Assistance to the Commission on Technological Socio-Economic and Cost-Benefit Assessment Related to Exemptions from the Substance Restrictions in Electrical and Electronic Equipment: Pack 10 Final Report

Study to assess 2 RoHS exemption requests [#1 Cadmium in colour converting II-VI LEDs (<10 µg Cd per mm^2 of light-emitting area) for use in solid state illumination or display systems (Request for renewal of Exemption 39 of Annex IV of Directive 2011/65/EU); #2 Cadmium in LCD Quantum Dot Light Control Films and Components]

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Executive Summary

Under Framework Contract no. ENV.C.2/FRA/2011/0020, a consortium led by Eunomia Research & Consulting was requested by DG Environment of the European Commission to provide technical and scientific support for the evaluation of exemption requests under the new RoHS 2 regime. The work has been undertaken by Oeko-Institut and has been peer reviewed by Eunomia Research & Consulting.

E.1.0 Approach

The RoHS Directive 2011/65/EU entered into force on 21 July 2011 and led to the repeal of Directive 2002/95/EC on 3 January 2013. The Directive can be considered to have provided for two regimes under which exemptions could be considered, RoHS 1 (the former Directive 2002/95/EC) and RoHS 2 (the current Directive 2011/65/EU).

- The scope covered by the Directive is now broader as it covers all EEE (as referred to in Articles 2(1) and 3(1));
- The former list of exemptions has been transformed in to Annex III and may be valid for all product categories according to the limitations listed in Article 5(2) of the Directive. Annex IV has been added and lists exemptions specific to categories 8 and 9;
- The RoHS 2 Directive includes the provision that applications for exemptions have to be made in accordance with Annex V. However, even if a number of points are already listed therein, Article 5(8) provides that a harmonised format, as well as comprehensive guidance – taking the situation of SMEs into account – shall be adopted by the Commission; and
- The procedure and criteria for the adaptation to scientific and technical progress have changed and now include some additional conditions and points to be considered. These are detailed below.

The new Directive details the various criteria for the adaptation of its Annexes to scientific and technical progress. Article 5(1)(a) details the various criteria and issues that must be considered for justifying the addition of an exemption to Annexes III and IV:

- The first criterion may be seen as a threshold criterion and cross-refers to the REACH Regulation (1907/2006/EC). An exemption may only be granted if it does not weaken the environmental and health protection afforded by REACH;
- Furthermore, a request for exemption must be found justifiable according to one of the following three conditions:

- Substitution is scientifically or technically impracticable, meaning that a substitute material, or a substitute for the application in which the restricted substance is used, is yet to be discovered, developed and, in some cases, approved for use in the specific application;
- The reliability of a substitute is not ensured, meaning that the probability that EEE using the substitute will perform the required function without failure for a period of time comparable to that of the application in which the original substance is included, is lower than for the application itself;
- The negative environmental, health and consumer safety impacts of substitution outweigh the benefits thereof.

- Once one of these conditions is fulfilled, the evaluation of exemptions, including an assessment of the duration needed, shall consider the availability of substitutes and the socio-economic impact of substitution, as well as adverse impacts on innovation, and life cycle analysis concerning the overall impacts of the exemption; and
- A new aspect is that all exemptions now need to have an expiry date and that they can only be renewed upon submission of a new application.

E.1.1 Revaluation of Exemptions for Cadmium Quantum Dot Technologies

The current study is a revaluation of two exemption requests submitted in 2012 and 2013, and first evaluated in 2013-2014. In December 2012 the Commission received a request for the renewal of Annex III exemption 39, and in May 2013 a request for a new Annex III exemption. The exemptions, both dealing with cadmium quantum dot (CdQD) applications, were both reviewed in the course of an evaluation performed in 2013-2014. The final report was published in April 2014[1].

On the 20 May 2015, the European Parliament objected to the Commission Delegated Act adopted on the basis of the mentioned report, claiming that the report need be updated[2]; thus, a revaluation of these requests has been performed. As the requests both concern the application of quantum dot technologies in EEE, a joint evaluation of was carried out.

An important aspect raised in the Parliaments objection to the Delegated Act regarded the changes that were understood to have taken place on the market in relation to

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[1] See final evaluation report here: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_IX/20140422_RoHS2_Evaluation_Ex_Requests_2013-1-5_final.pdf

[2] See Communication here: http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+P8-TA-2015-0205+0+DOC+XML+V0//EN&language=EN

CdQD applications and in relation to Cd-free quantum-dot applications, which at the time of the first review were understood to not yet be available on the market. Therefore, at the on-set of this project, both applicants as well as a manufacturer of Cd-free QD materials were asked to provide new information as to EEE that has become available on the EU market and on the global market using CdQD and Cd-free QD materials. The parties were also asked to provide data as to the performance of such applications, and as to how the technologies could be compared, when used in an end application. The initial information provided was then used, along with documents made available in the course of the 2013-2014 review, as a basis for stakeholders to review as part of a stakeholder consultation that took place between 30.10.2015 and 08.01.2016, to allow stakeholders to contribute to the ongoing revaluation. Documents contributed were then further reviewed to allow an evaluation of scientific progress regarding QD applications and their implications on the exemption requests at hand.

E.2.0 Key Findings

The exemption requests covered in this project and the applicants concerned, as well as the final recommendations and proposed expiry dates are summarised in Table E. 1. The reader is referred to the corresponding section of this report for more details on the evaluation results.

The – not legally binding – recommendations for the requests for the renewal of exemption requests 2013-2 and 2013-5 were submitted to the EU Commission by Oeko-Institut and have already been published at the EU CIRCA website on 2 June 2016. So far, the Commission has not adopted any revision of the Annex to Directive 2011/65/EU based on these recommendations.

Table E. 1: Overview of the Exemption Requests, Associated Recommendations and Expiry Dates

Ex. Re. No.	Wording: Main Entry Sub-Entry	Applicant	Recommendation: Proposed Exemption Wording Formulation	Proposed Duration
2013-2	Cadmium in colour converting II-VI LEDs (< 10 µg Cd per mm^2 of light-emitting area) for use in solid state illumination or display systems (Request for renewal of exemption 39 of Annex III of Directive 2011/65/EU);	QD Vision, Inc.	Cadmium selenide in downshifting cadmium based semiconductor nanocrystal quantum dots for use in display lighting applications (< 0.2 µg Cd per mm^2 of display screen area)	An exemption should be granted for three years
2013-5	Cadmium in LCD Quantum Dot Light Control Films and Components	3M Optical Systems Division		

The Report includes the following Sections:

Section 1.0: Project Set-up

Section 2.0: Scope

Section 3.0: Links from the Directive to the REACH Regulation

Section 4.0 through 7.0 cover the joint revaluation of the requested exemptions handled in the course of this project.

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1.0 Project Set-up

Assignment of project tasks to Oeko-Institut, started 25 August 2015. The overall project has been led by Carl-Otto Gensch. The project team at Oeko-Institut consists of the technical experts Yifaat Baron and Markus Blepp. Eunomia, represented by Adrian Gibbs, has the role of ensuring quality management.

2.0 Scope

The scope of the project covers the evaluation of two requests for exemptions – one request for the renewal of an exemption (Ex. 39 of Annex III of the RoHS Directive) and one request for a new exemption.

In the course of the project, a stakeholder consultation was conducted. The stakeholder consultation was launched on 30 October 2015 and held for a duration of 8 weeks, thus concluding on 8 January 2016.

The specific project website was used in order to keep stakeholders informed on the progress of work: http://rohs.exemptions.oeko.info. The consultation held during the project was carried out according to the principles and requirements of the European Commission. Stakeholders who had registered at the website were informed through email notifications about new steps within the project.

Information concerning the consultation was provided on the project website, including a general guidance document, the applicants' documents for each of the exemption requests, results from the earlier evaluation, a specific questionnaire and a link to the EU CIRCA website. All non-confidential stakeholder comments, submitted during the consultation, were made available on the RoHS Evaluation website and on the EU CIRCABC website (Communication and Information Resource Centre for Administrations, Businesses and Citizens)[3].

The evaluation of the stakeholder contributions led to further consultation including, inter alia, engaging with stakeholders in further discussion, further exchanges in order to clarify remaining questions, cross-checking with regard to the accuracy of technical arguments, and checks in respect of confidentiality issues.

The requests were evaluated according to the various criteria (cf. Section E.1.0 for details). The joint evaluations of the exemption requests appear in Chapters 4.0 through 7.0. The information provided by the applicants and by stakeholders is

[3] EU CIRCABC website: https://circabc.europa.eu (Browse categories > European Commission > Environment > RoHS 2014 Evaluations Review, at top left, click on "Library")

summarised in the first sections. This includes a general description of the applications and requested exemptions, a summary of the arguments made for justifying the exemption, information provided concerning possible alternatives and additional aspects raised by the applicants and other stakeholders. In some cases, reference is also made to information submitted by applicants and stakeholders in previous evaluations. The Critical Review follows these sections, in which the submitted information is discussed, to clarify how the consultants evaluate the various information and what conclusions and recommendations have been made. For more detail, the general requirements for the evaluation of exemption requests may be found in the technical specifications of the project. [4]

3.0 Links from the Directive to the REACH Regulation

Article 5 of the RoHS 2 Directive 2011/65/EU on "Adaptation of the Annexes to scientific and technical progress" provides for the:

> "*inclusion of materials and components of EEE for specific applications in the lists in Annexes III and IV, provided that such inclusion does not weaken the environmental and health protection afforded by Regulation (EC) No 1907/2006*".

RoHS 2 does not further elaborate the meaning of this clause.

Regulation (EC) No 1907/2006 regulates the safe use of chemical substances, and is commonly referred to as the REACH Regulation since it deals with **R**egistration, **E**valuation, **A**uthorisation and Restriction of **Ch**emical substances. REACH, for its part, addresses substances of concern through processes of authorisation and restriction:

- Substances that may have serious and often irreversible effects on human health and the environment can be added to the candidate list to be identified as Substances of Very High Concern (SVHCs). Following the identification as SVHC, a substance may be included in the Authorisation list, available under Annex XIV of the REACH Regulation: "List of Substances Subject to Authorisation". If a SVHC is placed on the Authorisation list, companies (manufacturers and importers) that wish to continue using it, or continue placing it on the market, must apply for an authorisation for a specified use. Article 22 of the REACH Regulation states that:
  "Authorisations for the placing on the market and use should be granted by the Commission only if the risks arising from their use are adequately

[4] Cf. under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Technical_specifications_Pack_10.pdf

controlled, where this is possible, or the use can be justified for socio-economic reasons and no suitable alternatives are available, which are economically and technically viable."

- If the use of a substance (or compound) in specific articles, or its placement on the market in a certain form, poses an unacceptable risk to human health and/or to the environment that is not adequately controlled, the European Chemical Agency (ECHA) may restrict its use, or placement on the market. These restrictions are laid down in Annex XVII of the REACH Regulation: "Restrictions on the Manufacture, Placing on the Market and Use of Certain Dangerous Substances, Mixtures and Articles". The provisions of the restriction may be made subject to total or partial bans, or other restrictions, based on an assessment of those risks.

The approach adopted in this report is that once a substance has been included into the regulation related to authorization or restriction of substances and articles under REACH, the environmental and health protection afforded by REACH may be weakened in cases where, an exemption would be granted for these uses under the provisions of RoHS. This is essentially the same approach as has already been adopted for the re-evaluation of some existing RoHS exemptions 7(c)-IV, 30, 31 and 40,[5] as well as for the evaluation of a range of requests assessed through previous projects in respect of RoHS 2.[6] Furthermore, substances for which an authorisation or restriction process is already underway are also reviewed, so that future developments may be considered where relevant.

When evaluating the exemption requests, with regard to REACH compliance, we have checked whether the substance / or its substitutes are:

- on the list of substances proposed for the adoption to the Candidate List (the Registry of Intentions);
- on the list of substances of very high concern (SVHCs- the Candidate List);
- in the recommendations of substances for Annex XIV (recommended to be added to the Authorisation List);
- listed in REACH Annex XIV itself (The Authorization List); or
- listed in REACH Annex XVII (the List of Restrictions).

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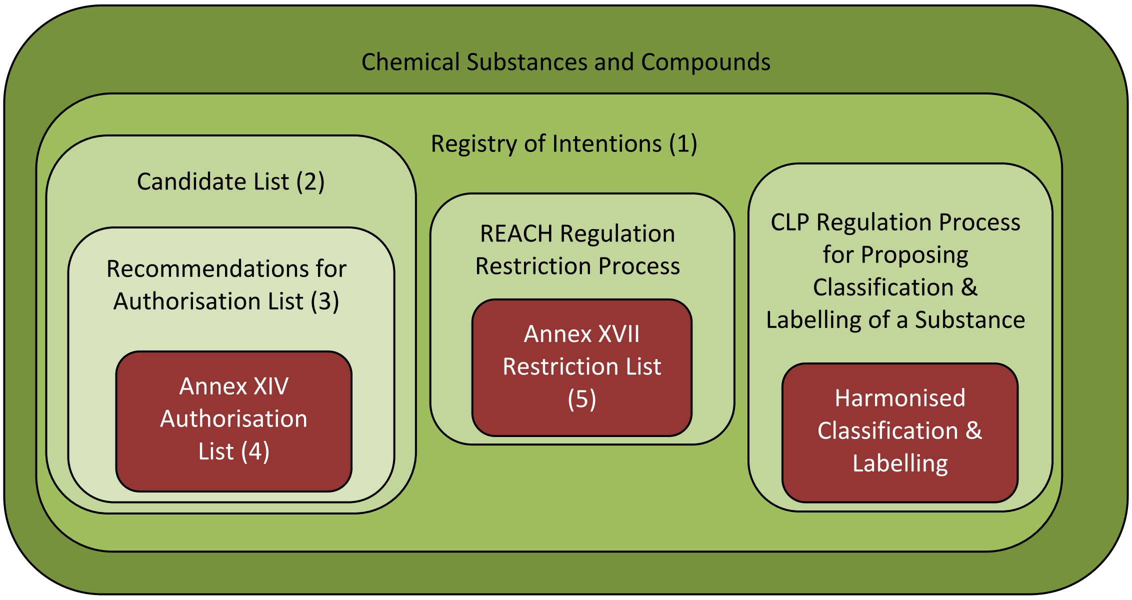
[5] See Zangl, S.; Blepp, M.; Deubzer, O. (2012) Adaptation to Scientific and Technical Progress under Directive 2011/65/EU - Transferability of previously reviewed exemptions to Annex III of Directive 2011/65/EU, Final Report, Oeko-Institut e. V. and Fraunhofer IZM, February 17, 2012, http://rohs.exemptions.oeko.info/fileadmin/user_upload/Rohs_V/Re-evaluations_transfer_RoHS_I_RoHS_II_final.pdf

[6] Gensch, C., Baron, Y., Blepp, M., Deubzer, O., Manhart, A. & Moch, K. (2012) Assistance to the Commission on technological, socio-economic and cost-benefit assessment related to exemptions from the substance restrictions in electrical and electronic equipment (RoHS Directive), Final Report, Oeko-Institut e. V. and Fraunhofer IZM, 21.12.2012 http://rohs.exemptions.oeko.info/fileadmin/user_upload/Rohs_V/RoHS_V_Final_report_12_Dec_2012_final.pdf

As the European Chemicals Agency (ECHA) is the driving force among regulatory authorities in implementing the EU's chemicals legislation, the ECHA website has been used as the reference point for the aforementioned lists, as well as for the exhaustive register of the Amendments to the REACH Legal Text.

Table 3-1 shows the relationship between the two processes and categories. Substances included in the red areas may only be used when certain specifications and or conditions are fulfilled.

