher ANSI lumen levels RGBB LEDs (7) are developed to increase the ANSI Lm by adding an additional blue LED. (increase from 800 ANSI lm to 1050 ANSI lm measured)

[27] Proc. SPIE 5740, Projection Displays XI, April 10 2005
[28] ANSI/NAPM IT7.228-1997 Electronic Projection—Fixed Resolution Projectors (IEC 61947-1)
ANSI/PIMA IT7.227-1998 Electronic Projection—Variable Resolution Projectors (IEC 61947-2)
[29] Are "LED lumens" a Real Thing?, M. David Stone, December 15, 2017, ProjectorCentral.com
[30] 7 Epson Brings Suit Over RCA Projector Claims, Rob Sabin, April 4, 2019 https://www.projectorcentral.com/epson-sues-over-RCA-projector-claims.htm
[31] See product reviews at e.g. www.projectorcentral.com, e.g. projectors HD91, DG-757, LGPF85U, ..

Examples of internal measurements are shown below, proving that no LED projector are found reaching ANSI lumen above 1100.



The remaining laser-based technologies (LED/Laser (-phosphor) Hybrid (4), Laser-phosphor (5) or RGB Laser (6)) entered the market quite some years ago, but the penetration rate is low. For several years now, the level of projectors with hybrid or laser solution is slowly growing to approximately 7% (2018) of the total market[32]. This slow penetration rate can be explained by the technological difficulties to make laser-based projection systems:

For laser-based (incl. hybrid) projectors, the cooling of the semiconductors requires bulky, heavy and/or noisy cooling systems, which makes them unsuitable for mobile use.

For RGB Laser (6), a measure for “Laser speckle noise” has to be taken for laser illumination without phosphor conversion. “Laser speckle noise” is created by mutual interference of the laser’s coherent light waves and results in a varying intensity of light spots in the projected image. The suppression of the speckle noise is necessary for laser-based projectors. This is also applied to Scanning Laser (2). Measures for safety have to be taken, as the light source is a class 4 laser.

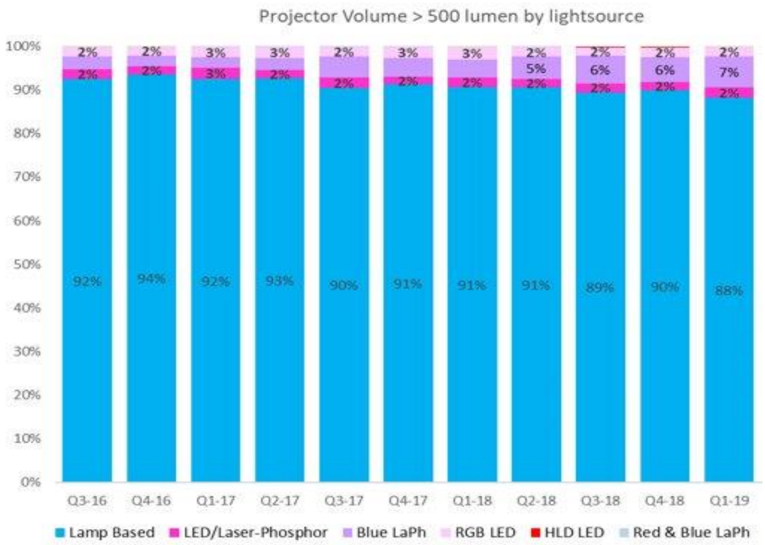
HLD LED solution (8) consists of HLD LED modules in combination with either 1 or 2 direct LED to create white light for projection. The HLD LED modules use a luminescent converter rod to convert blue LED light to green or yellow light with small etendue. This technique enables reaching higher ANSI lumen[33]

HLD LED technology is new technology currently in exploration phase with first application in the projector market. At this moment it is manufactured solely by one company only.

[32] Source: Futuresource-consulting
[33] LED light engine concept with ultra high scalable luminance: Christophe Hoelen

Conclusion: Solid state light sources ((1)-(8)) are not sufficiently mature to be used for mainstream projection purpose. Important remark: LED, Laser/LED Hybrid, and Laser light sources are not backwards compatible with projectors mounted with mercury containing lamps.

The graph below indicates the market penetration rate of the alternative technologies analyzed by FutureSource[34]



Graph with 2019 data

Retrofit solutions are neither possible nor available:

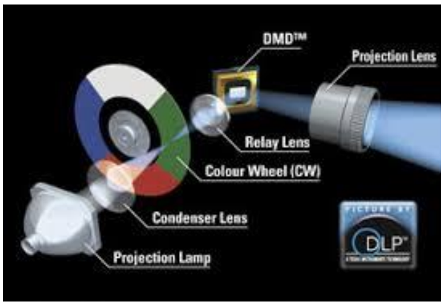
The mercury containing lamps used for projection in the existing equipment (projectors) are tailor made to the application/projector on form, fit and function. Consequently, no other replacement light source - besides mercury-based lamps - can fit in the projector. This is not at all like in general lighting where LED replacement bulbs are widely available. There are several reasons for this:

- Difference in projector architecture because mercury lamps emits white light and solid state need to combine multiple sources to create white light
- Different cooling requirement
- Different size of lightsource

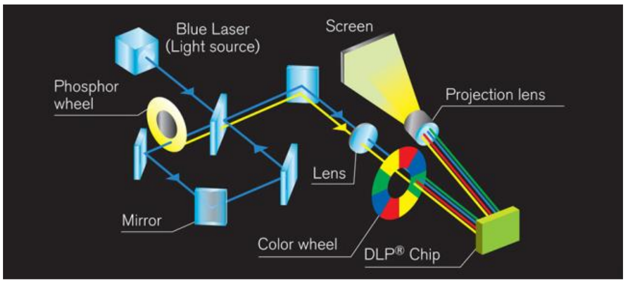
Difference in projector architecture because mercury lamps emits white light and solid state need to combine multiple sources to create white light:
A projector uses white light to project images on the screen. This leads to a difference in the architecture of a projector because solid state light needs to combine multiple sources while mercury lamps don't. The schematic below shows these differences. These differences are both valid for projectors based on DLP technology as well as for LCD technology.

[34] Source: Futuresource-consulting

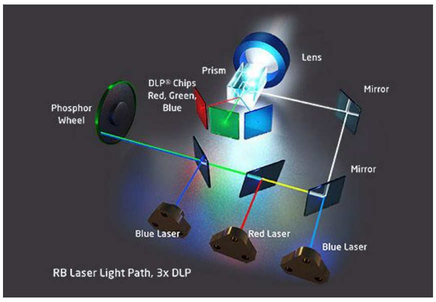
Typical examples of a DLP architecture



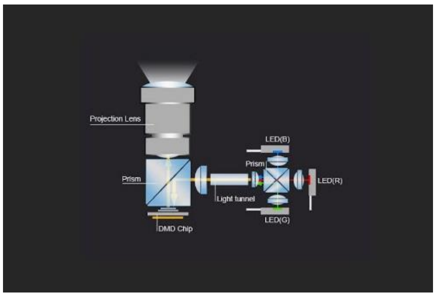
Mercury lamp DLP projector



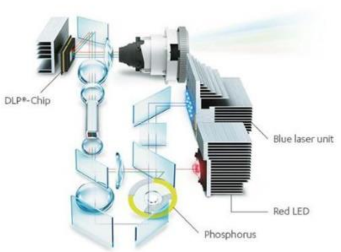
Laser DLP projector



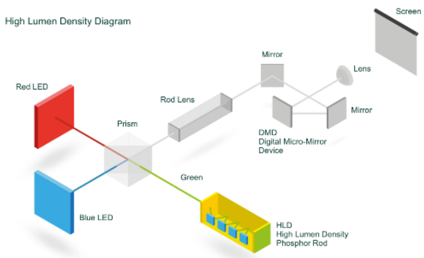
Laser DLP projector



RGB LED DLP projector

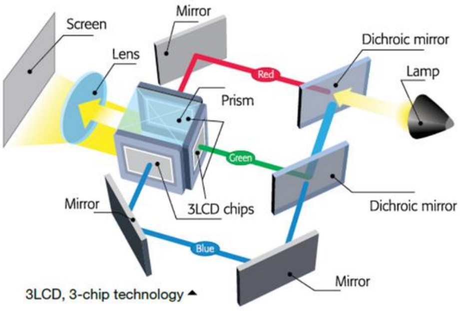


LED/Laser (-phosphor) Hybrid DLP projector

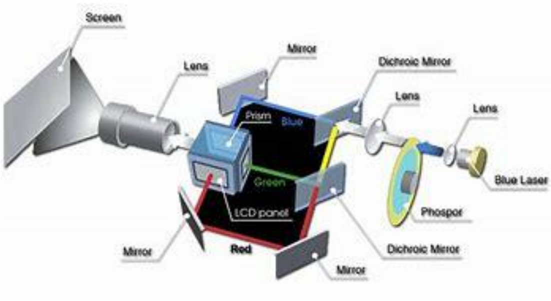


HLD LED DLP projector

Typical examples of an LCD architecture:



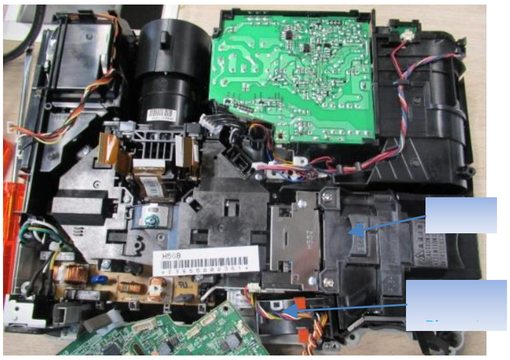
Mercury lamp LCD projector



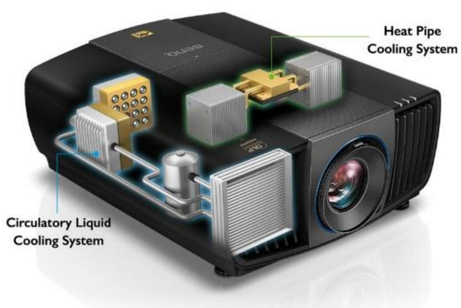
Laser LCD projector

Different cooling requirements

A mercury containing lamp requires direct forced cooling of the lamp bulb, while a laser or LED system is cooled via a heatsink or even via circulatory liquid cooling.



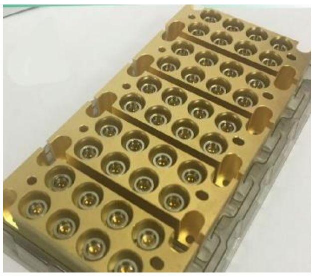
Mercury lamp projector cooling



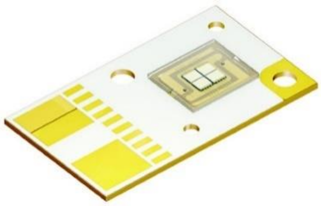
Laser projector cooling (11)

Different size of lightsource

A third reason why backward compatibility is not possible, is the size of the light source. A laser projector is typical equipped with grids of laser diodes in a flat plane. An LED projector is equipped with 3 high power LEDs. While a mercury light source consists of an arc tube with a reflector, existing in a large portfolio of different combinations of arc tubes and reflectors. These different technologies all require specific optics to focus the light output on the LCD or DLP panel, making it impossible to be backward compatible.



Laser diode grid



High power LED

Mercury lamp (bulb inside reflector)

Example of laser projector cooling:
https://businessdisplay.benq.com/en/findproduct/projector/installation-projectors/lk970.html

Alternative technologies for stage lighting, studio or entertainment

Solid state technology

Within entertainment, 3 different fixtures types can be distinguished: beam, spot and wash.

The difference between these fixture types is the beam angle:

- beam < 4°
- spot between 5° and 50°
- wash > 50°.

In reality, most manufacturers of stage, studio and entertainment lighting equipment make a combination of 2 or 3 types, the so-called hybrid fixtures: beam/wash (2-in-1) or beam/spot/wash (3-in-1).

Mainly in beam applications, the brightness level is extremely important. This high brightness (up to 28000lm/mm²) can be achieved by lamps with a very short arc. Even for the lowest power of the short arc lamps, the lumen output in beam mode is still higher than that of LED products (2000lm).

For wash and spot applications, LED is becoming more widely used.

Due to the fact that most of the entertainment fixtures are hybrid fixtures (beam/wash or beam/spot/wash) the main technology is still the short arc lamp containing mercury.

According to the commercial end-users of lamps used for studio and stage lighting, it is generally believed that it will be several years before an alternative light source will be found for the fixtures used in the larger arena & stadium based events as the LED technology is reaching its theoretical peak.

This is also true for theatres and other smaller venues. While the general trend is to replace mercury lamps (new moving lights are typically equipped with LED source and bright profile spotlights are most likely be replaced in the course of the next years), there are still applications needed to achieve certain artistic design objectives without acceptable replacements.

The biggest reason to switch from discharge to LED technology is the possibility to dim the source (not possible with discharge). But when high intensity and/or low density are required, it is technically not possible to replace discharge by LEDs. It should be noted that the adoption of alternative light sources will be rapid once they become available due to the high costs of the current lamps both in terms of the replacement lamps but also the maintenance required due to the high operating temperatures involved. Lower energy LED fittings are generally more reliable due to the lower temperatures and cheaper to operate due to the lack of a requirement for lamp replacement. Therefore, the discharge market is going down, but it will take time to be replaced.