Table 3-1: Relation of REACH Categories and Lists to Other Chemical Substances



The following bullet points explain in detail the above mentioned lists and where they can be accessed:

- Member States Competent Authorities (MSCAs) / the European Chemicals Agency (ECHA), on request by the Commission, may prepare Annex XV dossiers for identification of Substances of Very High Concern (SVHC), Annex XV dossiers for proposing a harmonised Classification and Labelling, or Annex XV dossiers proposing restrictions. The aim of the public Registry of Intentions is to allow interested parties to be aware of the substances for which the authorities intend to submit Annex XV dossiers and, therefore, facilitates timely preparation of the interested parties for commenting later in the process. It is also important to avoid duplication of work and encourage co-operation between Member States when preparing dossiers. Note that the Registry of Intentions is divided into three separate sections: listing new intentions; intentions still subject to the decision making process; and withdrawn intentions. The registry of intentions is available at the ECHA website at: http://echa.europa.eu/web/guest/addressing-chemicals-of-concern/registry-of-intentions;

- The identification of a substance as a Substance of Very High Concern and its inclusion in the Candidate List is the first step in the authorisation procedure. The Candidate List is available at the ECHA website at http://echa.europa.eu/web/guest/candidate-list-table;
- The last step of the procedure, prior to inclusion of a substance into Annex XIV (the Authorisation list), involves ECHA issuing a Recommendation of substances for Annex XIV. The ECHA recommendations for inclusion in the Authorisation List are available at the ECHA website at http://echa.europa.eu/web/guest/addressing-chemicals-of-concern/authorisation/recommendation-for-inclusion-in-the-authorisation-list/authorisation-list;
- Once a decision is made, substances may be added to the Authorisation List available under Annex XIV of the REACH Regulation. The use of substances appearing on this list is prohibited unless an Authorisation for use in a specific application has been approved. The Annex can be found in the consolidated version of the REACH Legal Text (see below);
- In parallel, if a decision is made concerning the Restriction on the use of a substance in a specific article, or concerning the restriction of its provision on the European market, then a restriction is formulated to address the specific terms, and this shall be added to Annex XVII of the REACH Regulation. The Annex can be found in the consolidated version of the REACH Legal Text (see below); and
- As of the 21 of April, 2016, the last amendment of the REACH Legal Text was dated from 13 January 2016 (Commission Regulation (EU) No 2016/26) and so the updated consolidated version of the REACH Legal Text, dated 03.02.2016, was used to check Annex XIV and XVII: The consolidated version is presented at the ECHA website: http://eur-lex.europa.eu/legal-content/en/TXT/PDF/?uri=CELEX:02006R1907-20160203.

Relevant annexes and processes related to the REACH Regulation have been cross-checked to clarify:

- In what cases granting an exemption could "weaken the environmental and health protection afforded by Regulation (EC) No 1907/2006" (Article 5(1)(a), paragraph 1)
- Where processes related to the REACH regulation should be followed to understand where such cases may become relevant in the future;

In this respect, restrictions and authorisations as well as processes that may lead to their initiation, have been reviewed, in respect of where RoHS Annex II substances are mentioned (i.e. lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyls (PBB) and polybrominated diphenyl ethers (PBDE).[7]

Compiled information in this respect has been included, with short clarifications where relevant, in Tables 1-5, which appear in Appendix A.1.0. The information has further been cross-checked in relation to the various exemptions evaluated in the course of this project. This has been done to clarify that the Article 5(1)(a) paragraph 1 threshold-criteria quoted above is complied with in cases where an exemption is to be granted / its duration renewed/ its formulation amended/ or where it is to be revoked and subsequently to expire as an exemption. The considerations in this regard are addressed in the joint evaluation report of the exemption requests under the section entitled "*REACH Compliance - Relation to the REACH Regulation*" (Sections 5.6.1 and 6.5.1).

[7] This review currently does not address the 4 phthalates, DEHP, BBP, DBP and DIBP, which according to Commission Delegated Directive (EU) 2015/863 of 31 March 2015, have been added to the Annex. Information regarding these substances shall be added in future reviews.

4.0 Cadmium Quantum Dots in EEE – A Joint Evaluation

Abbreviations

3M DMSD	3M Display Materials & Systems Division
BLU	Back light unit
CCT	Correlated colour temperature
Cd	Cadmium
CdQD	Cadmium quantum dots
CdSe	Cadmium selenide
CFQD	Cadmium-free quantum dots
CRI	Colour rendering index
EEE	Electrical and Electronic Equipment
EoL	End-of-Life
Ex. Re.	Exemption request
FWHM	Full width at half maximum
GaN	Gallium nitride [based LED]
InP	Indium phosphide
LCD	Liquid crystal display
LES	Lamp efficiency
OLED	Organic light-emitting diode
QD	Quantum dots
Rec. 2020	International Telecommunication Union (ITU) Standard Rec. 2020
SPD	Spectral power distribution
SSL	Solid state lighting
TV	Television
UHD	Ultra-high definition

4.1 Background

QD Vision, Inc. and 3M Optical Systems Division (or 3M Display Materials & Systems Division in the communication throughout the current review process) have submitted exemption requests No. 2013-2 and No. 2013-5:

- Cadmium in II-VI LED Down-conversion (Ex. Re. 2013-2, applicant QD Vision, Inc.)
- Cadmium in LCD Quantum Dot Light Control Films and Components (Ex. Re. 2013-5, applicant 3M Optical Systems Division)

The exemptions, both dealing with cadmium quantum dot applications, were evaluated in the course of an evaluation performed in 2013-2014. The final report was published in April 2014 and can be viewed here: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_IX/20140422_RoHS2_Evaluation_Ex_Requests_2013-1-5_final.pdf

On the basis of the evaluation report, the European Commission (EC) decided to amend exemption 39 of Annex III, which currently reads as follows:

> *"Cadmium in colour converting II-VI LEDs (< 10 µg Cd per mm² of light-emitting area) for use in solid state illumination or display systems*
>
> *Expires on 1 July 2014"*

The EC thus prepared a delegated act draft for this purpose[8], stipulating that an exemption with the following wording was to replace the current Ex. 39[9]:

"39(a)	Cadmium in colour converting II-VI LEDs (< 10 µg Cd per mm² of light-emitting area) for use in solid state illumination or display systems	Expires on 30 June 2017
39(b)	Cadmium in downshifting cadmium based semiconductor nanocrystal quantum dots for use in display lighting applications (< 0.2 µg Cd per mm² of display screen area)	Expires on 30 June 2018"

[8] EC (2015a), European Commission, COMMISSION DELEGATED DIRECTIVE ../…/EU of 30.1.2015 amending, for the purposes of adapting to technical progress, Annex III to Directive 2011/65/EU of the European Parliament and of the Council as regards an exemption for cadmium in illumination and display lighting applications, referenced as C(2015) 383 final of 30.1.2015, available under: http://ec.europa.eu/transparency/regdoc/rep/3/2015/EN/3-2015-383-EN-F1-1.PDF

[9] EC (2015b), European Commission, ANNEX to Commission Delegated Directive amending, for the purposes of adapting to technical progress, Annex III to Directive 2011/65/EU of the European Parliament and of the Council as regards an exemption for cadmium in illumination and display lighting applications, referenced as C(2015) 383 final of 30.1.2015, available under: http://ec.europa.eu/transparency/regdoc/rep/3/2015/EN/3-2015-383-EN-F1-1-ANNEX-1.PDF

On the 20 May 2015, the European Parliament objected to the Commission Delegated act adopted on the basis of the mentioned report[10], claiming that the report need be updated; thus a re-evaluation of these requests has been performed and is presented herein.

4.2 Description of the Requested Exemption

A short summary of the application for which the exemptions have been requested is provided in this section on the basis of the information available during the 2013-2014 review.

QD Vision[11] has explained that its requested exemption (renewal of exemption 39 of Annex III) is required to enable manufacturers to bring to the market a quantum dot down-conversion material for use in two kinds of applications: solid state lighting and display lighting applications. The II-VI down-conversion materials (e.g. quantum dots), due to their narrowband, tuneable, stable and efficient properties, will provide consumer products with superior performance, efficiency, and net benefit to the environment, for which there currently is no substitute available. QD Vision explains that in lighting, narrowband emission translates to warmer light with 20 - 40% greater efficacy[12]. Such products have already been placed on the market in the US. In the display market, narrowband emission translates to televisions, monitors, tablets and cell-phones that can achieve 100% of colour gamut (as defined by NTSC – see Section 5.1.1). This property has the added benefit of increasing light throughput through the display, which can in turn reduce energy consumption for identical perceived brightness by as much as 20%.

3M[13] explains that quantum dots (QDs) are a new class of non-naturally occurring materials that can be tuned to efficiently emit narrow spectral distribution light at the optimum wavelength for LCDs.[14] QDs are semiconductor nano-crystals, on the order of

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[10] EP (2015), European Parliament, European Parliament resolution of 20 May 2015 on the Commission delegated directive of 30 January 2015 amending, for the purposes of adapting to technical progress, Annex III to Directive 2011/65/EU of the European Parliament and of the Council as regards an exemption for cadmium in illumination and display lighting applications (C(2015)00383 – 2015/2542(DEA)), available under: http://www.europarl.europa.eu/sides/getDoc.do?pubRef=-//EP//TEXT+TA+P8-TA-2015-0205+0+DOC+XML+V0//EN&language=EN

[11] QD Vision (2013a), QD Vision original exemption request document concerning exemption request 2; available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_IX/Request_2013-2/20132301_NON-CONFIDENTIAL_Request_for_renewal_of_exemption_39.pdf, retrieved on 12.12.2013

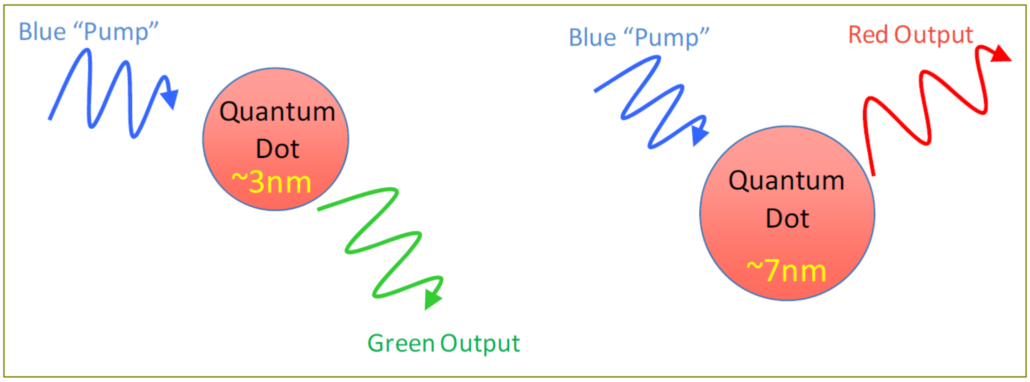
[12] It was not detailed in comparison to what type of lighting applications such an efficacy advantage is expected and thus the consultants interpret the statement to be general in nature.

[13] 3M (2013a), 3M Optical Systems Division original exemption request document concerning exemption request 2; available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_IX/Request_2013-5/3M_QDEF_Exemption_Dossier.pdf, retrieved on 05 June 2013

[14] Quoted by 3M (2013a) as: Hartlove, J. 2011. Quantum dots unleash high-colour-gamut performance in LED-backlit displays. LEDs Magazine

3-7 nm in size, in which excitons (an electron and hole excited pair) are confined on all three spatial dimensions. The wavelength of the light output from a semiconducting material is dependent on the band gap between normal and excited electron energy states. The spatial confinement of the electrons and holes of the quantum dot materials leads to higher band gaps compared to the band gap of same material in bulk. As a result, the band gaps of the quantum dots can be changed continuously by changing their physical size. Quantum dots are typically synthesized via solution chemistry (carefully controlled precipitation processes). By controlling different synthesis conditions (e.g. precursor, ligand concentrations, temperature, and time of the reaction) QDs of different sizes can be obtained. Light emitted from quantum dots can be tuned across most of the visual spectrum by controlling the size of the quantum dot as it is fabricated. According to the applicant, thin quantum dot light control films contain cadmium for which substitution is currently not technically practical. Alternative LCD technologies give broader ranges of colours which cannot be tailored to optimum wavelengths.[15]

Figure 4-1: Effects of Quantum Dots Size on Spectral Output (smaller QDs Emit Shorter Wavelength Light when Exposed to a Blue Source)



Source: 3M (2013a)

Quantum dots can be “pumped” with a blue source, such as the gallium nitride (GaN) LED, to emit at any wavelength beyond the pump source wavelength. The emission spectra of QDs have narrow line-widths and are free of “satellite” peaks, thus making them ideal candidates for display backlights to achieve high colour purity and increased system energy efficiency. QDs convert light with very high efficiency (>88% quantum efficiency) and with very narrow output spectral distribution of only 30 – 40nm full width at half maximum (FWHM). Due to their tunability, narrow spectral output distributions, and high quantum efficiencies, quantum dots are ideal for creating back light unit (BLU) light sources to increase colour gamut size and maximize LCD colour performance. [16]

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[15] Op. cit. 3M (2013a)
[16] Op. cit. 3M (2013a)

QD Vision states that the net benefit to the environment, of allowing the use of cadmium in the mentioned applications, is a result of the system level increase in efficiency that is achieved using the II-VI down-conversion materials, due to their narrowband, tuneable, and efficient nature.[17]

3M has stated in the past that the primary justification for this exemption is that only QD LCDs are able to achieve 100% colour gamut for all screen sizes and a secondary justification is that the potential substitutes have a greater negative environmental impact.[18]

At the time of the first review, a contribution was made by Nanoco-Dow[19] to the stakeholder consultation, providing information regarding a potential substitute – cadmium-free quantum dots. This substitute was explained to be a quantum-dot material and in that sense similar in how it could be applied in display and lighting applications as a possible substitute. Lack of detailed quantifiable information at the time did not allow an actual comparison of the two technologies. The understanding that articles using Cd-free QD technologies had not been placed on the market at the time of the first review led to a recommendation to grant a short termed exemption for Cd-QDs used in display applications. As it was understood that solid state lighting applications did not exist on the market at that time for either technologies, the consultants recommended not granting an exemption for the use of Cd-QDs in lighting applications.

For additional details as to the function principles of quantum dots please refer to the final evaluation report of the 2013-2014 review.[20] The following sections shall focus on information provided by the applicants and by stakeholders in the course of the current review. From the information and data provided by the applicants and by various stakeholders, it is apparent that a distinction between quantum dots in display applications and quantum dots in solid state lighting applications has to be made to facilitate the comprehension of the review and its conclusions. The report is thus separated into a chapter related to quantum dots in displays and a chapter related to quantum dots in solid state lighting. Each chapter includes a summary of available information of relevance to the evaluation, a critical review of the various arguments

[17] Op. cit. QD Vision (2013a)
[18] Op. cit. 3M (2013a)
[19] Nanoco-Dow (2013a), Contribution made concerning Ex. Re. 2013-2 – answers to RoHS Consultation Questionnaire, submitted by Nanoco Technologies Limited & Dow Electronic Materials on 06.11.2013, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_IX/Request_2013-2/20131106_Nonoco_Dow_Contribution_Ex_2013-2_Response_to_RoHS_Questionnaire.pdf
[20] Baron et al. (2014), Baron, Y.; Blepp, M.; Gensch, C.-O.; Deubzer, O.; in collaboration with Hogg, D., Assistance to the Commission on technological, socio-economic and cost-benefit assessment related to exemptions from the substance restrictions in electrical and electronic equipment (RoHS Directive) - Pack 4, Eunomia Research & Consulting Ltd. in cooperation with Oeko-Institut e.V. & Fraunhofer IZM; 2014, Commissioned by: European Commission, DG Environment, Brussels, available under:
http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_IX/20140422_RoHS2_Evaluation_Ex_Requests_2013-1-5_final.pdf

raised and final conclusions as to the justification for an exemption on the basis of the Article 5(1)(a) criteria. The two chapters are then followed by a recommendations chapter which summarises the consultants' endorsements for each of these two application areas.

5.0 Cadmium Quantum Dots in Display Applications

In the 2013-2014 evaluation of these requests, the two applicants (among others) provided data as to the first display products made available on the market making use of cadmium quantum dots (CdQD). In parallel it was understood that first products making use of cadmium-free quantum dots (CFQD), a potential substitute for CdQD based products, were expected to shortly be placed on the market. On this basis it was concluded that the availability of various QD based display products on the EU market in the short term, would allow a better understanding of the performance of each of the alternative QD materials, facilitating a more comprehensive understanding as to the justification of exemptions for CdQDs in display applications. The applicants and stakeholders have thus been requested to provide information as to changes in the market status of these technologies and as to their comparative performance. Information made available in this respect is presented in the following sections.

5.1 The Market Availability of Quantum Dot Displays

QD Vision[21] is a manufacturer of CdQD technologies. Products on the market using its technology are currently understood to use an on-edge configuration, in which the QDs are encapsulated in an optical tube or capillary, placed at the sides of the display. As for the market availability of products, QD Vision states that the availability of displays (monitors and televisions) is complex due to the complicated distribution practices of manufacturers. QD Vision provides detailed data from 20.10.2015 as to the displays using QDs on the global market and the EU market[22], adding that at the time of writing, two televisions and one monitor were commercially launched. QD Vision summarises the displays available on the EU market at the time of writing as appears in Table 5-1.