Conclusion:

Solid state light sources are not sufficiently mature to be used for entertainment purposes in beam applications and hybrid applications (beam/wash version or beam/spot/wash). Additionally, these LED solutions are not backwards compatible with fixtures mounted with mercury containing lamps, due to following reasons:

- Different cooling requirements
- Different size of light source
- Operation on the existing control gear suited for short arc mercury lamps only
- Mercury lamps emits white light and solid state need to combine multiple sources to create white light

Laser technology

Only very recently (April 2019), a first fixture based upon laser technology has commercially been released to the market. The technology is however still very new within the entertainment market. The expectation is that the penetration rate of the laser technology will be rather low (among other because of cooling requirements and safety). (see images below).

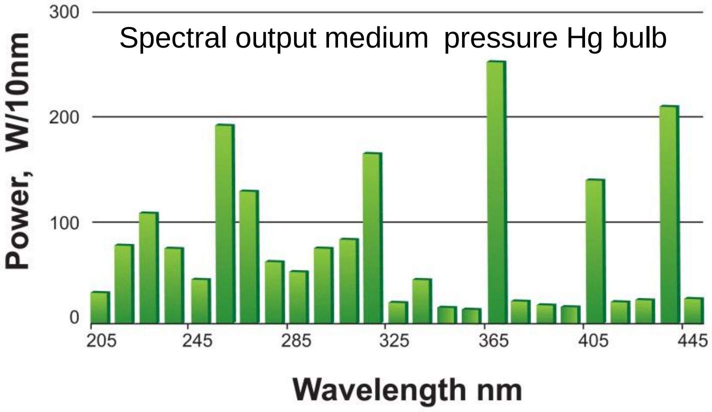
<u>Lamps for UV curing applications</u>

Although UV LED light sources are becoming commercially available as an alternative technology for medium pressure mercury lamps, there are significant limitations due to the spectral emission , viability on cost grounds and ease of replacement in the field.

Currently, medium pressure lamps containing mercury are used in a wide range of curing applications – including amongst others

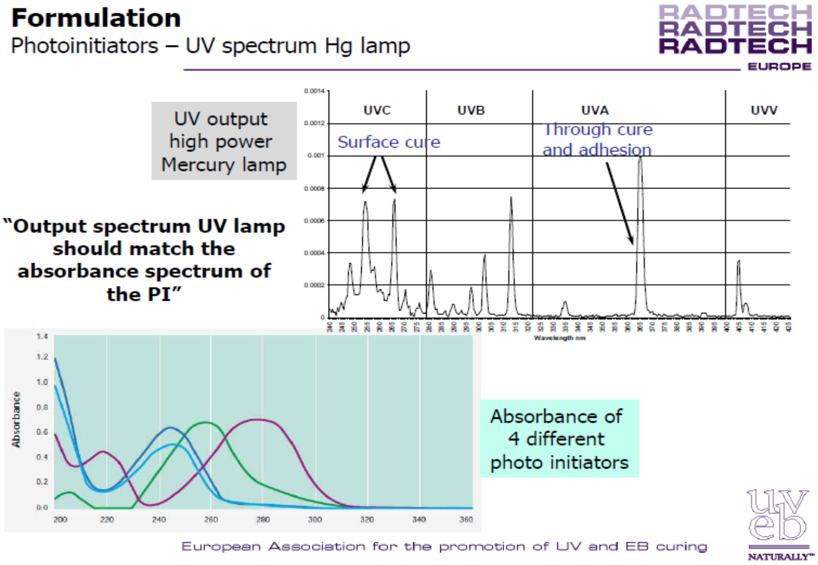
- curing of composites (e.g. glass-fibre)
- curing of paints, inks and adhesives in the automotive sector
- glass and plastic decorating (e.g. car interior, cell phones)
- wood finishing (e.g. curing of inside and surface of parquet, hardwood, wooden furniture)
- electronic components (e.g. PCB manufacture, bonding and sealing of displays, semiconductor fabrication, printed and flexible electronics)
- Curing of inks and coatings in printing processes (sheetfed offset, web offset, flexo, ink-jet, screen printing) on different substrates (paper, board, cardboard, foils, metal sheets, rigid and flexible materials, even shaped surfaces) for the printing and finishing of a for a very large variety of products (e.g. books, brochures, ad prints, posters, banknotes, credit cards, packaging materials, labels, signs, direct printed products, panels)

These applications are used in a wide range of well-known markets and industries. The inks, coatings and adhesives developed for these processes have been designed to respond very efficiently to the broad emission spectrum from the medium pressure mercury lamps (see picture below) to deliver a finished product that meets a wide range of very demanding product specifications.



Spectral output of medium pressure mercury lamps

The broad band emission from the medium pressure lamps is important because it allows the photo initiator, the component in a UV formulation that absorbs the light, to absorb a wide range of wavelengths and thereby enable the ink, coating or adhesive to deliver the required combination of properties. For example, in coatings on interior plastic parts for cars, a hard, scratch resistant surface is required and this is achieved by utilizing shorter wavelengths (280-320nm). Other required properties such as resistance to aggressive solvents or adhesion to plastic surfaces is supported by utilising longer wavelengths (320-365nm).

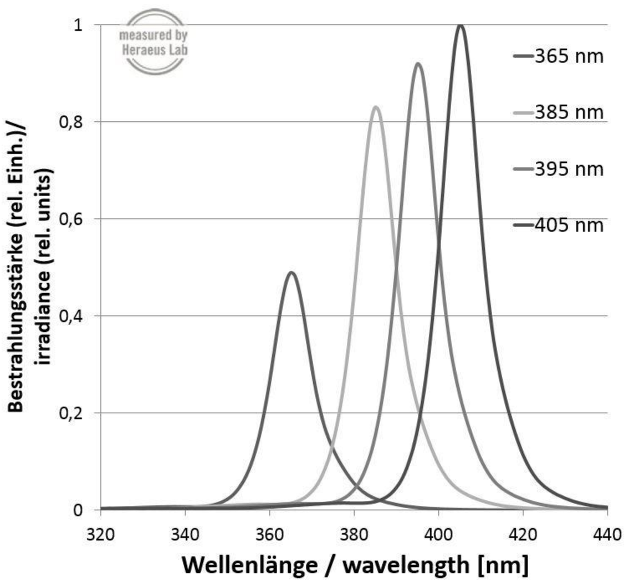


Spectral data of mercury based UV lamps

UV LED are a potential alternative technology that has been introduced into UV curing applications. However, to date their commercial success has only been on a relatively small scale, in some specific niche applications, where new inks are being developed that are optimized for the emission spectrum of the UV LED lamps. Nevertheless, after curing, the ink surfaces are not as robust and scratch resistant as with the mercury-lamp based systems as the availability of photo initiators that can be cured with UV LED is limited.

Examples where the use UV LEDs is already possible: adhesives in assembly operations such as PCBs in consumer goods; ink jet printing on labels or in wide format printing for point of sale displays; flexographic printing on heat sensitive films; in some coating applications in wood finishing, sometimes in combination with medium pressure mercury lamps.

One of the drawbacks of the UV LED is that the light is only produced in a very narrow band. UV LED lamps delivering 405nm, 395nm, 385nm and 365nm wavelengths are the most common, commercially available products. The most widely used products deliver 395nm and 385nm; these products have the highest output and the longest lifetimes.



Spectra of 4 different UV LED lamp types

Whilst, there has been growing adoption of UV LED light sources there are significant limitations due to the lack of viable UVB and UVC LED light sources. Short wavelength UVB and UVC is very important for coatings requiring hard scratch resistant surfaces required for example by applications such as coating plastic parts for the automotive industry. The highest performing UVC LED light sources currently have maximum output in the region of 20-60mW. Internal testing with various ink manufacturers indicates that output performance needs to be in excess of 250mW with similar cost per mW in comparison to a mercury lamp for full adoption to be possible. Taking this into consideration with current UVC LED development, it is likely to be a number of years (5-10 years) before viable UVC LEDs will be available.

Replacement / retrofit of UV LED lamps is not possible as the mercury lamps are used in special purpose equipment with existing controls, fixtures and cooling systems, which would not be compatible with an LED lamp. Furthermore, the process ink and chemistry is designed to work with the polychromatic mercury light source and would not be compatible with the LED lamp spectrum currently available. In addition, UV curing lamps have to be replaced several times over the life of the equipment. Hence, even if a new technology becomes available there will be a requirement for UV curing lamps as spare parts for legacy capital equipment for a considerable period.

Lamps for UV disinfection applications

UV energy can be used to disinfect water, surfaces and air by inactivating microorganisms such as bacteria, viruses, yeasts, fungi and parasites. The process reduces the pathogen count within seconds in an economic and environmentally friendly way without the need for the addition of chemicals. Furthermore, the UV process can be used to eliminate chlorine resistant pathogens such cryptosporidium.

Applications for water disinfection include municipal water treatment for household drinking water and sewage treatment, industrial water treatment for process water and also aquaculture and agriculture as well as ballast water for ships. Disinfection of air using UV is used to provide low germ air to improve hygienic and storage conditions in the pharmaceutical and food processing industries, clean rooms and highly frequented areas such as airports. Surface disinfection of packaging materials is also carried out by UV; for example, on filling lines for dairy products and beverages where cups, tops, lids and packaging foils etc are exposed to UV to kill germs on the surface. UV sterilisation of packaging is especially applied to sensitive food products (e.g. dairy products) as it increases shelf life in terms of consumer protection and food safety. Furthermore, in the food industry, equipment parts and transport containers are disinfected with UV.

UV disinfection is effective at wavelengths between 200-300nm, the spectral region for the most effective cell deactivation of the microorganisms. The germicidal action curve has a maximum at 265nm. UV-C radiation has strong bactericidal effect. It is absorbed by the DNA of the microorganism, destroys its structure and inactivates the living cells. Microorganisms are destroyed in a few seconds with UV radiation. Mercury vapor lamps used in disinfection applications (sometimes referred to as germicidal lamps) are designed to emit a narrow band radiation at a wavelength of 254nm. These mercury lamps have a wall plug efficiency of up to 50% for generating UV-C photons at 254nm. The stronger version, also mercury based, uses an amalgam to enhance the photon flux, but with a lower wall-plug efficiency of ~35%.

A possible mercury free solution could be a XeBr*- excimer lamp emitting at 282nm or a XeI*- excimer lamp emitting 253nm photons. In both alternative cases, the wall-plug efficiency is below 10%. So this is not a realistic alternative given the power consumption comparison with Hg lamps and the poor efficiency. Furthermore, the power supply technology is by far more complex and significantly more expensive compared to conventional ones used to drive Hg-based lamps.

Another alternative might be a Xe2*- excimer lamp emitting 172nm photons with an efficiency of up to 40%. A phosphor might convert the radiation into the germicidal range around 265nm. Assuming a quantum efficiency for the phosphor of 90% and the Stokes shift being ~65% the total electrical lamp efficiency will come down to ~23%. This low value might only be partly compensated by a larger germicidal action due to the wavelength. Lifetime values for the Hg-based conventional lamps easily exceed 10000h, which is very hard to be achieved with a 172nm based Hg-free version.

Currently, mercury free solutions, such as excimer lamps have only been successful in a few applications in niche markets. In some cases, Flash lamps have already been used for disinfection applications. Costs for Flash Systems are more than 5 times higher compared to systems with Hg containing gas discharge lamps as housing and cooling equipment is much more complex. The lifetime of Flash lamps is 2-3 times shorter than medium pressure lamps, which results in even higher costs and more electrical waste for replacement parts as the lamps have to be replaced more often. Moreover, Noise pollution when operating Flash lamps is high at the workplace and handling of photobiological safety is more complex due to the high intensity in UV radiation per flash. Retrofit of Flash lamps into existing applications is not possible.

The development of LEDs emitting in the ultraviolet spectral range is an ongoing trend but there are still no suitable substitutions available in the UVC range as the current R&D prototypes have a very low power output, low efficiency, low lifetimes and high costs.

Efficiency of UVC LEDs that are currently available is with only 3-5% not competitive to the efficiency of conventional mercury vapor lamps with an efficiency of up to 50%. Moreover, with an output of 50mW a huge number of LEDs is needed to achieve the necessary intensity. UVC LED technology might currently suit for small consumer applications like toothbrush disinfection containers but not for the professional market where high power and high turnover is needed as the efficiency and performance of UVC LED technology per milli Watts is still too low. This results in higher energy consumption compared to an application where conventional mercury vapor lamps are used. With a lower lifetime of approx. 30% of the lifetime of a mercury vapor lamp, UVC LEDs need to be replaced more often which results in higher costs for the operator of the application. Moreover, other than it is often advertised by LED manufactures, the performance of UVC LEDs isn't independent of the temperature. Increased temperature and ageing of these shortwave LEDs have a negative effect on their performance.