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[21] QD Vision (2015a), QD VISION Responses to Question by Oeko-Institut Regarding Exemption 39.b, submitted 28.10.2015, available under:
http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_QD_Exs__QD_Vision_a_QD_Vision_Response_to_Oeko-Institut_Regarding_Exemption_39.B.pdf

[22] Please see detailed data under:
http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_QD_Exs__QD_Vision_f_QD_Product_List_20_October_2015.pdf

Table 5-1: Available QD Displays on the EU Market According to QD Vision

	CdSe displays available on EU market	InP displays available on EU market
Current model televisions	Thomson : 55UA9806 – 55"	Samsung UN55JS9000F – 48"-88"
Televisions to be launched 10-11/2015:	Hisense: based on K7100 – understood to be 55"	
Current model monitor:	Philips : 276E6 – 27"	

Source: QD Vision (2015)

In a later communication, QD Vision[23] explains that display manufacturers are not consistent in the way they bring their models to market. For instance, it appears that Hisense has decided to launch their QD-based TVs in China first, while waiting for the exemption process in Europe to be clarified. On the other hand, TPV (Philips) has introduced its QD-based monitor in all major markets, including the US and Europe. "*Characteristically, during the period of the exemption process, we have found models appearing and disappearing from retail sites and online stores. We strongly believe, however, that many more models would come to market if the regulatory uncertainty around the QD exemption were resolved*".

QD Vision[24] was asked to further elaborate as to the differences in the variety of Cd QD displays distributed globally and within the EU and further elaborated the following. "*A number of QD Vision's customers and prospects have expressed concerns about shipping their existing or future QD TV models into the EU, due to the uncertainty around the status of the RoHS exemption. Since last May, QD Vision executives have been asked by each of our customers to present status reports on the RoHS process, suggesting keen interest in the results of this evaluation and substantial business implications. QD Vision is not aware of any other features… that would preclude them from being shipped into the EU. All can be adapted for operation at either 110 or 220V, all are in common screen sizes (55" or 65"), and all feature multi-lingual user interfaces. In addition, they are all offered under globally-recognized brands – TCL, Hisense, Philips, and Thomson – from multi-national corporations that ship products in all major markets*."

3M DMSD [25] is a manufacturer of backlight enhancement films in the liquid crystal display (LCD) industry. 3M DMSD explains that it is a consumer of Quantum Dot (QD) materials and not a manufacturer of QD materials, currently utilizing cadmium selenide (CdSe) containing QDs as they provide the most energy efficient solution to achieve

[23] QD Vision (2016c), QD VISION Response to Oeko Institut Questions (2nd Round) on Rohs Exemption 39b, submitted 19.4.2016

[24] QD Vision (2016d), QD VISION Response to Oeko Institut Questions (3rd Round) on Rohs Exemption 39b, submitted 21.4.2016

[25] 3M DMSD (2015), 3M Display Materials & Systems Division, Re: 1st Questionnaire Regarding CdQD Exemptions, submitted 26.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_QD_Exs_3M_DMSD_QDEF_RoHS_Excemption_1st_Questionnaire_PACK_10_20152610_.pdf

current and future colour standards. 3M DMSD provides the following table, summarising devices currently available on the market:

Table 5-2: Commercial Quantum-dot Based Displays According to 3M

Type	Manufacturer	Product Family/Model	Diagonal (")	CdSe Based	Available as of Oct 20, 2015
TV	Samsung	SUHD	48 to 85	No (InP)	Yes
TV	Hisense	ULED	55 to 65	Yes	Yes
TV	Vizio	Reference Series	65	Yes	Yes
TV	TCL	H9700	55 to 65	Yes	Yes
TV	Philips	55PUF6850/T3	65	Yes	Yes
Monitor	Asus	PA329Q	32	Yes	Pending (within 2015)
Monitor	BENQ	SW2700PT	27	Yes	Yes
Monitor	Philips	276E6ADSW	27	Yes	Yes
Notebook	Asus	NX500	15.6	Yes	Yes
Tablet	Amazon	Fire HDX	7	Yes	End of Life

- There are other devices on the market using 3M's QDEF but 3M is not at liberty to disclose this information

Source: 3M DMSD (2015)

3M DMSD[26] explains that the life cycle of an electronic device [the period throughout which a device is sold on the market – consultants' interpretation] is typically 6 to 12 months, and it is customary with these types of electronic devices to replace models on a frequent basis. It is the nature of the electronic industry that models will be replaced with the next generation seeking to improve brightness, colour and energy efficiency. 3M DMSD further details the following press releases anticipating additional implementation of Cd based QD technology:

- AUO (large panel supplier to the industry) announced full line up of QD TV's (scaling production, but end TV brands not disclosed yet): http://www.auo.com/?sn=107&lang=en-US&c=9&n=1775
- Changhong QD TV: http://www.changhongglobal.com/egdch/1982_10022.htm
- German article: http://www.areadvd.de/tests/ces-2015-die-tv-neuheiten-von-changhong-uhd-curved-undquantum-dot-technologie/
- 3M and Nanosys demonstrated displays showing over 90% of the Rec. 2020 gamut at SID [the Society for Information Display Week event] (June, 2015);
- At IFA (September 2015 consumer electronics trade show) TCL and QD Vision demonstrated a TCL- branded TV that presented over 90% of the Rec. 2020 colour gamut;

[26] Op. cit. 3M DMSD (2015)

- Vizio announced commercial availability of first REC 2020 TV (R-series) on October 6, 2015.

3M DMSD[27] continues that there is also strong interest from display makers for medical devices to incorporate the QD technology, as the enhanced colour image is an invaluable asset in that market segment, allowing for better discrimination in and enhanced ability to read diagnostic images. The automobile industry is said to be eager to use these higher performing displays in their applications as they provide better daylight readability.

In relation to the availability of QD materials, 3M DMSD further states that it is committed to utilize non-Cd based alternatives if and when they can meet customer requirements. However in this respect it is further stated "*to date no commercially viable non-Cd substitutes are available for purchase on the market. Although one manufacturer (Samsung) has put one line of TVs on the market containing a non-Cd (indium phosphide) QD material, this is a captive supply used in only one line of TV. For clarity, the Samsung non-Cd QD material is not available for purchase by others. Aside from the single line of Samsung televisions, there are no other electronic displays, in any application, using non-Cd QD solutions, and there are absolutely no non-Cd Qd materials available for purchase in production quantities from third parties due to repeated delays by QD manufacturers to bring a non-Cd solution to the market for general purchase*." In this respect, 3M DMSD argues that "*Article 5(l)(a)(2) of Directive 2011/65/EU provides that one basis for granting an exemption is when the reliability of substitutes is not ensured. This criterion is met, because there is no available substitute on the market today for CdSe based QDs.*"[28]

3M DMSD[29] claims that the performance and suitability of both non-Cd and Cd-based QD materials were discussed by leading producers in the industry at a QD Forum held in March 18, 2015 in San Francisco. At this event, based on the current demonstrated state of technology, it is said to have been clear that commercialized non-Cd materials have not demonstrated the ability to fuly meet current colour standards (DCI-P3) nor are they able to meet pending colour standards in an energy efficient way. QD Vision has made similar statements. Prior to the presentation of information that the applicants have provided to substantiate these claims (Section 5.4), some information is reproduced in Section 5.1.1 as to the various standards and methods available for comparing the performance of display applications.

Nanoco Technologies[30] develops and manufactures a Cd-free alternative that it explains to be an inorganic semiconductor alloy based on indium and including other metallic and

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[27] Op. cit. 3M DMSD (2015)
[28] Op. cit. 3M DMSD (2015)
[29] Op. cit. 3M DMSD (2015)
[30] Nanoco (2015a), Nanoco Technologies, Nanoco Response to 1st Questionnaire Regarding CdQD Exemptions, submitted 28.10.2015, available under:

non-metallic elements. Nanoco provides data reproduced in Table 5-3 as to displays available on the market containing Cd-free QDs and Cd-based QDs, also stating that announcements have been made about one or two other Cd-based QD display products being launched soon in the EU, such as a Philips 27” computer monitor.

Table 5-3: Cadmium-free (above) and Cadmium-based (below) QD Displays Available in EU as of October 2015, According to Nanoco

Manufacturer	Model	Size	QD Type	Application	Availability
Samsung	JS8500	48"	Nano Crystal (Cd-free QD)	SUHD Film	All EU
Samsung	JS8500	55"	Nano Crystal (Cd-free QD)	SUHD Film	All EU
Samsung	JS8500	65"	Nano Crystal (Cd-free QD)	SUHD Film	All EU
Samsung	JS9000	48"	Nano Crystal (Cd-free QD)	SUHD Film	All EU
Samsung	JS9000	55"	Nano Crystal (Cd-free QD)	SUHD Film	All EU
Samsung	JS9000	65"	Nano Crystal (Cd-free QD)	SUHD Film	All EU
Samsung	JS9500	65"	Nano Crystal (Cd-free QD)	SUHD Film	All EU
Samsung	JS9500	78"	Nano Crystal (Cd-free QD)	SUHD Film	All EU
Samsung	JS9500	88"	Nano Crystal (Cd-free QD)	SUHD Film	All EU

Manufacturer	Model	Size	QD Type	Application	Availability
Sony	KDL-X9000A	55"	Cadmium based	Glass tube	Withdrawn 2014
Kindle	Fire HDX	7"	Cadmium based	QDEF Film	Withdrawn 2014
Asus	NX500	15.6"	Cadmium based	QDEF Film	Very limited
Thomson	UA 9806	55"	Cadmium based	Glass tube	Very limited

Source: Nanoco (2015)

Nanoco[31] further claims that the commercial availability of Cd-free QD materials and components is now well established:

- Samsung and its manufacturing partner Hansol have large scale commercial production capacity already operational in Korea.
- Nanoco has commercial production of CFQD® QD technology in the UK.
- Dow has built a large scale commercial plant in Korea to produce CFQD® QD technology.
- Several other QD companies have announced plans for Cd-free QD supply. These include Nanosys who has recently stated that 40% of its sales are already from Cd-free QDs.

In a later communication, Nanoco informs that the Dow plant is complete and Dow TREVISTA™ products using Nanoco CFQD® quantum dot technology are expected to be used in commercial display products this year [i.e. 2016 – consultants’ comment]. Also, in order to accelerate the commercial adoption of CFQD® technology, Nanoco and Dow

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http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_QD_Exs_Nanoco_Response_to_RoHS_Questions_27_Oct_2015.pdf

[31] Op. cit. Nanoco (2015a)

has agreed to make the Dow license non-exclusive. Nanoco is now actively working to launch CFQD® film products in commercial displays this year based on its own QD production capacity in the UK.[32]

Nanoco[33] also states that other cadmium-free display technologies (non-QD) include:

- LED/phosphor technology is the most widely used for displays of all sizes. Phosphor and colour filter technology improves year-on-year to provide increasing colour gamut with acceptable energy efficiency.
- Colour filter technology is improving, which enables LED/phosphor technology to achieve higher colour standards.
- OLED technology is widely available in small screen sizes, mainly for mobile devices. Large TV displays are also available in increasing numbers and at reducing prices. Colour performance is usually very high, but energy efficiency is typically lower than for a comparable LED TV or Cd-free QD TV. Nanoco believes that manufacturing costs for large OLED screens will continue to be significantly higher than for LED screens for the foreseeable future.

Nanoco[34] provides information as to further alternatives to Cd-based QD colour-converting materials including various types of Cd-free QDs emitting across the visible spectrum, as well as alternative technologies, such as QLED technology, which utilises the electroluminescent (EL) properties of QDs, OLEDs, LG's "IPS Quantum Display" technology and various new non-QD high performance phosphor materials:

- QLED - Within a QLED device, a QD layer is sandwiched between electron- and hole-transporting organic layers. The application of an electric field causes electrons and holes to move into the QD layer, where they recombine to emit photons. QLED technology could be used for both displays and backlighting. The development of QLED technology using Cd-free nanoparticles, including InP and $CuInS_2$, has been reported in the literature.
- OLED - OLED displays show high colour gamut and high contrast to give very good image quality. Wider adoption has been held back by high manufacturing costs and lower energy efficiency compared to LCD displays. However, this technology is continuing to improve and major companies like LG are committed to using it and are investing $9billion.
- IPS Quantum Display – This technology, developed by LG, uses potassium- and nitrogen-based compounds in combination with a blue LED. The technology can be used to achieve 98% of the DCI colour standard, and is currently available in LG G4 smartphones.

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[32] Nanoco (2016b), Nanoco Technologies, Response to Additional Questionnaire (2nd Round)Regarding Cadmium QD Exemptions, submitted 20.4.2016

[33] Op. cit. Nanoco (2015a)

[34] Op. cit. Nanoco (2015a)

- High Performance Phosphors – Several new, narrow band emission phosphors have been developed recently. These can be used to provide improved CRI and R9 quality for lighting with improved energy efficiency. They can also provide improved colour gamut in display applications. Examples include:
    - Apple recently launched a new range of monitors for their iMac computers that use high performance phosphors to achieve wide colour gamut in line with the DCI-P3 standard.
    - TriGain™ Phosphor from GE. GE claims a 32% improvement in luminous efficiency at CCT of 4000K compared to a conventional high CRI LED. This uses a $K_2SiF_6:Mn^{4+}$ phosphor that is referred to by GE as PFS and by others as KSF. GE is also licensing TriGain for display applications with >90% NTSC.
    - Sharp produces β-sialon:Eu, which is a narrow emission green phosphor using a rare earth doped oxy nitride (β-$SiAlON:Eu^{2+}$). This has been used by Sharp, in conjunction with KSF red phosphor, to produce LEDs for displays that can achieve 107% of NTSC area (CIE 1976) while achieving high brightness.
    - Dexerials has used a narrow green thiogallate phosphor ($SrGa_2S_4:Eu$) and red sulphide phosphor (CaS:Eu) to make a film for displays with 90% NTSC.

5.1.1 Amount of Cadmium Used under the Exemptions

In the 2013-2014 review, the following information was presented concerning the amount of Cd to come onto the EU market through relevant applications.

At the time, QD Vision[35] provided estimations for the Cd content that is present in various products manufactured with CD QDs:

- *"Large Display (TV): Average = 500-1500ppm, 1200 ppm (µg/gram) of homogeneous material (quantum dots distributed in polymer matrix) typical, 1.5mg total cadmium per unit.*
- *Medium Display (Computer Monitor): Average = 1000-3000ppm, 2000 ppm typical, 0.2mg cadmium per unit.*
- *Small display (Cellphone): Average = 1000-5000ppm, 3000 ppm typical, 10 ug cadmium per unit.*
- *Lighting device (bulb/fixture): Average = 1000-5000ppm, 3000 ppm typical, 20 ug cadmium per unit.*

…At 100% penetration of II-VI down-conversion materials for both lighting and displays, our calculations show that a maximum of 120kg of cadmium could enter the EU annually under this exemption. Given the current lack of product on the

[35] *Op. cit. QD Vision (2013a)*

market, a reasonable product ramp projection and the proposed 2019 expiry of the renewed exemption, 44kg of total cadmium would enter the EU over the 2014-2019 time period (Annex 6[36]). This represents an average of 8.8kg per year for this time period…"

3m[37] estimated in the course of the past review that typically 147 kg of cadmium will be placed on the EU market annually by this application (i.e. QD on-surface applications). Table 5-4 outlines the calculations used to develop this estimation. Using the same numbers it is estimated that 565 kg of cadmium will be placed on the global market annually (i.e. the EU has a 26% share of global sales).

Table 5-4: 3M Estimation of Cd Placed on the EU Market through QD Applications Addressed in Ex. Re. 2013-5

Application	Global Annual LCD Area (1) (m^2)	EU Share of LCD Area (2) (m^2)	% Using QD Film(3)	LCD Area Using QD Film in EU (m^2)	Typical Cd Content per LCD Screen Area (g/m^2)	Total EU Cadmium (kg)
TV	157,333,925	26%	2%	818,136	0.05	41
Monitor	29,365,561	26%	3%	190,876	0.05	10
Notebook/Ultrabook	22,819,763	26%	7%	415,320	0.05	21
Tablets	12,174,293	26%	60%	1,899,190	0.03	57
Small displays (phones, etc.)	12,000,660	26%	20%	624,034	0.03	19
					Total	***147***

1. Based on forecasts from iSuppli in the Q4 2011 LCD Market Tracker Database and the Q4 2011 Small & Medium Display Market Tracker Database
2. Estimated based on EU's share of global GDP
3. Estimates for the potential use of QD film for the various segments

Source: 3M (2013a)

In parallel, estimations provided for the current evaluation as to the potential for energy savings and for subsequent savings of Cd emissions facilitate the assessment on the basis of the data used. 3M DMSD submitted a report prepared by Goodman[38] in which among others the environmental impacts related to energy savings of CdQD displays was calculated. These calculations assumed that one 55" CdQD TV contains 39.7 mg Cd and stated that recent research shows that there are on average two TVs per EU household, and that there are 216 million households in the EU. This would mean that there are 432 million TVs in the EU. For energy savings related to Cd QD TVs, Goodman's calculations assume that 10% of the TVs currently in use in the EU would be CdQD ones.