Replacement / retrofit of UVC LED lamps is not possible as the mercury lamps are used in special purpose equipment with existing controls, fixtures and cooling systems, which would not be compatible with an LED lamp. Furthermore, disinfection and sterilisation processes only works with short wave UV spectrum which cannot efficiently be achieved with the UVC LEDs currently available. In addition, UV curing lamps have to be replaced several times over the life of the equipment. Hence, even if a new technology becomes available there will be a requirement for UV curing lamps as spare parts for legacy capital equipment for a considerable period.

An overview on the status of the development of UV LED is given by the *Advanced UV for Life* consortium[35][36].

Alternatives for high pressure short arc mercury lamps

Short arc mercury lamps are mainly used for microlithography in the semiconductor industry. This industry is fully dependent on the availability of these lamp types.
For high pressure short arc mercury lamps currently there are no alternatives available

[35] https://www.advanced-uv.de/en/about/welcome/
[36] https://www.advanced-uv.de/fileadmin/user_upload/Infopool/Advanced_UV_for_Life_2018.pdf

- Mercury cannot be replaced in short arc lamps, there are no other suitable chemical elements for substitution of mercury
- Also retrofit solutions are not available

Mercury lamps are used in one of the litho-steps in the semiconductor manufacturing industry. It is used in thousands of systems and the average lifetime of a litho-tool (with machine costs several millions) is >25 years. Those tools contain optics that are special designed for the wavelength generated by Mercury lamps (365 nm) and there are no other alternatives that provide the same effective performance. Changing this means a big burden for litho-equipment manufacturers, resist suppliers and semiconductor manufacturing fabs, including but not limited to:

- Litho-equipment manufacturers must redesign the equipment for a new wavelength,
- Resist suppliers must develop a new type of resist,
- Fabs need to update the equipment, requalify the processes.

A consequence might be that fabs decide to move the production of “low end” chips (existing products) to other countries where mercury lamps can be used. Lamps itself are very low risk because mercury is not released to the environment and can very well be recycled.

It is important to stress that specialty UV bulbs containing mercury are critical to the semiconductor process of photostabilization. Photostabilization ensures optimum resist stability and critical dimension (CD) control through etch and implant sequences, and is a key enabler of improved device quality. The photostabilization process is a balance of UV energy applied to the top of the wafer and thermal heating applied to the backside of the wafer to remove residual solvents from the photoresist and to further crosslink the resist.

The irradiator is the source of UV radiation for photostabilizer systems. It generates radiation through a process that first converts high voltage DC power to microwave energy using two magnetrons. The microwave energy, generated by the magnetrons, is used to develop a high temperature-plasma inside a sealed bulb. The plasma then re-radiates this energy in the form of infrared, visible, and ultraviolet radiation. The selected fill and bulb shell materials are tailored to produce high "light" intensities in wavelengths suitable to cure photo masking materials used in the fabrication of semiconductor components, quartz displays, and disk drives. Other uses include curing low-K dielectrics, SOG, multi-level resist applications and EPROM erasure.

The UV irradiator is capable of producing UV energy at power levels two orders of magnitude greater than that supplied by an excimer laser. Unlike the laser which covers a spot size of approximately 5mm, the irradiator is capable of supplying full power uniformly over the entire wafer surface.

The bulb consists of a hollow quartz sphere filled with materials, including mercury, selected for their specific emission characteristics under high-energy microwave excitation. When microwaves energize the fill materials, plasma is generated. High energy plasma causes the bulb temperature to exceed 1000°C. To extend the life of the bulb, it is constantly rotated within air supplied by pre-aligned quartz cooling jets.

Because these bulbs contain no electrodes, there is no possibility of electrode sputtering and decay. As a result, better spectral consistency, longer useful life, improved process control and yields are achieved over other arc bulb assemblies.

Photostabilizers such as those discussed above are in use in many locations within the EU. The specialty UV bulb is necessary for the functionality of these systems. Without a supply of replacement bulbs, this equipment would become obsolete, harming the productivity and efficiency of the semiconductor manufacturers using this technology.

Other High Pressure Mercury lamps for special purposes (Cat. 8&9 applications)

High pressure mercury lamp, high pressure mercury xenon lamp.

Mercury vapor lamps for medical, industrial research and development applications are used for qualitative and quantitative analysis, color comparison, observation and inspection. In order to carry out those applications, multiple specific wavelengths, high-intensity, and a spotlight source are required. At present, only mercury (or combinations of mercury and other elements/substances) in a single light source achieve the requirements for above mentioned applications. As these lamps are manufactured in various sizes and power consumption corresponding to equipment, it is impossible to determine the definite amount of mercury limit value.

The following table shows simulation data both of mercury xenon lamp and LEDs, this is simulation for embedding light source to optical equipment.

Light source	Mercury xenon lamp	LED array
Lamp power rating	100W	100W Equivalent
Intensity	3500 mW/cm2	1600 mW/cm2
Operating conditions wavelength: 365nm, leads light to φ5 bundle fiber, compare intensity from edge of light output		

Table 4: simulation data both of mercury xenon lamp and LEDs

Mercury xenon lamps have point source of light which makes it possible that leading light to optical equipment with high efficiency by maximum intensity on the end of cathode. On the other hand, LED has different features, such as surface emission and diffusion light, thus LEDs are not suitable for applications mentioned above.

LED must become larger point source of light than what mercury containing lamp has. As the light emission intensity of a single LED is much lower, it would be necessary to array the LEDs to achieve higher intensity. However, there is a limit to reduce the diameter of light spot of arraying LEDs. Point source of high intensity is required for variety fields like medical, research and development, LED is not substitute to mercury containing lamp at point source.

Please provide information and data to establish reliability of possible substitutes of application and of RoHS materials in application

As far as non-mercury technologies are available, they are considered to be reliable. No alternatives are available for Hg in discharge lamps (see chapter 6(A)).

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7. Proposed actions to develop possible substitutes

(A) Please provide information if actions have been taken to develop further possible alternatives for the application or alternatives for RoHS substances in the application.

See also chapter above.

<u>Application with alternative substances</u>
Mercury has been used for many decades, because it has a unique combination of properties that no alternative has been found to provide. Mercury has a relatively low boiling temperature so is readily able to produce a vapour of suitable pressure. The heavy mercury atom slows down the fast electrons on their track though the plasma. Upon collisions of the electrons with the mercury atom UV light is generated very efficiently.

The mercury vapour is essential: all of the mercury is evaporated and the resulting pressure is chosen in such a way that:

- the system can provide the exact power to the lamp,
- the discharge radiates as effective as possible,
- generates the required wavelengths for the desired application and finally
- with a brightness that allows the most effective collection of the light.

Since the applications for 4(f) vary, the designs and the amount of mercury differs widely. For example, very high power lamps, need a certain lamp volume to prevent the heat generated in the discharge melting the wall of the discharge vessel. At the same time 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 100 gram). Other lamps require very efficient UV generation for instance for water purification. Here the generated UV must escape from the discharge without radiation trapping, these lamps have a medium mercury pressure (below 1 bar).

Alternative elements for mercury either lack the required vapour pressure at a low enough temperature, or do not radiate efficiently upon collisions with electrons or react violently with the transparent quartz wall and block the light when the lamp becomes older.

All single elements, stable combinations of elements and stable compounds with suitable vapour pressure have been evaluated as possible alternatives to mercury and none give either the same broad UV spectrum or the required wavelengths with sufficient intensity to perform required the necessary functions. Therefore, the only potential future alternatives to use of mercury could be from different technologies.

Application with alternative technology

There is a high variety of applications using special purpose lamps. While for some applications solutions based on new technology, mainly LED solutions, are in work, or have already entered the market, in other areas substitution is still not possible. This has several reasons. A good overview can be found under the consortium "Advanced UV for Life" [37][38]

UV LEDs are clearly not as mature as LED technology emitting in the visible region and which are used for general lighting. The development of LED is much more difficult and complex compared to LED in the blue and white spectrum. The market for general lighting is many orders of magnitude larger than the UV applications market, thus the pull from the market is much higher and so are the resources that are put into developing corresponding solutions. Due to the smaller UV applications market, the UV LED technology developments slower and costs of the devices is much higher than in the visible range.

One of the main areas of R&D for UV LED lamps is to deliver products which have high output and high efficiency in the UV-C and UV-B regions. This would allow the LEDs to work more efficiently with a wider range of formulations and produce the required film properties for a wider range of applications. In particular, to produce better surface cure and produce scratch resistant coatings required by many applications, including wood finishing, coatings for plastic components, metal decorating etc.

Most UV LED light source system manufacturers do not have such highly expensive semiconductor production technology in house, so the risks of uncertain supply chains need to be covered, which is difficult as the technology is still developing and in an early stage.

UV LEDs are in development mainly in the wavelength range between 340 nm and 220 nm, with an emphasis on the wavelengths 310 nm, 280 nm and 265 nm, which are important for many applications. The manufacturing takes place in a process chain and contains a series of

[37] https://www.advanced-uv.de/fileadmin/user_upload/Infopool/Advanced_UV_for_Life_2018.pdf

[38] https://www.advanced-uv.de/en/about/the-consortium-advanced-uv-for-life/

steps: Design of the LED hetero-structure and chip layout, growth of the substrate and base layers, epitaxy of the semiconductor heterostructure, processing of LED components at the wafer level, and finally the dicing of the wafers into LED chips and their assembly into housings.

In all of these steps it is important that the electrical power be transformed into optical light output power as efficiently as possible, whereby the manufacturing processes developed for this purpose should be transferrable to industrial production as directly as possible. The wall-plug efficiency (abbreviated: WPE), or radiant efficiency, is particularly relevant as an important parameter for this application. The WPE is given by the ratio of the total optical output power Pout to the input electrical power, i.e. the product of current I and voltage V.
The WPE is determined by the design of the UV LEDs and their material properties, and is largely determined by four processes:

- Contact and layer resistances determine the electrical efficiency.
- The injection efficiency indicates the proportion of charge carriers reaching the light-producing layers. There, the generation of light through radiative recombination is in competition with processes that produce only heat, but not light. The ratio is the radiative recombination efficiency.
- Next, the light must escape from the LED (extraction efficiency), which is hindered by reflection on the surfaces.
- The product of the injection, recombination and extraction efficiencies is the external quantum efficiency (EQE). [39]

	Blue LED	UVC LED
η_{rad}	96 %	50 %
η_{inj}	98 %	80 %
$\eta_{extraction}$	89 %	16 %
$\eta_{electrical}$	95 %	64 %
η_{EQE}	84 %	6,4 %
WPE (wall plug efficiency)	81 %	4,1 %

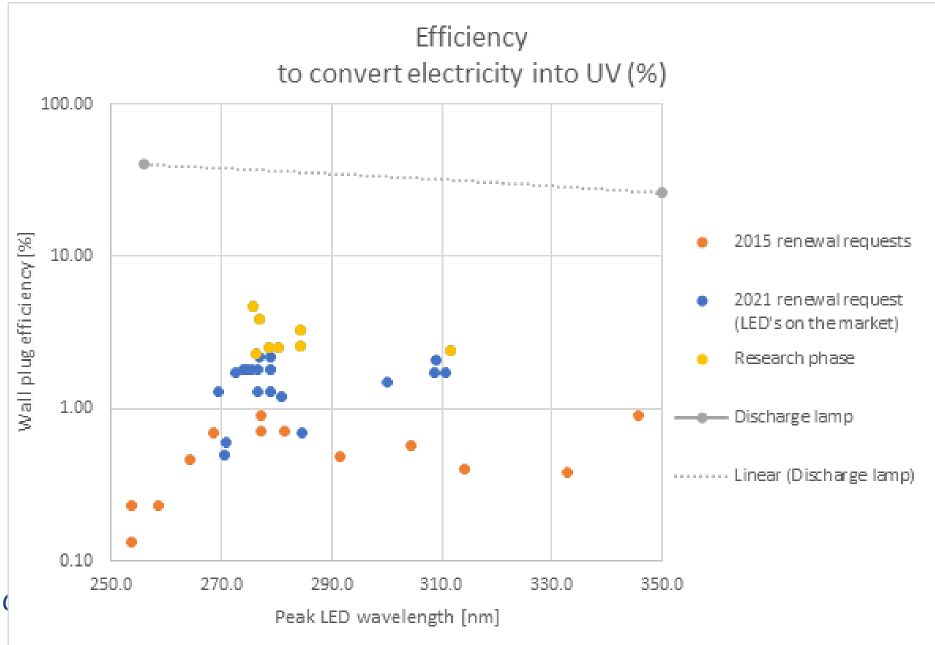
Table 5: Comparison of the wall plug efficiency (WPE) or external quantum efficiency (EQE) of blue-emitting LEDs and UVC LEDs [40]

The efficiencies of typical blue-emitting LEDs and UVC LEDs are compared in Table 5. While blue-emitting LEDs can now achieve a very high WPE of 81 %, LEDs with emissions in the deep UVB and UVC have a significantly lower WPE of less than five percent. As shown by the comparison in the table, this strong difference in WPE cannot be ascribed to one single cause.