The consultants thus calculate that this estimation would mean that such TV's would have brought 1,715 kg of Cd onto the market. It should be noted that this amount

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[36] *For more detail, see Annex 6 to the Applicants Dossier, available under:* *http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_IX/Request_2013-2/Annex_06_Cd_calculations_summary.pdf*

[37] *Op. cit. 3M (2013a)*

[38] Goodman (2015), EdifERA, Socio-economic assessment for Cd QD displays, submitted to stakeholder consultation by 3M DMSD on 7.1.2016, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/3M_socio_economic_reportf.pdf

however is not related to an annual amount and that it should be assumed that this amount would be placed on the EU gradually, were 10% of all TV's to be Cd QDs containing 39.5 mg Cd.

An LCA report[39] prepared on behalf of QD Vision by Engler et al. refers to an update of the estimate of the LCD TV market in the EU[40], which calculates that "*if every one of the estimated 57.4 million LCD TVs expected to be sold in Europe in 2015 used on-edge CdSe QD optical components, 86 kg of additional Cd (as CdSe QDs) would enter the EU. A more realistic estimate of 35 percent market penetration would lead to about 30 kg of Cd (as CdSe QDs) entering the EU*".

The QD Vision estimation is understood to refer to the additional amount of Cd to be placed on the market per annum. It is noted from the information provided by QD Vision (see for example in Section 5.4.2.1), that on-edge configurations use much less Cd than on-surface ones (1.5 mg per display in comparison with 25-166 mg), possibly explaining in part the differences between 3M estimations and QD Vision ones.

5.2 Standards and Methods for Comparing Display Performance

For the purposes of this exemption request, QD Vision[41] recommends the reassessment be based on a direct comparison of the CdSe QD and InP QD at the level of the technologies, and not at the level of the applications, i.e. the qualities of the displays in which they are included. While the displays can give some indication of certain colour qualities of the QD technologies, the displays do not permit a fair and complete comparison of the underlying QD technologies themselves. For example, aspects of the display design, e.g., panel choices, optical film choices, and LED selection can all influence the overall system efficiency and colour. According to QD Vision, the parameters required for a comparison are external quantum efficiency and FWHM ("full width at half maximum") of emission. If a system level comparison is also of secondary value, parameters of importance become:

- Luminance efficiency (i.e. Nits/Watt) of the electronic device; and
- % coverage of NTSC colour gamut area.

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[39] Engler et al. (2015), Engler, R. E., MacDougall, L. S., Xu, J. B., and Willis, J., The Acta Group on behalf of QD Vision, Inc., L.L.C, Supplemental Statement on Life Cycle Analysis and Comparison of Cadmium (CASRN 7440-43-9, EC 231-152-8), Cadmium Selenide (CASRN 1306-24-7, EC 215-148-3) vs. Indium Phosphide (CASRN 22398-80-7, EC 244-959-5) for Colour Conversion in Displays, 26.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_QD_Exs__QD_Vision_d_QDV_Supplemental_Life-Cycle_Analysis.pdf

[40] Referred to in Engler et al. (2015) as Risk & Policy Analysts (2015): Cadmium Selenide Quantum Dots—RoHS Exemption Supporting Arguments. Final Report.

[41] Op. cit. QD Vision (2015a)

QD Vision[42] explains that the Rec. 2020 specification was approved in October 2015 and is now an industry standard. QD Vision admits that meeting this standard is challenging [i.e. also for CdQDs – consultants' comment]. But the whole point of new standards is to set a bar that companies must aim for, but cannot fully meet at adoption. QD Vision claims that it is generally understood in the industry that CdSe QDs show the promise of achieving Rec. 2020 colour gamut targets. QD Vision claims that there is currently no known technical path to Rec. 2020 for InP QDs.

3M DMSD[43] states that it is intended that upcoming ultra-high definition (UHD) television broadcasting will use the ITU-R Rec. 2020 standard. Additionally, 3M DMSD states that it is anticipated that the first UHD BluRay™ players, supporting this standard will be introduced to the market in early 2016. 3M DMSD also claims that this colour performance cannot be met by non-Cd technology at this time.

According to 3M DMSD[44], the relative parameters for enabling a comprehensive comparison of performance are:

A. Colour gamut – the ability to meet current and future colour standards;
B. Luminance and power - energy-efficiency;
C. Net positive environmental impact;
D. Reliability;

3M DMSD[45] provides a comparison of colour standards reproduced in Table 5-5.

[42] QD Vision (2016a), QD Vision Response to Nanoco's Oeko Submission on Exemption 39.B, submitted 8.1.2016, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/QD_Vision_Response_to_Nanoco_Submission_FINAL_010816.pdf

[43] Op. cit. 3M DMSD (2015)

[44] Op. cit. 3M DMSD (2015)

[45] 3M DMSD (2016a), 3M Display Materials & Systems Division, Re: Pack 10 Stakeholder Comment Questionnaire Regarding CdQD Exemptions, submitted 7.1.2016, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/3M_DMSD_Stakeholder_Contribution_PACK_10__002_.pdf

Table 5-5: Comparison of Colour Standards Submitted by 3M

Color Specification	What It Covers	Where It Is Used	Characteristics
National Television System Committee (NTSC) (Also known as Standard Red Green Blue or S RGB)	Analog television systems, with color specifications, lines and refresh rate, color encoding, transmission modulation. Many countries have shifted to ATSC which contains no defined color standard.	Televisions, mainly. There is a related cinema standard, used rarely.	SMPTE "C" colorimetry, using relatively narrow primary and white point colors based on CIE 1931 standards; covers about **38%** of colors visible to the human eye
International Telecommunications Union recommendation BT.709 (Rec 709 or BT 709)	International standard developed for high definition televisions in 1990; specifies refresh rate, pixel count, chromicity, standards conversion, luma coefficients, transfer characteristics	Televisions	Covers about **36%** of colors visible to the human eye
Adobe RGB	Developed by Adobe Systems Inc in 1998, it was meant to encompass most printed colors covered in CMYK color space.	Generally used by graphic designers and others working with print production to ensure color on a display matches the color in print. Televisions, desktop displays (monitors), notebook computers. Very limited and relatively expensive	Covers about **50%** of colors visible to the human eye
Digital Cinema Initiatives (DCI P3)	This is the common colour space for digital movie projection from the American film industry.	Considered the pre-cursor to the significantly wider color gamut delivered by the BT.2020 or Rec 2020 standard	DCI-P3 is said to have distinct drawbacks in the blue-green range. Covers about **42%** of colors visible to the human eye
International Telecommunications Union recommendation BT.2020 (Rec 2020 or BT 2020)	This ITU recommendation, introduced in 2012, sets standards for broadcast-enabled devices; includes such aspects as resolution, frame rate, chroma subsampling, bit depth, and color space.	Displays on televisions, desktop displays, notebook computers, tablets and smartphones are subject to this recommendation. At this time, no one has achieved 100% of the Rec 2020 color space.	Nearly **100%** of the colors visible to the human eye are included in the Rec 2020 space

Source: Referenced in 3M DMSD (2016a) as Noteloop, a group of cinema and broadcast designers who work specifically in colour for the industry.

Nanoco[46] explains that the main reason for using QD technology in display products is to provide improved colour gamut. However, the required colour gamut is determined by the colour standards used by the display and media industries, as extra colour capability can only be used when there is content available that has been encoded with the appropriate colour data. Also, it is necessary to differentiate between area and coverage. The colour triangle area of a display could be 110% of the area of the NTSC colour standard triangle, but only covers 85% of the position of the standard triangle. In this

[46] Op. cit. Nanoco (2015a)

case the display would only be able to show 85% of the NTSC standard colours, so the 85% coverage is the relevant performance measure. Nanoco states that there are three relevant colour standards for displays, noting that displays are usually designed to optimise performance against one of these standards. Because the red, blue and green primary colours for these standards are at different wavelengths, displays that are optimised for one standard may not have optimum performance when compared against a different standard:

- DCI (P3) - The standard most widely referred to by leading TV manufacturers is DCI P3, which has been developed for digital cinema. This represents the highest quality media generally available.
- sRGB (Rec. 709) - The standard most widely referred to by computer monitor manufacturers is sRGB, which has the same colour space as Rec. 709 that is also used for TVs.
- NTSC - Generally regarded as a secondary standard, but is more commonly used in certain markets.

According to Nanoco[47], the secondary factor for the environmental life-cycle performance of displays is their energy consumption. This is regulated by the Energy Labelling Directive 2010/30/EU. Manufacturers must provide power consumption data under standard test conditions and an overall efficiency rating, so that similar size/type of displays can be easily compared. This is intended to encourage consumers to use more energy efficient products.

In relation to the Rec. 2020 standard, Nanoco states the following: "*The applicants have argued that only cadmium QD technology can meet colour performance standards for the high colour gamut display market, but this is clearly not true as the increasing sales of Samsung SUHD televisions show, as does Samsung's policy commitment not to use cadmium based technology… the relevant current standards (sRGB, DCI-P3, Abobe RGB) can all be effectively achieved (>90% coverage) using 1st generation commercial cadmium-free QD technology. The technical performance of this technology will continue to improve rapidly through innovation… It is possible that standards for high colour displays will change in future, with Rec. 2020 being a possible contender. However, that standard is still in development, commercial media content is not yet available and no commercially available cadmium QD displays achieve >90% coverage. Rec. 2020 performance therefore cannot be used as a test for the practicality of substitution of cadmium based QDs in this review*." Nanoco provides among others comparisons of the performance of various televisions in relation to gamut colour according to various standards to support this point, reproduced in Table 5-10 and Table 5-11.

[47] Op. cit. Nanoco (2015a)

5.3 Applicant's Justification for Exemption

3M DMSD[48] raises the following points to justify an exemption for displays:

- There is no substitute for CdSe QDs that meet the **colour quality and energy consumption performance** metrics required by 3M's customers in the electronics market.
- **Reliability**: 3M's evaluation of leading-edge, experimental non-Cd QDs indicates that they would result in unacceptable in-device lifetimes for electronics industry customers. While Samsung has made a single line of devices (TVs) available on the market using non-Cd based QDs, the QD material itself is not available for purchase by third parties, and the performance of the Cd free material is not equivalent with that of CdSe QDs
- **Environmental impacts**: The lower energy consumption of CdSe QDs containing display devices[49] reduces the amount of electrical energy needed, thereby reducing the environmental pollutants created during the electrical energy production process.
- **Socio-economic impacts**: There is also an economic benefit for consumers. Devices that use less energy cause less pollution from electricity generation and are also cheaper to run.
- **Availability**: To date no substitutes that deliver the performance required by their customers has been made available on the open market.

5.4 Comparative Performance of Quantum Dot Displays

QD Vision[50] provides a number of comparisons.

To demonstrate the performance of the QD material, QD Vision compared two television sets in the following manner:

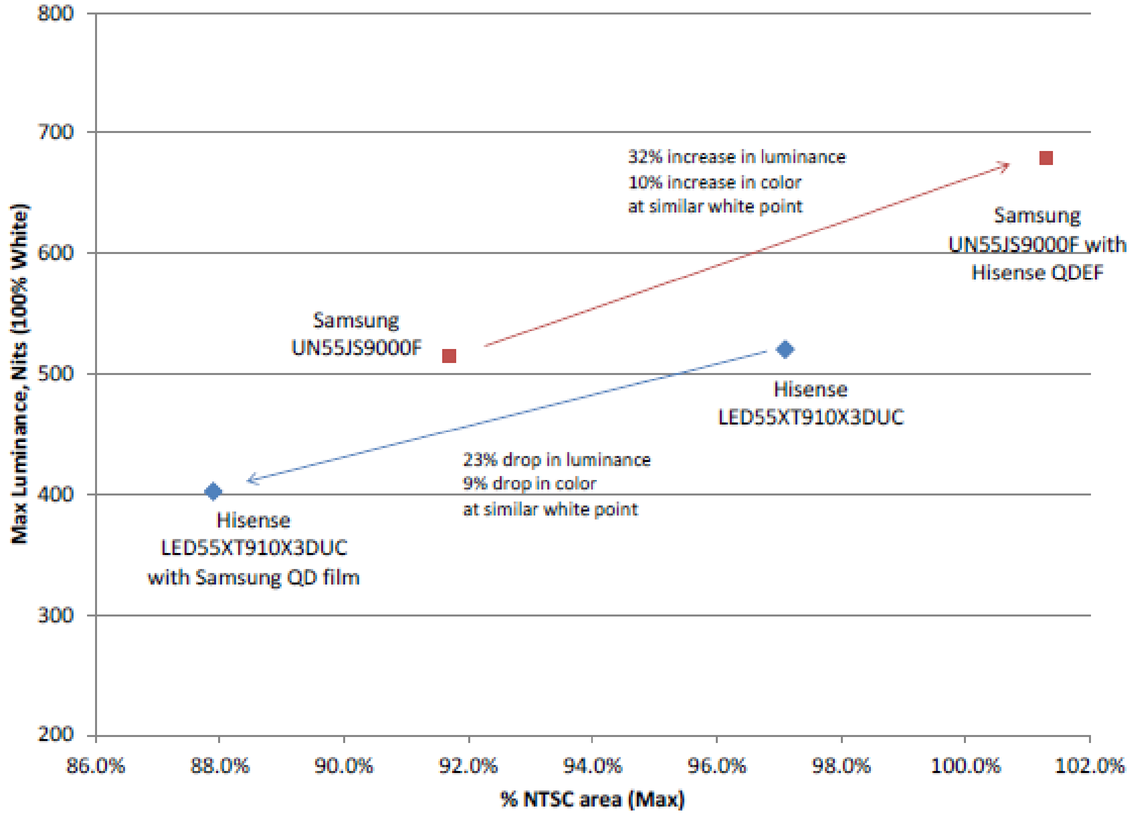
- An InP-based QD film taken from a Samsung television (model # UN55JS9000F) is placed in a Hisense television (model # LED55XT910X3DUC) originally configured with a CdSe-based QD film from 3M; and
- A CdSe-based QD film from 3M taken from the aforementioned Hisense television is installed in the aforementioned Samsung television originally configured with an InP-based QD film.

QD Vision states that the results of this test (see Figure 5-1) demonstrate the dramatic disparity in performance between the CdSe-based QD film from 3M and the InP-based QD film used by Samsung. Swapping the CdSe-based QD film into the Samsung television

[48] Op. cit. 3M DMSD (2016a)
[49] Consultants' comment - It is not specified compared to what Cd QDs exhibit lower energy consumption. From available data, it has been shown that this statement is relevant for display models where an InP QD film was swapped with a Cd QD film, however comparative data as to displays does not show that an advantage is always relevant when different displays are compared to each other.
[50] Op. cit. QD Vision (2015a)

originally configured with an InP-based film results in a 32% increase in luminance (explained by QD Vision to result from the higher efficiency of the CdSe-based QD film) and an increase in colour gamut from 91.7% to 101.3% NTSC area (explained to result from the narrower emission spectra from the CdSe-based QD film). QD Vision states that these results are supported by component-level testing, where the CdSe-based QD film was found to be significantly more efficient than the InP-based film (external quantum efficiency of 73% vs. 57%) and to have much narrower emission spectra (FWHM for green and red of 33 and 37nm, respectively, for the CdSe-based QD film, compared to 41 and 55nm for the InP-based QD film). [51]

Figure 5-1: QD Vision Comparison of Luminance Efficiency (nits/watt) vs. Colour Gamut for CdSe and InP Films in Samsung and Hinsense TV Models



TV	Model #	Edge Lit/ Back Lit	Setting	Luminance (nits)	Power (W)	Luminance Efficiency (nits/watt)	NTSC Area (1931)	White CP
Hisense 55" QDEF	Hisense LED55XT910X3DUC	Back Lit	Cinema	520	189.9	2.74	97.1%	(0.282, 0.290)
Hisense with Samsung QDEF	Hisense LED55XT910X3DUC with Samsung QD film	Back Lit	Cinema	402	189.7	2.12	87.90%	(0.279, 0.299)
Samsung 55" QDEF	Samsung UN55JS9000F	Edge Lit	Dynamic	515	210.0	2.45	91.7%	(0.274, 0.289)
Samsung with Hisense QDEF	Samsung UN55JS9000F with Hisense QDEF	Edge Lit	Dynamic	680	209.1	3.25	101.30%	(0.277, 0.284)

Source: QD Vision (2015b)

[51] Op. cit. QD Vision (2015a)

QD Vision[52] emphasizes that "*screen quality and the ability to exceed NTSC c.q. meet AdobeRGB or REC 2020 is not an aesthetic aspect, but a crucial criteria for the assessment as it is the linchpin of performance and competitiveness and critical for Europe to remain current and competitive in such fields as medical diagnostics, e-commerce and entertainment*." QD Vision claims that today's high-end displays are able to produce only 30% of the colours visible to the human eye. With QD Vision QDs, it is said that displays approaching 60% of the human visible colour gamut are possible. A few key aspects raised in relation to the importance of colour gamut are:

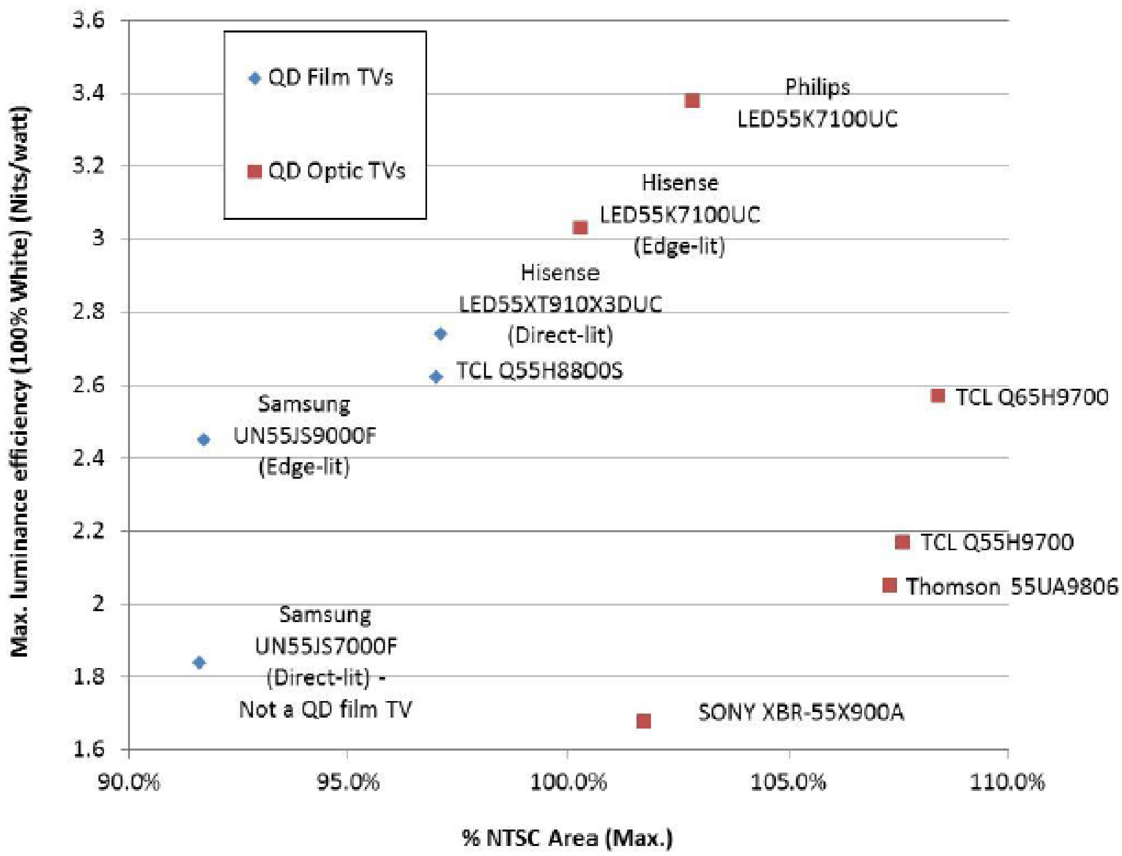
- Diagnostics – medical and otherwise – rely in a large part on colour. Higher display quality improves the precision and therefore impact of these technologies;
- Audio-visual productions, whether artistic or of sports and events, have become consistently more popular as screen quality has improved; and
- E-commerce is materially affected by the quality of displays as this in part drives their high return rate [understood in part to be a result of products returned following dissatisfaction with purchased product appearance – consultants' comment].

QD Vision[53] has characterized QD TV performance (luminance, colour, power consumption) for various TV settings. The luminance efficiency (nits/watt) vs. colour gamut is compared for various wide colour gamut TVs that are current in the market, and is shown in Figure 5-2 along with comparative data. QD Vision provides the following observations:

- Hisense QDEF TV has better colour gamut and luminance efficiency compared to Samsung SUHD TV. Both these TVs have luminance greater than 500 nits.
- Hisense Colour IQ TV (edge lit) has better colour gamut and luminance efficiency compared to Hisense QDEF TV (direct lit). Edge lit Hisense TV has 400 nits luminance while the direct lit has 500 nits luminance.
- Philips Colour IQ TV (edge lit) has the best luminance efficiency of all wide gamut TVs. All measured TVs have luminance greater than 400 nits. These results line up well with our expectations that for a given size (i.e. 55") 1H orientation TVs lead the luminance efficiency, followed by 2V and finally by 2H designs.
- TCL and Thomson Colour IQ TV (edge lit) has the best colour gamut of all wide gamut TVs.
- Samsung Direct lit UN55JS7000F (direct lit) does not use QD film. It uses a LED with RG phosphor and a notch filter film to minimize Green-Red channel leak to improve colour quality.

[52] Op. cit. QD Vision (2015a)
[53] QD Vision (2015b), Benchmarking of QD Televisions, submitted 28.10.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_QD_Exs__QD_Vision_e_QD_Television_Benchmarking.pdf

Figure 5-2: QD Vision Comparison of Luminance Efficiency (nits/watt) vs. Colour Gamut for Various Wide Colour Gamut TVs on the Market



TV	Model #	Edge Lit/ Back Lit	Setting	Luminance (nits)	Power (W)	Luminance Efficiency (nits/watt)	NTSC Area (1931)	White CP
Samsung 55" QD Film	Samsung UN55JS9000F	Edge Lit	Dynamic	515	210.0	2.45	91.7%	(0.274, 0.289)
Hisense 55" QDEF	Hisense LED55XT910X3DUC	Back Lit	Cinema	520	189.9	2.74	97.1%	(0.282, 0.290)
Samsung 55" QD Film	Samsung UN55JS7000FXZA	Back Lit	Dynamic	411	223.6	1.84	91.6%	(0.282,0.299)
TCL 55" QD TV	TCL Q55H9700	Edge Lit	Vivid	462	213.0	2.17	107.6%	(0.272, 0.270)
Philips 55" QD TV	Philips 55PUF6850/T3	Edge Lit	Vivid	408	120.7	3.38	102.8%	(0.282, 0.289)
Thomson 55" QD TV	Thomson 55UA9806	Edge Lit	Dynamic	435	212.1	2.05	107.3%	(0.281, 0.299)
TCL 65" QD TV	TCL Q65H9700	Edge Lit	Vivid	433	168.5	2.57	108.4%	(0.281, 0.279)
Hisense 55" QD TV	Hisense LED55K7100UC	Edge Lit	Cinema	417	137.8	3.03	100.3%	(0.279, 0.287)
TCL 55" QD TV	TCL Q55H8800S	Direct Lit	Vivid	447	170.5	2.62	97.0%	(0.275,0.283)
SONY 55" QD TV	SONY XBR-55X900A	Edge Lit	Vivid	388	231.0	1.68	101.7%	0.271, 0.273

Source: QD Vision (2015b)

3M DMSD[54] notes that devices containing displays (such as televisions, monitors, notebooks, tablets, phones, etc.) are designed and implemented by different manufacturers to meet a variety of different needs. While it is possible to measure the colour, luminance, and power consumption of multiple devices, comparing these data is not a meaningful way to compare the relative performance of specific components within the devices. Too many other attributes vary among different devices since a

[54] Op. cit. 3M DMSD (2015)

display is an entire system that combines components, and the combination of the performance characteristics impacts the overall system performance. For example it is possible that a device could have an extremely efficient colour enhancement film, but has overall low energy efficiency because of poor electronics design or the choice of cheaper and lower efficiency LEDs. In 3M's experience, the only meaningful way to compare the relative performance of different, specific components is to evaluate those components in the same device so that the performance of the particular component is isolated, thus eliminating other factors introduced by testing differing systems. 3M DMSD has evaluated one sample each of two commercial InP-based TV models and modified them with 3M Cd-based film. At equivalent luminance, the two TVs with Cd-based QDs consumed 15% and 29% less power than the TVs with InP-based QDs while still providing 12% and 13% higher colour (see Table 5-6). 3M DMSD uses this comparison to show that replacing the InP QD sheet with the CdSe QD sheet results in both an increase in luminance (28% and 39%) and colour gamut (13% and 12%) of Rec. 2020 overlap. 3M DMSD further states that by decreasing the electrical current to the LEDs (and, hence, reducing energy consumption of the LEDs), the TVs with different QD chemistries can be made to have the same luminance. This is achieved in practice by reducing the backlight setting of the TV. The luminance and power as a function of backlight settings were characterized for both TVs and found to be linear with a coefficient of determination (R^2) of >0.999. These relationships are used by 3M DMSD to determine the power consumptions at equivalent luminance, which are reported in Table 5-7.

3M DMSD[55] also states that it is impossible to infer the energy impact of two different display components by comparing the EU energy rating of two different TVs that use those components. The fact that one type of television that utilizes CdSe QDs consumes more power than a different type of television that utilizes InP QDs says nothing about the efficiency characteristics of different QDs.

Table 5-6: 3M DMSD Measured Performance Comparison of TVs at Constant Power (Different Luminance and Colour)

SUHD Model	Quantum Dot Film (Chemistry)	Luminance (cd/m²)	IEC On-Mode Power (W)	Color Gamut (1931 CIE xy)		
				NTSC Area	DCI-P3 Overlap	Rec2020 Overlap
UN48JS9000F	As-Received (InP)	420.2	193.5	88.4%	90.0%	65.9%
UN48JS9000F	3M Modified (CdSe)	537.6	193.5	99.9%	91.6%	74.6%
UN65JS9500FXZA	As-Received (InP)	427.7	339.7	89.3%	90.4%	66.6%
UN65JS9500FXZA	3M Modified (CdSe)	596.6	339.7	99.7%	91.1%	74.5%

Source: 3M DMSD (2015)

[55] Op. cit. 3M DMSD (2016a)

Table 5-7: 3M DSD Measured and Calculated Performance Comparison at Constant Luminance

SUHD Model	Quantum Dot Film (Chemistry)	Luminance (cd/m²)	IEC On-Mode Power (W)	Color Gamut (1931 CIE xy)		
				NTSC Area	DCI-P3 Overlap	Rec2020 Overlap
UN48JS9000F	As-Received (InP)	420.2	193.5	88.4%	90.0%	65.9%
UN48JS9000F	3M Modified (CdSe)	420.2	163.8†	99.9%	91.6%	74.6%
UN65JS9500FXZA	As-Received (InP)	427.7	339.7	89.3%	90.4%	66.6%
UN65JS9500FXZA	3M Modified (CdSe)	427.7	240.3†	99.7%	91.1%	74.5%

Source: 3M DMSD (2015)

In contrast, Nanoco uses an approach of comparing different TVs to establish the differing capabilities of the various technologies. According to Nanoco[56], manufacturers do not publicly provide the detail needed for a full comparison. However, Nanoco provides a comparison of energy efficiency using published data, shown in Table 5-8.

Table 5-8: Nanoco Comparison of Energy Efficiency of Various Displays

Device	Type	Screen size	Energy Consumption kWh/annum	On-mode Consumption W	EU energy rating	Source
Samsung JS9000 SUHD	Cd-free QD	55″	153	110	A	http://www.samsung.com/uk/consumer/tv-audio-video/televisions/curved-tvs/UE55JS9000TXXU
Sony KDL-55X9000A	Cd-based QD	55″	215	155	B	http://campaign.odw.sony-europe.com/tvme/h322/brochure/tv_brochure_en.pdf
Thomson UA9806	Cd-based QD	55″	164	112	A	http://www.lcd-compare.com/televiseur-THO55UA9806-THOMSON-55UA9806.htm
Sony Bravia KD55X85	Non-QD	55″	160	115	A	http://www.johnlewis.com/sony-bravia-kd55x85-4k-ultra-hd-led-3d-android-tv-55-with-freeview-hd-youview-built-in-wi-fi/p1919340?colour=Black
Samsung KS9000 SUHD	Cd-free QD	55″	118	85	A+	http://www.johnlewis.com/samsung-ue55ks9000-curved-suhd-hdr-1-000-4k-ultra-hd-quantum-dot-smart-tv-55-with-freeview-hd-playstation-now-360-design-uhd-premium/p2573458

Device	Type	Screen size	Energy Consumption kWh/annum	On-mode Consumption W	EU energy rating	Source
Samsung JS8500 SUHD	Cd-free QD	65"	161	116	A+	http://www.currys.co.uk/gbuk/tv-and-home-entertainment/televisions/televisions/samsung-suhd-ue65js8500-smart-3d-ultra-hd-4k-65-curved-led-tv-
Hisense XT910	Cd-based QD	65"	416	285	A	http://www.johnlewis.com/hisense-65xt910-curved-4k-uled-3d-smart-tv-65-with-freeview-hd-and-built-in-wi-fi/p2247274
LG EG960V	OLED	65″	207	142	A	http://www.johnlewis.com/lg-65eg960v-curved-4k-ultra-hd-oled-3d-smart-tv-65-with-freeview-hd-built-in-wi-fi-harman-kardon-audio-2x-3d-glasses/p1921644
Sony Bravia KD65X85	Non-QD	65″	207	149	A	http://www.johnlewis.com/sony-bravia-kd65x85-4k-ultra-hd-led-3d-android-tv-65-with-freeview-hd-youview-built-in-wi-fi/p1919151?colour=Black

Source: 55" comparison: Nanoco (2016b) and 65" comparison: Nanoco (2016a)

[56] Op. cit. Nanoco (2016a)

On the basis of internal testing, Nanoco also provides a comparison of various displays in terms of colour performance, reproduced in Table 5-9.

Table 5-9: Nanoco Comparison of Colour Performance of Various Displays

Manufacturer	Model	Type	DCI-P3 %	
			Area	Coverage
Samsung	JS9000	Cd-free	101	97
Nanoco	CFQD® Film	Cd-free	102	99
Sony	KDL-X9000A	Cd-based	105	95
Kindle	Fire HDX	Cd-based	78	78

Note: the Kindle tablet was not designed to have a very high colour gamut, but rather it was optimised for low power consumption to improve battery life so the colour gamut was deliberately restricted.
Source: Nanoco (2015a)

In order to compare the colour performance of cadmium and cadmium-free QD TVs, Nanoco[57] obtained four commercially available samples of 55" 4K HD TVs, as shown in Table 5-10. The Samsung JS9000 was selected to represent cadmium-free and the Thomson UA9806 and Hisense XT910 to represent cadmium QD products available in EU, plus a TCL model that is available in China for a broader perspective. According to Nanoco, Thomson uses the 'on-edge' system with glass capillary and the other 3 all use 'on-surface' QD film designs. The colour standard coverage was measured for each television using the CIE 1976 colour space.

Table 5-10: Nanoco Comparison of Colour Performance of Various Displays

		CIE 1976				
Manufacturer	**Type**	Rec 709/ sRGB	DCI-P3	Adobe RGB	NTSC 1953	Rec 2020
		Coverage	Coverage	Coverage	Coverage	Coverage
Thomson (55UA9806)	CdQD capillary	100%	98%	98%	94%	82%
Hisense (LED55XT910X3DUC)	CdQD film	96%	91%	96%	94%	71%
TCL (Q55H8800S-CUDS)	CdQD film	98%	93%	96%	92%	73%
Samsung (JS9000)	Cd-free QD film	100%	96%	92%	87%	73%

Source: Nanoco (2016a)

[57] Nanoco (2016a), Page Response to Public Consultation Questionnaire Regarding Cadmium QD Exemptions, submitted 8.1.2016, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/Nanoco_Technologies_RoHS_response_final_20160108.pdf

In a later communication, Nanoco[58] provides additional comparisons, also referring to other alternative technologies and their performance. In Table 5-11 comparisons of displays are reproduced in relation to colour gamut, whereas Table 5-12 provides comparisons of energy consumption for television of 55” and of 65”. Nanoco explains for these comparisons that the Samsung KS9000 is a new 2nd generation model with increased efficiency that has recently been launched in the EU market and was not available at the time of the stakeholder consultation submission.