[39] https://www.advanced-uv.de/fileadmin/user_upload/Infopool/Advanced_UV_for_Life_2018.pdf
[40] https://www.advanced-uv.de/fileadmin/user_upload/Infopool/Advanced_UV_for_Life_2018.pdf

Instead, the development of more efficient and more powerful UV LEDs requires improvements in all areas. [41]

The expected timeline for the development work to overcome the current limitations and achieve a secure supply chain is more than 5 years, with market maturity 10+ years. Furthermore, the gap between costs of the mercury-based lamp technology and UV LED technology is high; at least 1-5 orders of magnitude depending on the emission range and complexity of the lamp.



Since the major impact on the environment of lamps is during the use phase, the UV LED's show no alternatives that are more beneficial to the environment yet

(B) Please elaborate what stages are necessary for establishment of possible substitute and respective timeframe needed for completion of such stages.

Not foreseeable for most applications in new equipment. For existing equipment where the lamps are used, a mercury free alternative is not possible. See details above.

It should also be noted that the few potential long term solutions for applications in exemption 4f contain component materials using substances regulated in RoHS but exempted in certain exempted applications (e.g. lead in high melting temperature type solders in diodes, lead in glass or ceramic in electronic components, lead in copper alloys etc.). Negative or zero

[41] https://www.advanced-uv.de/fileadmin/user_upload/Infopool/Advanced_UV_for_Life_2018.pdf

environmental impacts of substitutes are an additional disincentive to pursue new technologies that have little prospect of functional success in small markets.

8. Justification according to Article 5(1)(a):

(A) Links to REACH: (substance + substitute)

1) Do any of the following provisions apply to the application described under (A) and (C)?

Not applicable.

- ☐ Authorisation
  - ☐ SVHC
  - ☐ Candidate list
  - ☐ Proposal inclusion Annex XIV
  - ☐ Annex XIV
- ☐ Restriction
  - ☐ Annex XVII
  - ☐ Registry of intentions
- ☐ Registration

2) Provide REACH-relevant information received through the supply chain.
Name of document:

Based on the current status of Annexes XIV and XVII of the REACH Regulation, the requested exemption would not weaken the environmental and health protection afforded by the REACH Regulation. The requested exemption is therefore justified as other criteria of Art. 5(1)(a) apply.

(B) Elimination/substitution:

1. Can the substance named under 4.(A)1 be eliminated?
   - ☐ Yes. Consequences? _____
   - ☒ No. Justification:

Mercury free discharge lamps for the scope of exemption 4f are not yet available.

2. Can the substance named under 4.(A)1 be substituted?
   - ☐ Yes.
     - ☐ Design changes:
     - ☐ Other materials:
     - ☐ Other substance:
   - ☒ No.

   Justification:

Mercury free discharge lamps for the scope of exemption 4f are not available.

3. Give details on the reliability of substitutes (technical data + information):

In those cases where alternative technologies enter the market reliability of the products is assumed. But of course, long term reliability information needs the necessary time.

4. Describe environmental assessment of substance from 4.(A)1 and possible substitutes with regard to
   1) Environmental impacts:
   2) Health impacts:
   3) Consumer safety impacts:

⇨ Do impacts of substitution outweigh benefits thereof?
Please provide third-party verified assessment on this:

(C) Availability of substitutes:

Mercury free retrofit lamps are not available. As described in detail in the chapters above for certain limited applications new equipment has been developed which is not using discharge lamps but technologies based on LED or lasers.

a) Describe supply sources for substitutes:

b) Have you encountered problems with the availability? Describe:

c) Do you consider the price of the substitute to be a problem for the availability?

☐ Yes ☐ No

d) What conditions need to be fulfilled to ensure the availability?

(D) Socio-economic impact of substitution:

Mercury free retrofit lamps are not available. As described in detail in the chapters above for certain limited applications new equipment has been developed which is not using discharge lamps but technologies based on LED or lasers.

As described in the chapter above, lamps covered by exemption 4(f) are not suitable for substitution and cannot be substituted

It must be borne in mind that special purpose lamps are used in a variety of installed equipment on the EU Market. Therefore, a premature ban of 4f lamps would render the equipment in which they are installed, obsolete. This equipment would become avoidable and unnecessary waste before reaching the end of its service life when these lamps are no longer available.

There are no one-to-one substitutes available for the lamps covered by exemption 4(f) types due to the big variety of applications they are used in and the application-specific requirements they often must comply with. For special purpose lamps, no substitute/retrofit lamps are expected for existing equipment. The denial of an exemption renewal for 4f lamps would lead to the consequence that these lamps can no longer be placed on the market. The impact will therefore be borne not only by the manufacturers of these lamps (i.e. loss of jobs, closing of factories), but also the end-users who will no longer have access to lamps to service existing equipment. The lack of lamps for existing equipment will essentially make that installed equipment obsolete and avoidable and unnecessary waste before its end of life (refer to section 5 (A) for the impact on waste).

Granting the exemption as requested and justified in this request will ensure that:

- a high negative socioeconomic impact for applications using (non)-UV spectra is avoided. This impact can be very high for downstream users who rely on these products to continue functioning and by far exceeds the effects considered by the 2019 Oeko Socio Economic Impact Assessment, which is limited for the most part to the administrative burden of applying for exemptions.
- ensures EEE using these lamps as spare parts will not become unnecessary and avoidable waste
- allows commercial and industrial processes to continue, avoiding job losses and the impact on SMEs producing small amounts of very specific lamps and applications.
- prevents users from stockpiling lamps.

We have presented an overview of the various applications covered by this exemption within the UV and non-UV range and the potential socio-economic impact in the event of a non-renewal of this exemption.

1. ***UV-Lamps:***

As optionally proposed by Oeko in their 2016 report and their 2019 SEIA, all UV applications need to be included in exemption 4f. This for example avoids dramatic harm to:

Semiconductor manufacturing:

European Semiconductor and LED industry needing lamps for microlithography and spectroscopy. According to the 2019 "Study to assess socio-economic impact of substitution of certain mercury-based lamps currently benefitting of RoHS 2 exemptions in Annex III" carried out by the Oeko Institute, the impact on the semiconductor and other IC producing industry, as a user of lamps and equipment could be in the range of 25-40 billion Euros.[42]

[42] Page 144, "Study to assess socio-economic impact of substitution of certain mercury-based lamps currently benefitting of RoHS 2 exemptions in Annex III" , Oeko Institute 2019, available at: https://rohs.exemptions.oeko.info/fileadmin/user_upload/reports/FWCW_RoHS_Lamps_SEA_20190729_Final.pdf

Based on information collected for this exemption renewal dossier, the Electronics industry in Europe, including semiconductors, employs directly 200-250,000 people and contribute to 1,000,000 jobs indirectly across the ICT supply chain (jobs in systems, applications and services in Europe). Overall, micro- and nano-electronics enable the generation of at least 10% of GDP in Europe and the world. As a provider of key enabling technologies the semiconductor industry creates innovative solutions for industrial development, contributing to economic growth and responding to major societal challenges. Being ranked as one of the most R&D intensive sector by the European Commission.

UV – curing:

A ban will lead to a loss in business, as several applications that require robust and scratch resistant prints can no longer be served with UV curing printers. An alternative is going back to solvent based inks, which are much more hazardous to human health and the environment.

UV – disinfection (air/water):

A ban will lead to a massive loss in business, applications and disinfection quality. The existing method for water/air treatment would no longer be possible, resulting in the use of chemicals to achieve safe water quality. If LED technology is used, more energy would be needed as LED efficiency and output is lower than conventional UV discharge lamp and therefore more LEDs are needed.

UV – disinfection (food):

A ban would have a negative impact on businesses but also a significant number of food filling machines could no longer meet the hygienic requirements for safe food. Instead of UV disinfection lamps chemicals like H_2O_2 would be needed for packaging disinfection.

2. ***Lamps with visible spectrum:***

Horticultural lighting:

The high power HPS lamps with a power >= 600 W for horticulture applications require specialized luminaires to provide the right light distribution on the crops. There are no direct LED replacement lamps. Changing to an LED solution requires reconstruction of the whole greenhouse as the roof of the greenhouse is designed to bear the light weight HPS luminaires. Full LED solutions require a different set up of the greenhouse. Banning the horticulture lamps will result in a sudden stop in the production of many vegetables particularly tomatoes and paprika. The other sector in horticulture is the production of flowers and pot plants. In the Netherlands only, these sectors use 9000 hectares and are responsible for 32.000 jobs.

(source: central Bureau of statistics the Netherlands)[43]. The economic value of this segment, just for the Netherlands, is around 7.4 Billion Euro. (source: University of Wageningen)[44].

Projectors:

The lack of lamps for projectors will render existing equipment non-serviceable and therefore will result in premature waste and will prevent new projectors from being produced. The total projector business has a turnover of approx. 6.2 million projectors on annual basis, which corresponds with a value of 8 billion dollars. The majority of projectors are equipped with a mercury containing lamp (see chapter 6A reference 29). If projection will not be included in this exemption this will have a direct impact on the projector market and on the employability in this sector. Jobs that are affected can vary in a wide range, eg. logistic, service, developing and manufacturing of both projector and the mercury containing lamps. The projector business itself serves 2 main market segments:

- Education market focusing on solution for projecting content in classroom
- Corporate market focusing on projector to facilitate meeting experience

Those two market segments together cover +/- 80% of the total projection market.

The consequence in the market if no exemption is granted in combination with the lack of equal performing alternatives, will be that the new projectors or replacement lamps cannot be bought anymore, this will result in:

- Since the projector is widely adopted in European classrooms, the level of education will reduce if the projector cannot be upgraded to the latest models offering higher brightness, higher resolutions, connectivity and even more if the key spare part is not available anymore. (as indication: typical replacement cycle for lamps in US schools is said to be every 2 years)
- In the corporate segment the projector has a prominent place in meeting room, to be able to share and project content. Specially in the digital world where the interactivity and connectivity are becoming more important to have efficient meetings and corporation. Due to poor screen projection this trend can be set back resulting in less efficient meeting. To overcome this, presentation will be shared as printed handouts, resulting in more paper consumption and paper waste. Furthermore, less effective meetings might lead to more travel in order to have face to face discussions.

Studio, stage and entertainment lighting:

The impact on theatres of a mercury ban would affect around 20% of light sources (from this 20% there might be replacements for 80%, but no replacements for 20%). A premature mercury ban would have the following consequences:

[43] Available at the following link here: https://www.cbs.nl/nl-nl/nieuws/2012/14/tuinbouw-goed-voor-125-duizend-banen

[44] Available at the following link here: https://www.agrimatie.nl/SectorResultaat.aspx?subpubID=2232&sectorID=2240&themaID=2280

- Artistic quality: If these lamps are banned before a viable alternative is available, the artistic quality of the event or performance will be compromised (i.e. you won't be able to see the performers).
- Theatres, concert halls, festivals and other live events would make investments on products that artistically cannot replace discharge lamps.
- Carbon footprint: As theatres and events would need to use a much larger quantity of LED fixtures, implications on the carbon footprint would grow. It would significantly affect the logistics for touring companies (i.e. would require more trucks) and would probably increase the power consumption as the higher-powered LED fixtures are of an equivalent power consumption to existing arc source fixtures.
- Market: The sector is already reducing the quantity of sold arc lamps as most of the new moving lights are shipped in LED. By banning discharge lamps too quickly, the market will be « killed » as nobody will be able to change inventories so quickly. This also means that manufacturers that are researching to replace discharge lamps might not be able to do so anymore.
- Financial burden for cultural institutions: Replacing discharge lamps without giving the market the time to develop new products would result in an enormous financial burden for event companies, theatres, festivals and other venues.

⇨ What kind of economic effects do you consider 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: _____

⇨ Provide sufficient evidence (third-party verified) to support your statement:

9. Other relevant information

Please provide additional relevant information to further establish the necessity of your request:

As both the Ecodesign Regulation and RoHS regulate the access of mercury containing lamps to the EU market, LightingEurope expects alignment between these regulations to ensure confidence of the customers and the industry.

In the recently published Ecodesign Regulation[45] the short arc mercury lamps are exempted from the regulation since there are no suitable LED replacement lamps.

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[45] Commission Regulation (EU) 2019/2020 of 1 October 2019 laying down ecodesign requirements for light sources and separate control gears pursuant to Directive 2009/125/EC of the European Parliament and of the Council and

To quote ANNEX III (exemptions) of the Ecodesign Regulation 2019/2020:

"Any light source or separate control gear within the scope of this Regulation shall be exempt from the requirements of this Regulation, with the exception of the information requirements set out in point 3(e) of Annex II, if they are specifically designed and marketed for their intended use in at least one of the following applications:

(a) signaling (including, but not limited to, road-, railway-, marine- or air traffic-signalling, traffic control or airfield lamps);

(b) image capture and image projection (including, but not limited to, photocopying, printing (directly or in pre-processing), lithography, film and video projection, holography);"

10. Information that should be regarded as proprietary

Please state clearly whether any of the above information should be regarded to as proprietary information. If so, please provide verifiable justification:

LightingEurope will provide the European Commission under confidentiality an overview of the mercury content and lamps placed on the market that are in the scope of this exemption.

repealing Commission Regulations (EC) No 244/2009, (EC) No 245/2009 and (EU) No 1194/2012 (Text with EEA relevance.)