Table 5-11: Nanoco Comparison of Colour Gamut Performance of Displays

TECHNOLOGY	MODEL	COLOUR GAMUT (%)					NOTES
		Rec. 7098/sRGB	DCI-P3	Adobe RGB	NTSC	Rec. 2020	
Cd-Based QD	Thomson 55UA9806	100	98	98	94	82	Coverage[1]
	Hisense LED55XT910 X3DUC	96	91	96	94	71	Coverage[1]
	TCL Q55H8800S-CUDS	98	93	96	92	73	Coverage[1]
Cd-Free QD	Samsung JS9000	100	96	92	87	73	Coverage[1]
	CFQD® Film in commercial TV	99	95	92 (100)[2]	87	73	Coverage[1] Ref: [3]
OLED (White OLED)	LG EG960V		86				Coverage[4] Ref: [5]
IPS Quantum Display (not QD)	LG G4 Smartphone		98				Coverage Ref: [6]
Hi-Performance Phosphor (types not disclosed)	Apple iMac		99				Ref: [7]
TriGain™ Phosphor	Research (Sharp)				90		Ref: [8]
β-sialon:Eu + $K_2SiF_6:Mn^{4+}$ Phosphor	Research (Sharp)				107		Area[9] Ref: [10]
$SrGa_2S_4$:Eu + CaS:Eu Phosphor	Research (Dexerials)				90		Ref: [11]

Notes: [1] CIE 1976 colour space; measured at Nanoco
[2] With colour filters selected for AdobeRGB performance
[3] Measured using a commercially available TV designed for DCI performance with cadmium-free QD film
[4] CIE 1931 colour space
[5] http://www.hdtvtest.co.uk/news/55eg960v-201504224046.htm
[6] http://www.pocket-lint.com/news/133728-lg-g4-ips-quantum-display-explained-how-is-it-different-to-a-normal-lcd
[7] http://www.techradar.com/reviews/pc-mac/pc-mac-desktops/apple-imac-with-5k-retina-display-27-inch-late-2015-1310384/review
[8] http://techon.nikkeibp.co.jp/english/NEWS_EN/20131217/323134/
[9] CIE 1976 colour space
[10] K. Yoshimura et al., White LEDs using Sharp β-sialon: Eu Phosphor and K2SiF6: Mn Phosphor for Wide-Colour Gamut Display Application, IDW, 2015, ISSN-L 1883-2490/22/0504
[11] Y. Ito et al., SID Digest, 2013, 44, 816
Source: Nanoco (2016b)

[58] Op. cit. Nanoco (2016b)

Table 5-12: Comparison of Energy Consumption of Displays

TECHNOLOGY	MODEL	ENERGY CONSUMPTION (kWh/annum)	ON-MODE CONSUMPTION (W)	EU ENERGY RATING	REF
Cd-Based QD	Sony KDL-55X9000A 55" display	215	155	B	12
	Thomson UA9806 55" display	164	112	A	13
Cd-Free QD	Samsung JS9000 55" display	153	110	A	14
	Samsung KS9000 55" display*	118	85	A+	15
OLED	LG EG960V-ZA 55" display	196	134	B	16
TECHNOLOGY	MODEL	ENERGY CONSUMPTION (kWh/annum)	ON-MODE CONSUMPTION (W)	EU ENERGY RATING	REF
Cd-Based QD	Hisense XT910 65" display	416	285	A	17
Cd-Free QD	Samsung JS8500 65" display	161	116	A+	18
OLED	LG EG960V	207	142	A	19

Source: Nanoco (2016b)

5.4.1 Reliability of Quantum Dot Displays

According to 3M DMSD, Cd-based QD film systems have been in the market since October, 2013. 3M DMSD performs extensive aging of its Cd-based QD films to meet customers' demands for device lifetimes in the 20,000 to 30,000 hour range. To date, 3M has been unable to achieve acceptable reliability using the prototype sample InP QDs that have been provided by QD suppliers. 3M DMSD states that reliability data would need to be confirmed for fully scaled QD production. [59]

5.4.2 Environmental Arguments

5.4.2.1 Energy Savings and Cd Emissions

QD[60] Vision provides calculations to show how energy savings related to a CdSe QD television shall result in subsequent savings of Cd emissions as well as other emissions (emissions CO_2 equivalents as well as of other heavy metals emitted from coal combustion). As for the relation between the reduction in Cd emissions and the Cd used in respective displays, QD Vision states that the 25% improvement in energy efficiency

[59] Op. cit. 3M DMSD (2015)
[60] Op. cit. QD Vision (2016c)

for CdSe-based QD implementations is based on a film-swap of InP film for CdSe film in both a Samsung and a Hisense QD-based television. This methodology was employed to isolate the relationship between the quantum dot material and luminance, which – in a test where all other variables are held constant – can be considered a proxy for energy performance. It is further explained that QD Vision uses an on-edge configuration because it is the lowest cost and, therefore, the most available QD solution, while using the minimum amount of Cd in a Cd-based solution; approximately 1.5mg for a 55" diagonal display. While QD Vision does not offer an on-surface QD configuration, it concurs with 3M's submission, which estimates Cd levels of 3-5µg/cm^2 typical, no more than 20µg/cm^2 or approximately 16mg per 55" diagonal display. For reference, QD Vision states that InP-based QD displays of comparable size and performance require roughly 40mg of InP material.

In respect to this last statement, the consultants note that 20µg/cm^2 actually translates to 167mg of Cd for a 55" diagonal screen, this being 47.9" in width and 27" in height. The LCA submitted by QD Vision, in relation to which these statements have been made, estimates that "*an on-surface film for the same size display* [55"] would *require 162 mg Cd*". QD Vision's reference to 16 mg in this later communication is thus assumed to by typo, as also confirmed by the calculation.

QD Vision argues that the use of CdSe-based QD technology enables significant savings in Cd emissions, when considering the Cd emissions related to energy production. In addition to the other advantages of wider colour and high energy savings, the total Cd savings are estimated as roughly 10 times the amount of Cd used in an on-edge display implementation, and somewhat greater but roughly equivalent to that used in an on-surface implementation. This is said to be the "tip of the iceberg." Seeing that power plant pollution control technologies have Cd-reduction efficiencies of between 90% for electrostatic precipitation and wet flue gas desulfurization, and 95% for fabric filters, QD Vision concur that for every 1.3mg of atmospheric Cd released, another 11.7 - 24.7mg of Cd would be captured from the stack and sent to European landfills. A reduction in consumed energy thus also saves these emissions – roughly 10 times the amount of Cd used in an on-edge display implementation and somewhat greater but roughly equivalent to that used in an on-surface implementation. [61]

3M DMSD submitted a report prepared by Goodman[62] raising various socio-economic aspects. Among others it is stated that the use of a Cd QD TV will result in less cadmium in emissions and waste from electricity generation since these have been shown by comparative measurements to be more energy efficient than standard designs of LCDs and also InP QD LCDs used in a television. Calculations are provided to show what savings in energy and Cd emissions could be related to the use of a CdSe QD display in comparison to a standard display and in comparison to an InP one. Results of these calculations can be viewed in the report.

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[61] Op. cit. QD Vision (2016c)
[62] Op. cit. Goodman (2015)

5.4.2.2 Toxicity

Various arguments are raised by the applicants and stakeholders as to the toxicity of the substances used to produce QD, in part opposing each other.

QD Vision[63] explains that CdSe is stable and the release of Cd(II) ions is very small in the absence of electron acceptors under reducing conditions. CdSe is subject to photo- and air oxidation and generates free radicals and therefore, gradual dissolution of CdSe can occur in the presence of electron acceptors such as oxygen. CdSe is insoluble in water. Dissolution of CdSe is pH-dependent, but the dissolution rate of CdSe is very low even under the most favourable acidic pH and/or aerobic conditions.

According to QD Vision, there is not a significant amount of information on the toxicity and health effects of exposure to CdSe in the public literature. It is generally assumed that the systemic toxicity of Cd compounds is attributed to the Cd(II) ion. A few existing studies indicate that the oral bioavailability of CdSe is very low and its adverse health effects depend primarily on Cd(II) ions released from CdSe and free radicals generated from photo- and air oxidation of CdSe. A 28-day oral (sub-chronic) study in rats showed that CdSe did not cause any toxic effect at doses of 30, 300 and 1,000 mg/kg/day. No chronic studies are available on CdSe. The classification of CdSe is based on the categories of “cadmium compounds” and “selenium compounds”. Based on the CLP classification principles and considering the 28-day rat oral study, CdSe could be classified as Acute inhalation and dermal toxicity Category 4, Acute aquatic Category 1 and Chronic aquatic Category 1. CdSe is classified as much less hazardous as the classification for cadmium itself.[64]

As for InP, QD Vision states that InP is insoluble in water, soluble in simulated gastric fluid and hardly soluble in simulated lung fluids. InP was determined to be a 1B probable human carcinogen based on well-conducted inhalation toxicity studies in experimental animals. The evidence includes high incidences of malignant neoplasms of the lung, adrenal and liver in rats and mice exposed to InP as low as 0.03 mg/m^3 and for as short as 22 weeks. InP was subject to a harmonized classification proposal sponsored by France and reviewed by the Risk Assessment Committee in 2009 in association with EU CLP regulation. The harmonized classification of InP is Carcinogen 1B (H350), Reproductive toxicant Cat 2 (H361f), and specific target organ toxicity (STOT) Repeat (RE) Cat 1 (H372).[65]

QD Vision summarises that the risks of InP and CdSe should not be exaggerated – particularly in the QD form that they have they present no hazard to the user or the environment. Only at the point of recycling can there be an issue of exposure to workers however this is not materially different from far greater risks involved in recycling work. According to QD Vision, it is arguable that as a suspected carcinogen, the vastly higher

[63] Op. cit. QD Vision (2015)
[64] Op. cit. QD Vision (2015)
[65] Op. cit. QD Vision (2015)

quantities of InP required and due to its lower recycling rate, InP is the slightly more harmful substance. What further argues in favour of CdSe is that by being on the market, further reduction steps are being taken and it is possible that the 0.01% concentration limit [the RoHS restriction threshold for Cd – consultants' comment] will be met in the not too distant future. For these developments to happen the technology must remain on the market at this critical stage.[66]

3M DMSD[67] supports for the most part QD Vision's point of view, however also states that that correctly predicting the hazards of either an InP-based or CdSe-based quantum dot in the absence of toxicological data is difficult. While it may seem preferable to replace a compound containing cadmium with an unidentified compound without known human health hazards, it is possible that there is no hazard reduction from replacing the cadmium containing compound, and that the replacement may be a regrettable substitution. Nonetheless, since there is no exposure to quantum dots in 3M QDEF during typical use phase, the film poses no health risk to consumers.

In contrast, Nanoco regards the toxicity of their own QDs, explained to be based on In but not on InP, to be lower than that of Cd QDs. Nanoco[68] claims for example that a further advantage of CFQD® materials is their very low toxicity, because they are cadmium-free and are not made from indium phosphide. Nanoco presents testing results carried out to regulatory standards that show how CFQD® quantum dots are much safer than cadmium selenide, the material used to make most cadmium-based QDs:

[66] Op. cit. QD Vision (2015)
[67] Op. cit. 3M DMSD (2016a)
[68] Op. cit. Nanoco (2016b)

Table 5-13: Nanoco's Survey on Testing Results for CFQD® and CdSe

CFQD® Quantum Dots

Hazard Type	CLP Rating
Toxicity	Negative
Mutagenicity	Negative
Eye irritation	Negative
Skin irritation	Negative
Skin sensitisation	Negative / Cat. 1b, H317[1,2]
Biodegradability	Readily biodegradable
Aquatic toxicity	Cat. 2 (algae), H411[2]

Source: Nanoco's CFQD® quantum dot Material Safety Data Sheet

1. Weak positive result for Red quantum dots only
2. Positive results may be caused by ligand chemicals rather than the CFQD® semiconductor alloy material

VS.

Cadmium Selenide

Hazard Type	CLP Rating
Acute toxicity, oral	Category 3, H301
Acute toxicity, inhale	Category 3, H331
Acute toxicity, dermal	Category 4, H312
Carcinogenicity	Category 1a, H350
Specific target organ toxicity	Category 2, H373
Aquatic acute toxicity	Category 1, H400
Aquatic chronic toxicity	Category 1, H410

Source: European chemical supplier Material Safety Data Sheet

GHS regulatory test data for CdSe/ZnS quantum dots not available

Source: Nanoco (2016b)

5.4.2.3 Resource Use and Recycling

QD Vision[69] explains that the raw material used for synthesis of QD precursors, cadmium oxide (CdO), can be produced from recycled Cd very easily. QD Vision currently purchases CdO from distributors who procure CdO from global suppliers, some of whom do not distinguish the source of their Cd. However, in the course of this exemption process, QD Vision has identified a recycling company who would be able to supply 100% recycled CdO with the ability to globally source waste Cd, including materials from Europe. QD Vision was, however, not able to provide an estimation as to how much of the CdO purchased for conversion to QD precursors has been derived from recycled Cd feedstocks.

5.4.3 Road Map to Substitution

Various statements made suggest that once a Cd-free QD alternative becomes available on the open market, which provides comparable colour gamut performance and efficiency, that it would replace CdSe in QDs. However, a detailed roadmap is not provided. The applicants do not detail what research they are undertaking or promoting to enable this substitution, nor what the timeline and the stages towards a full substitution may be.

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[69] Op. cit. QD Vision (2016c)

5.5 Stakeholder Contributions

Aspects raised in this chapter are relevant for applications of QD technologies in both displays and solid state lighting. A similar chapter is thus not included in the chapter evaluating QD solid state lighting applications.

The **American Lighting Association (ALA)**[70] explains the trade-off made by developers of LED technologies between efficacy (lumens per watt) and light colour performance. This is explained to be motivated by the general strive to reduce energy consumption related to lighting. Industry is expected to need to pay more attention in the future to customer needs in terms of colour performance, if more efficacious colour sources are to enter residential homes. ALA supports the requests, explaining that maintaining exemption 39 shall "allow time for manufacturers to finalize designing these materials into their products, and to test the products to determine their advantages and disadvantages. Eliminating the exemption at this time would be detriment to the years of research and development aimed at improving energy efficiency as well as the consumer experience."

BASF[71] explains that it has recently signed a joint development agreement with QD Vision for a QD enhanced backlight and a colour filter for use in LCDs. It supports the request and raises various advantages of this technology for displays, which are already mentioned for the most part in the sections above and thus not repeated here.

Department for Business and Innovation Skills (BIS)[72] objected to the applicants' requests to exempt the use of cadmium in quantum dot technology in the past, as the effect of such measures meant that quantum dot technology containing cadmium and cadmium free (CFQDs) would be allowed on to the EU market until July 2018. Even at that time, cadmium free technology was being commercialised and was already available in certain markets since the start of February 2015. BIS urges the EC to speed up the current evaluation so that should the exemptions be denied, that this not extend the period under which such Cd-based technologies can be placed on the market beyond necessary.

[70] ALA (2016), The American Lighting Association, Contribution to consultation on the Revaluation of Two Requests Related to Cd-QD Technologies, submitted 8.1.2016, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/the_American_Lighting_Association_ALA_Cadmium_Letter.pdf

[71] BASF (2016), BASF, RoHS Exemption Request 2013-2 QD Vision, submitted 8.1.2016, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/BASF_QD_Vision_Oekoinstitut.pdf

[72] BIS (2016), Department for Business and Innovation Skills, Contribution to Stakeholder Consultation 2015-3 – Joint Revaluation of Two Requests for Exemption, First Reviewed in 2013-2014, Related to Cadmium Quantum Dot Applications, submitted 7.1.2016, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/Department_for_Business_Innovation_Skills_Contribution__Exemption_39_8_Jan_2016.pdf

The **International Chemical Secretariat (ChemSec)**[73] does not support the requests for exemption, explaining that Cd causes serious illness and presents severe danger to the environment, throughout the production chain and should therefore be restricted. This they explain to be even more relevant in cases where alternative technologies are available, as an exemption would discourage sustainable and responsible innovation, having a great environmental impact, which can be avoided. It is further elaborated that though some stakeholders warn against the carcinogen properties of indium phosphide, one of the alternatives, that ChemSec, despite also having warned against the dangers of InP in the past, does not believe that this aspect should be construed as support for a CdQD technology.

The Close Brothers Asset Management[74], **Baillie Gifford & Co**[75] and **Henderson Global Investors Ltd**[76] explain that they do not find merit in the requests at hand. They do not support the requests given the availability of safer alternative materials.

DOW Europe GmbH[77] endorses the submission made by Nanoco on 8 January 2016 and emphasis various aspects in relation to the Nanoco submission, which are already mentioned for the most part in the sections above and thus not repeated here.

The European Environmental Bureau[78] states that it is a known fact that cadmium and other heavy metals may cause serious illnesses and present a severe danger to the

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[73] ChemSec (2015), the International Chemical Secretariat, Response to 2015 Consultation 3: Joint Revaluation of Two Requests for Exemption, First Reviewed in 2013-2014, Related to Cadmium Quantum Dot Applications, submitted 21.12.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/151221_PC_RoHS_Cadmium_Chemsec_FINAL.pdf

[74] Close Brothers (2015), The Close Brothers Asset Management, Response to 2015 Consultation 3: Joint Revaluation of Two Requests for Exemption, First reviewed in 2013-2014, Related to Cadmium Quantum Dot Applications, submitted 21.12.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/21122015_OKO_INSTITUT_LETTER_FROM_RFM__2_.pdf

[75] Baillie Gifford (2015) Baillie Gifford & Co, Response to 2015 Consultation 3: Joint Revaluation of Two Requests for Exemption, First reviewed in 2013-2014, Related to Cadmium Quantum Dot Applications, submitted 22.12.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/Letter_to_Ms_Baron_Related_to_Cadmium_Quantum_Dot_Applications_21_Dec_20....pdf

[76] Henderson (2015), Henderson Global Investors Ltd, Response to 2015 Consultation 3: Joint Revaluation of Two Requests for Exemption, First reviewed in 2013-2014, Related to Cadmium Quantum Dot Applications, submitted 16.12.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/Hwnderson_Globa_Investors201512231029.pdf

[77] Dow (2016), DOW Europe GmbH, Contribution to Stakeholder Consultation, submitted 8.1.2016, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/DOW_Europe_GmbH_Letter_RoHS_Jan_2016_final_.pdf

[78] EEB (2015), The European Environmental Bureau, Response to 2015 Consultation 3: Joint Revaluation of Two Requests for Exemption, First reviewed in 2013-2014, Related to Cadmium Quantum Dot Applications, submitted 7.12.2015, available under

environment, throughout the production chain. Cadmium and other heavy metals in consumer products should therefore be restricted. This is even more necessary in cases where clean alternative technology is available. EEB fully supported the European Parliament's vote to reject the Delegated Act by the EC extending the use of toxic cadmium in televisions and other displays until July 2018, as displays using Cd-free QDs had become widely available, whereas Cd-based displays had all been withdrawn from the EU market since 2014.

Hinsense[79] produces ultra-high definition (UHD) televisions, which contain 3M QD Enhancement Films that leverage Cd-based QDs to bring about more vivid colours. Hinsense supports the two requested exemptions, claiming that UHD televisions that utilize Cd-based QD technologies are demonstratively more efficient than QD technologies comprised of other materials, i.e. indium-based solutions. Hinsense believes that Cd-based QD technology remains the only viable way to simultaneously achieve high-colour performance and energy efficiency. Discontinuing the exemption may lead to an increase of consumers' electric bills, and may contribute to an overall negative impact on the environment.

InGaN Research Ltd[80]objects the requested exemption is granted. InGaN raises various questions of importance for the evaluation at hand. In InGaN's view, Quantum Dots are not a new technology and have been available for over a decade in many applications and industrial sectors. There are a significant number of questions that still need to be answered in regards to nanomaterials (both Cadmium and Cadmium free) suitability for the wider environment especially in terms of health impacts however it is clear that heavy-metal based Quantum Dots cannot be good for the environment and EU Citizens health in the long term. InGaN claims that the aims of the original RoHS and REACH directives were to limit and remove hazardous materials within Europe, with exemptions being a method of last resort to allow the market to transition itself responsibly to alternatives and environmentally symbiotic alternatives. The previous exemption for Cd-based QDs has provided ample time for the Industry to make that transition and InGaN argues that the market for Cd-based QDs within the Display and Lighting Industry has failed due to technology performance and consumer concerns. The number of units shipped in the display and lighting markets that contain CdQDs is less than negligible and therefore an outright ban would not impact the general market through restricted

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http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/20151207_EEB_response_to_RoHS_Exemptions_Evaluation.pdf

[79] Hisense (2016) Hinsense, About Quantum Dot Enhancement Films, submitted 8.1.2016, availiable under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/Hisense_Contribution.pdf

[80] InGaN (2016), InGaN Research Ltd, Response to 2015 Consultation 3: Joint Revaluation of Two Requests for Exemption, First reviewed in 2013-2014, Related to Cadmium Quantum Dot Applications, submitted 8.1.2016, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/InGaN_Research_Ltd_Response_to_RoHS_exemption_of_QDs_-_7-1-16.pdf

supply chain or consumer choice and provides a strong commercial case to reject the proposed exemption extension.

The Swedish Chemicals Agency (KEMI)[81] regrets that a final decision is still lacking for the exemption requests for cadmium in quantum dots. Any further delay will prolong the possibility to place on the market equipment containing elements made with quantum dot technology that contains Cd. KEMI suggests that the applications for exemptions be refused and that exemption 39 be terminated as fast as possible according to the rules in the RoHS directive. Since the products were not introduced to the EU market at the time of the original application/reapplication for an exemption, the transition time for the current exemption 39 should be as short as possible (12 months). The intention must be to avoid the risk of an expanding market of cadmium containing products in the EU, for which the shortest possible transition period shall act as a clear signal that such products should not be introduced on the EU market. KEMI argues that alternatives are available, both using QD technologies and using other technologies. In this respect it is further explained that the Article 5(1)(a) criteria would not be fulfilled in respect of substitutes as KEMI does not interpret "general use in lighting or displays" as a specific application for which exemptions can be granted. Furthermore, it can be understood that should an exemption not be available, this would not result in a lack of supply of lighting and display applications on the EU market. There would still be televisions, monitors, tablets and cell-phones as well as light bulbs free from cadmium available for sale. If there is equipment for a specific application where the quantum dot technology with cadmium is necessary to set this type of equipment on the market, new applications should be submitted particularly for that equipment.

KEMI[82] disagrees with the way the functional parameters for comparing performance of Cd free and Cd-based technologies are defined by the applicants, because the question is based on incorrect premises. Exemptions shall be given for "specific applications", not for a specific technology. A definition of the functional unit should start with a specific equipment from one of the categories in Annex I of the RoHS directive. Since there are cadmium free televisions, monitors, tablets and cell-phones as well as light bulbs available for sale, this specific technology is not crucial for the basic lighting function of those kind of equipment. Thus all claims regarding functions should be made in relation to a specific equipment. If necessary in various equipment, multiple exemption applications may be submitted for the function of such equipment.

[81] KEMI (2015), The Swedish Chemicals Agency, Contribution to Stakeholder Consultation 2015-3 - Joint Revaluation of Two Requests for Exemption, First Reviewed in 2013-2014, Related to Cadmium Quantum Dot Applications submitted 21.12.2015, submitted 21.12.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/SE_CA_Answer_to_SC_RoHS_2015_3_Joint_Revaluation_of_cadmium_in_quantum_dots.pdf

[82] Op. cit. KEMI (2015)

In relation to environmental impacts at EoL, KEMI[83] states that one of the applicants state that "Furthermore, the cadmium in the QD-LCD can be recovered safely by recycling whereas the cadmium and other toxic metal emissions from power generation contaminate the environment, enter the food chain, etc.". KEMI comments that the safety of the recycling process seems to be highly overestimated by the applicant. The described safe recovery of Cd from displays and light sources in electronic waste requires that the workers of recycling facilities have knowledge about which of the parts contain cadmium. Since there are no such systems for transmission of information, it will not be possible to ensure that such safe recovery will occur.

LightingEurope (LEU)[84] supports the requests for exemptions, claiming that past argumentation remains valid and is currently also backed with recent external research backing the efficacy improvements of Cd QDs in comparison with other alternatives on the market. LEU raises various aspects, which are already mentioned for the most part in the sections above and thus not repeated here.

Nanosys[85] supports the requests at hand, providing test results of a further "swap" comparison of Cd-based and Cf-free QD films in displays. Results are not reproduced here as they are similar in nature to those presented of the applicants. Nanosys concludes that Cd-free (InP) quantum dots have progressed significantly in the past year from being the subject of academic papers and conjecture to being used in successful commercial products. However, they are not the dominant quantum dot technology in use today. Nanosys believes that Cd-free quantum dots will continue to make progress over the coming year, but would recommend based on their analysis and the review of the LCA report submitted by 3M, that 2013-5 be granted for at least one year.

NDF Special Light Products BV[86] is a manufacturer of CFLs and since 2010 it also produces LEDs in combination with remote phosphor. It objects to the requests, explaining that Cd is restricted because of the widely known health risks associated with it. While NDF Special Light Products B.V. has warned against the dangers of indium phosphide, it believes that this should not be construed as support for Cd QD technology.

[83] Op. cit. KEMI (2015)

[84] LEU (2015) LightingEurope, Support Letter on Exemption 39, submitted 9.12.2015, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/LE_support_letter_RoHS_Ex_39_Cadmium_20151209.pdf

[85] Nanosys (2016), Input for stakeholder consultation for RoHS exemption requests 2013-2 and 2013-5, submitted 8.1.2016, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/Nanosys_Input_for_Stakeholder_Consultation_-_CdSe_vs_InP__Cd-free__Quantum_Dot_Performance_Measurement_and_Analysis.pdf

[86] NDF (2015), NDF Special Light Products BV, NDF CW adj 1514 - Cadmium Quantum Dot applications, submitted 3.12.2015, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/NDF_CW_adj_1514_-_Cadmium_Quantum_Dot_applications.pdf

Other contributions made by 3M, CREE, Lumileds, Nanoco and QD Vision are not mentioned here as they have been included in the course of the report.

5.6 Critical Review

5.6.1 REACH Compliance - Relation to the REACH Regulation

Appendix A.1.0 lists various entries listed in the REACH Regulation annexes that restrict the uses of various compounds. In the context of this exemption, the annexes were screened for entries related to cadmium, cadmium selenide, indium and indium phosphide, and the following was found:

Entry 23 of Annex XVII restricts the use of Cd and its compounds in various applications. Paragraph 1 of this entry restricts the use of Cd in mixtures and articles produced from various synthetic organic polymers (thereafter referred to as plastic materials) and among others polyethylene terephthalate (PET). Mixtures and articles produced from these plastic material "shall not be placed on the market if the concentration of cadmium (expressed as Cd metal) is equal to or greater than 0,01 % by weight of the plastic material". In the course of the 2013-2014 review, it was understood that QD films are manufactured using among other PET layers. However it was also clarified that the Cd QDs are immersed in a resin, located between two sheets of PET. In this sense Cd is not understood to be in the PET and this article would not apply. Other paragraphs restrict uses in paints, in metal plating, brazing fillers and jewellery. None of these applications are understood to be relevant to the exemption at hand.

Various cadmium compounds are also restricted through entry 28 including: Cd chloride, Cd fluoride, Cd oxide, Cd sulphide, Cd sulphate, Cd (pyrophoric), entry 29 and entry 30 including: Cd chloride, Cd fluoride, Cd sulphate. As these entries refer to specific compounds, none of which is CdSe, they are understood to be irrelevant.

Entry 28 also lists indium phosphide, and does not allow supplying this compound to the general public as a substance, a mixture or a constituent thereof. As InP used in QDs in displays and solid state lighting (SSL) is placed on the market as part of an article, this entry is understood not to be relevant. InP is not made available to the general public as a substance, a mixture or a constituent thereof.

No other entries, relevant for the use of cadmium and its compounds or indium phosphide, related to the requested exemptions, could be identified in Annex XIV and Annex XVII (status April 2016).

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. An exemption could therefore be granted if other criteria of Art. 5(1)(a) apply.

5.6.2 Introductory Note

In the first review of these exemption requests, the market availability of actual products on the market made a comparison of the applications for which the exemption is requested and their potential alternatives complicated. Thus a first aspect in this review, also addressed in the communication of the EU Parliament, was to understand the availability of Cd QD displays as well as the availability of their alternatives. As pointed out by the various applicants and stakeholders, the market status of QD displays has changed in the meantime, and though the market still appears to be rather dynamic, a range of products is available using CdSe quantum dots or using InP quantum dots.

- From the information provided by 3M DMSD, QD Vision and Nanoco, it is observed that displays are available using CdSe QDs for the following sizes: 55” (television), 27” and 15.6” (monitors, notebooks). A 7” display (E-book reader) was also available in the past; however its production was discontinued.
- As for displays using InP, at present only televisions are understood to be available, however in a large range of sizes, ranging from 48” to 88”.

In this sense, it seems that the current market situation can facilitate a better comparison and thus a better understanding as to the comparability of these two technologies.

In parallel, non-QD technologies have been named, for which displays are on the market, which can be understood to also be potential alternatives to QD displays.

The following section thus discusses the available information in relation to the following aspects:

- Possible reasons for the differing market availability of QD products in the EU and beyond;
- Comparability of CdSe QD displays and of InP QD Displays;
- Comparability of CdSe QD displays and displays using other than QD technologies; and
- Aspects related to the RoHS 5(1)(a) third criterion, i.e. impacts on the environment, on health and on consumer safety.

5.6.3 Scientific and Technical Practicability of Substitution

Before reviewing the performance of the various displays, it is worth mentioning that the submitted information suggests a wider range of products being available beyond the EU. From the product lists submitted by QD Vision, it is understood that on the global market the following display sizes are available using CdSe QDs: 40-120” (televisions). For smaller displays (monitors, tablets) further sizes are not specified beyond the ones stated above.

QD Vision suggests that the difference in the availability of various display sizes could be related to the uncertainty of the further availability of Ex. 39. Further supporting this assumption, QD Vision explains that the design of the various displays is not expected to limit their marketability to certain countries or regions.

The consultants agree that there seems to be no apparent reason aside from the uncertainty of the exemption for the differing market strategies. However, this reasoning is in itself not logical, as the exemption is an existing one, for which a renewal was requested. Article 5(5) of the RoHS Directive stipulates in this respect "*The existing exemption shall remain valid until a decision on the renewal application is taken by the Commission*". Article 5(6) further clarifies that "*In the event that the application for renewal of an exemption is rejected or that an exemption is revoked, the exemption shall expire at the earliest 12 months, and at the latest 18 months, after the date of the decision*". In this sense, even were the exemption to expire tomorrow, it would still remain valid for at least 12 more months. It is observed that the period throughout which display articles are sold on the market in some cases is quite short (many displays placed on the market in the past are understood to no longer be made available, for example many of the Sony TVs, the Kindle device, etc.). 3M's statement that the market lifecycle of an electronic device is 6-12 months supports this understanding. Thus, though the uncertainty of the exemption duration could explain other display manufacturers not developing QD displays, it does not support that ones who have would not place certain articles on the EU market for fear of the fate of the exemption. The consultants would like to note the importance of this aspect to the case of a short termed exemption. Regardless of how manufacturers shall choose to develop displays in the future, it cannot be claimed that a short termed exemption would put EU consumers at a disadvantage to non-EU consumers in relation to display choice. As long as an exemption is valid and assuming that its renewal would be timely requested when necessary, manufacturers can expect that should the exemption be revoked, a transition period would be provided to facilitate the legal withdrawal of affected products.

As it can be understood that there is already a wider availability of products, the next aspect to be reviewed concerns their performance. The applicants and other stakeholders have stated that CdSe QD can provide advantages in terms of their higher colour gamut and in terms of their (lower) energy consumption and (higher) efficiency. To support this claim, QD Vision, 3M and others provide "Swap" comparisons, in which televisions using QD films of one type have been swapped with the other type in order to compare performance of the QD film within the same display. This approach is explained to allow establishing that the performance of CdSe QDs is superior to that of InP ones, once all other parameters are held constant. Data presented from such comparisons indeed shows that CdSe QDs can provide better performance in relation to both colour gamut and energy consumption.

- QD Vision's data, using two 55" televisions for the "swap" comparison, shows a 9.6-10% difference in the coverage of NTSC, in the favour of CdSe, which also provides a 32% increase of luminance. This increase, when compared to the power is understood to result in an efficiency difference of 23-25%, depending on the display tested.
- In results of a swap comparison presented by 3M in which a 48" and a 65" television were compared, the range of difference was wider, with the energy consumption of CdSe TVs being 15 % to 29% lower. In parallel, this comparison shows that there is a 12-13% colour difference in relation to the Rec 2020 standard, however the higher coverage achieved by the CdSe TVs is

still only 75%. In contrast, the DCI P3 difference is of only 0.7-1.6% and the NTSC Coverage difference is 10.4-11.5%.

For convenience, the data are summarised in Table 5-14. Results of the Nanosys[87] "swap" comparison are also presented to allow a wider basis of data for conclusions. The Nanosys comparison was done using the Vizio television model P65, which is a direct backlit, 65" UHD television that does not use QD dots. The original white LEDs were replaced with blue LEDs and a QD film was added (CdSe or InP based) The comparison also provides data for the original configuration of this display, which has not been reproduced here.

Table 5-14: Results of Applicant's "Swap" Comparisons

Television	Film used	Luminance efficiency (lm/w)	NTSC Area (1931)	DCI-P3 Overlap	Rec 2020 Overlap	Source
Samsung 48"	With 3M film (CdSe	2.77	99.9%	91.6%	74.6%	3M DMSD (2015)
	As received (InP)	2.17	88.4%	90.0%	65.9%	
Difference	**Favouring CdSe**	**21.8%**	**11.5%**	**1.6%**	**8.7%**	
Hinsense 55"	Hinsense QDEF (CdSe)	2.74	97.1%	n.a	n.a	QD Vision (2015b)
	Samsung QD film (InP)	2.12	87.9%	n.a	n.a	
Difference	**Favouring CdSe**	**22.7%**	**9.2%**	n.a	n.a	
Samsung 55"	Hinsense QDEF (CdSe)	3.25	101.3%	n.a	n.a	QD Vision (2015b)
	Samsung QD film (InP)	2.45	91.7%	n.a	n.a	
Difference	**Favouring CdSe**	**24.3%**	**9.6%**	n.a	n.a	
Samsung 65"	With 3M film (CdSe	1.75	99.7%	91.1%	74.5%	3M DMSD (2015)
	As received (InP)	1.25	89.3%	90.4%	66.6%	
Difference	**Favouring CdSe**	**28.3%**	**10.4%**	**0.7%**	**7.9%**	
Visio 65", blue LEDs	With 3M film (CdSe	3.95E+18*	n.a	94%	85.4%	Nanosys (2016)
	Samsung QD film (InP)	5.225E+18*	n.a	92.7%	73.7%	
Difference	**Favouring CdSe**	**24%**	**n.a**	**1.3%**	**11.7%**	

Differences between CdSe and InP performance are calculated by the consultants. n.a=data not available.

Numerical values rounded to two decimal places by the consultants

Nanosys (2016) also provided results of a "swap" comparison, which are only summarised in this table and not detailed elsewhere in this report.

**Nanosys did not provide data as to luminous efficiency, but calculated the photon conversion ratio, i.e., the ratio between the photons being produced by television set and between its photon input (the same for both sets).*
Source: Compilation of applicant and stakeholder data.

From these results it can be understood that CdSe QDs may have advantages in terms of energy consumption and colour gamut, however the range of advantage depends on the

[87] Op. cit. Nanosys (2016)

products in which they are used, i.e., the technology of the display. In terms of colour gamut, it can be observed that the advantage depends on the standard used for comparison, however it is possible as mentioned by Nanoco[88], that displays are designed to optimise performance against one of these standards and not against all. In this case the question would be whether the performance difference is significant for the standard for which the display had been optimised. In the comparisons of QD Vision, 3M DMSD and Nanosys, the Cd QD displays all show better colour gamut, though in some cases the difference may be less significant. Based on the comparison of standards provided by 3M and reproduced in Table 5-5, the consultants understand the results to be inconclusive. NTSC is said to cover about 38% of the colours visible to the human eye, DCI P3 to cover 42% and Rec 2020 nearly 100%. Though differences in the colour gamut performance are more significant when compared to NTSC (9.2-11.5 %) and Rec 2020 (7.9-11.7 %), they are much less significant when compared to DCI P3 (0.7-1.6%). The data from the three comparisons also does not allow showing a trend related to the size of the display in this respect. Nevertheless, all comparisons show a significant advantage for Cd QDs in terms of luminous efficiency. Though this difference varies, in all cases the displays using CdSe Qds exhibit a higher efficiency by at least 20% to the InP counterparts. Though the QD Vision and 3M DMSD data could suggest a relation between the luminance efficiency benefits and the size of the display, the Nanosys data does not support this trend.

A second approach for display comparison is of actual products available on the market. Some of these comparisons are based on internal measurements and some on producer declarations. Results of such comparisons are interesting for two reasons. They show that the preference of QD technologies do not translate directly to a preference in the television set performance (colour, energy consumption). More importantly, they allow a partial comparison between QD technologies and other technologies (in relation to colour gamut and in some cases to luminance efficiency).

QD Vision compares 10 displays of which 9 are of the 55” size, 7 using CdSe QDs, one using InP QDs and one not being a QD Display (see summary in Table 5-15 as well as Figure 5-2 for graphic comparison).

[88] Op. cit. Nanoco (2015a)

Table 5-15: QD Vision Comparison of Luminance Efficiency (nits/watt) vs. Colour Gamut for Various Wide Colour Gamut TVs on the Market

TV	Model #	Edge Lit/ Back Lit	Setting	Luminance (nits)	Power (W)	Luminance Efficiency (nits/watt)	NTSC Area (1931)	White CP
Samsung 55" QD Film	Samsung UN55JS9000F	Edge Lit	Dynamic	515	210.0	2.45	91.7%	(0.274, 0.289)
Hisense 55" QDEF	Hisense LED55XT910X3DUC	Back Lit	Cinema	520	189.9	2.74	97.1%	(0.282, 0.290)
Samsung 55" QD Film	Samsung UN55JS7000FXZA	Back Lit	Dynamic	411	223.6	1.84	91.6%	(0.282,0.299)
TCL 55" QD TV	TCL Q55H9700	Edge Lit	Vivid	462	213.0	2.17	107.6%	(0.272, 0.270)
Philips 55" QD TV	Philips 55PUF6850/T3	Edge Lit	Vivid	408	120.7	3.38	102.8%	(0.282, 0.289)
Thomson 55" QD TV	Thomson 55UA9806	Edge Lit	Dynamic	435	212.1	2.05	107.3%	(0.281, 0.299)
TCL 65" QD TV	TCL Q65H9700	Edge Lit	Vivid	433	168.5	2.57	108.4%	(0.281, 0.279)
Hisense 55" QD TV	Hisense LED55K7100UC	Edge Lit	Cinema	417	137.8	3.03	100.3%	(0.279, 0.287)
TCL 55" QD TV	TCL Q55H8800S	Direct Lit	Vivid	447	170.5	2.62	97.0%	(0.275,0.283)
SONY 55" QD TV	SONY XBR-55X900A	Edge Lit	Vivid	388	231.0	1.68	101.7%	0.271, 0.273

Source: QD Vision (2015b)

This comparison clarifies that indeed the CdSe displays have better gamut colour in all cases, however when the detailed data is compared, the difference is understood not always to be significant. The Samsung InP TV has an NTSC area of 91.7% whereas the other displays range between 97% to 108.4%. Though a 16.7% difference at the top end of this range may be considered relatively significant, a 5.3% difference at the bottom end of the range is much less significant and hence all the more questionable against potential toxicological considerations etc. In this respect it is also important to note, as also observed in the 3M DMSD and Nanosys “swap” comparisons, that a preference in relation to one standard does not ensure a preference in relation to other standards. The NTSC preference observed from the table above cannot be concluded to suggest a preference in relation to additional standards. All the more so, as according to the standard comparison provided by 3M in Table 5-5, the NTSC standard covers less colours than for example the DCI-P3 and the Rec 2020 standards (38% in comparison to 42% and near to 100% of colours visible to the human eye, respectively). As for the energy efficiency, here the Samsung InP TV shows better performance than some of the CdSe models having an efficiency of 2.45 within the general range of 1.68-3.38.

Nanoco has also made comparisons of current products and shows that InP televisions have better performance in terms of energy consumption, for example an annual energy consumption of 118-153 kWh as compared to 160-215 kWh for CdSe TVs (see Table 5-8). When comparing colour performance in relation to DCI P3 (see Table 5-9), it is observed that InP TVs have a coverage of 97, whereas CdSe show a coverage of 78 to 95. However Nanoco itself notes that the kindle tablet was not designed to have high colour gamut and both of these models are understood to be older, as Nanoco states they were withdrawn in 2014 as can be seen in Table 5-3). A comparison of colour gamut for additional displays, summarised in Table 5-16, shows that the performance depends very much on the standard chosen as well as on the technology.

Table 5-16: Summary of Nanoco Comparative Data for Colour Gamut Performance of Displays

Technology	Rec 709/sRGB	DCI-P3	Adobe RGB	NTSC 1953	Rec 2020
InP QDs (TVs)	100%	96%	92%	87%	73%
CdSe QDs (TVs)	96-98%	91-98%	96-98%	92-94%	71-82%
OLED (TVs)		86%			
IPS Quantum (smartphone)		98%			
Apple iMac Hi-performance phosphors (monitor)		99%			
Trigain*				90%	
ß-sialon:Eu + $K_2SiF_6:Mn^{4+}$ Phosphor*				107%	

**The consultants are not aware if actual products using these technologies are available on the market.*
Source: Compiled by the consultants

This information suggests that though CdSe QDs can be used to provide higher colour gamut and/or lower energy consumption, that this is not always the case in products currently available on the market. Though the various comparisons show that in many cases the colour gamut performance afforded with the use of CdSe QDs can be significant (though not in all cases), in relation with energy consumption, this seems to depend very much on how the technologies are implemented aside from the QDs. It is further assumed that the time when the product first came on the market also influences the results. As can be expected, newer products, of all categories show better performance in comparison with their predecessors. For most models, however it is not clear when the display first came on the market and thus a trend cannot be assumed based on the various data.

Nonetheless, from the “swap” comparisons, the consultants can follow that where all parameters determining the performance of a display are held constant except the type of QD film used, that CdSe provides higher performance than InP in relation to energy efficiency and colour gamut. This is understood to confirm that at least in the comparison with InP QD technologies, that CdSe QD technologies can provide a better performance, when all other factors are held constant. Though this conclusion is relevant for the comparison of CdSe QD displays and InP QD displays, it does not allow drawing conclusions as to other emerging technologies. In some cases these may show comparable colour gamut in relation to one standard, however it cannot be concluded on the basis of available data whether performance would be comparable for other standards, nor in relation to luminous efficiency.

As for the ability to comply with the recently launched Rec 2020 standard, though all data suggest that InP QDs are still lagging behind CdSe QDs, neither of these technologies have achieved as of yet a full coverage of the standard, nor consistent coverage in all displays on the market. Though the consultants can agree that QDs may be a stepping stone in the direction of achieving Rec 2020 colour gamut, it is still not clear if either of these technologies could be the first to achieve full coverage. As QD Vision points out, this is also currently not observed as a justification for either of the technologies, as the standard was only approved at the end of 2015 and can be expected to promote innovation and further development in the display sector.

In terms of reliability, both technologies are already available in products on the market. Under the assumption that products of unacceptable reliability would not reach the market, the reliability needs to be understood to be sufficient in both cases. In this respect it also needs to be mentioned that the market is very dynamic and that it is not clear if the quick withdrawal of products is a result of poor reliability or solely of rather short design cycles and general decisions on product strategies. This is also seen in relation to the differences in performance between products placed on the market for example in 2014 and those placed on the market more recently and is relevant for all displays and not just QD displays.

3M argues that InP QDs are not available on the open market and that this would hamper substitution. Though aspects of availability can be considered when deciding on the duration of an exemption, they are not understood to be a justification on their own. Furthermore, aspects of availability are understood to be of relevance when a product is at risk of being expelled from the market for which alternatives cannot be produced in a large enough market volume in order to cover the demand. However the case of QD technology is different than substitution related to other exemptions. In the case of most existing exemptions, the substitution of a product widely available is usually considered in comparison with a product, which is new on the market and possibly produced at much lower volumes. QD technologies, of both kinds, used in displays are still relatively new on the market. As such, their market share is still expected to be relatively small. Should QD Displays have a lower availability, this would only delay their general market uptake, and affect competitiveness of different manufactures, but cannot be assumed to create significant impacts on consumers. Such aspects are not understood to be relevant for justifying an exemption.

5.6.4 Environmental Arguments

5.6.4.1 Energy Consumption and Reduction of Emissions

The applicants provide calculations to quantify the possible reduction of CO_2e emissions, Cd emissions and emissions of other heavy metals. Though there is no argument that a reduction of energy can have a positive impact in terms of various environmental impacts, the calculations provided cannot be used to support that CdSe QD displays shall always achieve such benefits in comparison to other displays.

Such advantages have been shown to exist by the applicants, when a CdQD film is used in a display to replace an InP film, in relation to the difference in energy consumption of the two displays.

In an LCA prepared on behalf of QD Vision, Engler et al.[89] explain that depending on the baseline selected, CdSe QDs improve energy efficiency by approximately 20-30 percent when compared to In-based QD TVs. Using the mid-point 25 percent improvement and emission rates calculated in the RPA analysis allow a calculation of the benefits related to the energy savings, as shown in Table 5-17.

Table 5-17: Lifetime Emissions Reductions for CdSe QD TVs Compared to In QD TVs

Benefit	Lifetime reductions per TV (based on 2013 emission rates)	Total savings in EU (35% market penetration)
CO_2 emissions	436 kg CO_2 eq.	8.7 billion kg CO2 eq.
Cadmium emissions	1.3 mg	24 kg
Mercury emissions	3.0 mg	61 kg
Lead emissions	17.8 mg	356 kg
SOx emissions	230 g	4.6 million kg
NOx emissions	210 g	4.2 million kg
PM_{10} emissions	15 g	300,000 kg

Notes: Assumptions: 25% improvement in energy efficiency (CdSe QD TV vs In QD TV), 30,000 hour (20.5 yr) lifetime for each TV, and 35% market penetration (20 million TVs in EU). Emission rates from RPA[90] document.
Source: Engler et al. (2015)

However, this estimation is based on a lifetime of 30,000 hrs or 20 years, assuming the television is operated for 4 hours per day. According to Prakash et al.[91], 50% of the

[89] Op. cit. Engler et al. (2015)
[90] Referred to in Engler et al. (2015) as Risk & Policy Analysts (2015): Cadmium Selenide Quantum Dots—RoHS Exemption Supporting Arguments. Final Report.
[91] Prakash el al. (2016), Prakash, S.; Antony, F.; Dehoust, G.; Gsell, M.; Köhler, A. R.; Schleicher, T.; in collaboration with Stamminger, R.; Oeko-Institut e.V. in cooperation with Friedrich-Wilhelm-Universität Bonn, Einfluss der Nutzungsdauer von Produkten auf ihre Umweltwirkung: Schaffung einer Informationsgrundlage und Entwicklung von Strategien gegen „Obsoleszenz" [Influence of the service life of products in terms of their environmental impact: Establishing an information base and developing policies against "obsolescence"] Commissioned by: German Federal Environment Agency (UBA), Dessau

televisions disposed of in Germany do not reach the age of 10 years. Though it cannot be concluded that this is true throughout the EU, in the consultants view, a 20 year service life at 4 hours per day is an over-estimation, meaning that the estimated emission reductions could be lower. In this respect it should be noted that displays using an on-surface configuration shall have a higher content of Cd (between 25-167 mg for a 55" television on the basis of 3-20 µg Cd per cm^2). It is possible that the energy savings of an on-edge configuration television are comparable to that of an on-surface configuration. However, this has not been substantiated, whereas the energy savings used for the above calculation are related to results of a swap comparison of CdSe and InP films in on-surface configurated televisions. In this sense, the Cd emission reductions throughout the life time of a television are expected to be below the assumed 1.5 mg *of Cd contained in an on-edge Cd QD television* and much lower than the amount of Cd used in the CdSe QD film of a television with an on-surface configuration. As for other reduced emissions, these are also expected to be lower than estimated. Thus the above results may give some indication, but should be treated cautiously. When weighing the possible use of Cd with the potential for reductions in emissions of other RoHS restricted substances, it should however also be kept in mind that Cd is not expected to emit from the QDs under normal operation.

In contrast, it is also apparent that there are displays on the market using other than Cd QD technologies that consume less energy than some Cd QD ones. As is apparent from the various comparisons, there is a difference in the potential of CdSe QDs and in what they achieve in actual products on the market. In other words, the available information only supports that though advantages could be expected in some cases they should not be expected in all cases. There are still other displays consuming lower amounts of energy and in this sense it cannot be assumed that a wide range application of CdSe QD displays would result in significant energy savings and savings of related emissions in the EU.

5.6.4.2 Toxicity

As for toxicity, the consultants agree that it is very difficult to compare between the toxicity of two substances without comprehensive data. The information provided by the applicants and by Nanoco shows various discrepancies, the source of which is not clear, aside from the understanding that the applicants compare between Cd and CdSe and between InP, whereas Nanoco compares CdSe to the compounds used in its own QD material, explained to be based on In but not on InP.

The consultants have consulted the website of the European Chemicals Agency (ECHA) for information as to the classifications of the various substances. From the Registration

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(FKZ UFOPLAN 3713 32 315), pg. 149, available under: https://www.umweltbundesamt.de/sites/default/files/medien/378/publikationen/texte_11_2016_einfluss_der_nutzungsdauer_von_produkten_obsoleszenz.pdf database[92] it is understood that neither CdSe nor InP are registered. The information retrieved is shown in Table 5-18.

Table 5-18: Information from ECHA Registration Database

Compound	Statements related to classification		Comments and source
Cadmium Selenide	**Classification**		“Self”-Classification of a substance supplier. See: http://www.sigmaaldrich.com/catalog/product/ALDRICH/244600?lang=en&region=US
	Hazard Class and Category Code(s)	**Hazard Class and Category Code(s)**	
	Acute Tox. 3 *	**H301**	
	Acute Tox. 3 *	**H331**	
	Acute Tox. 4 *	**H312**	
	Carc. 1B	**H350**	
	Causes damage to organs through prolonged or repeated exposure	**H373**	
	Aquatic Chronic 1	**H410**	
Indium Phosphide	**Classification**		Annex VI of CLP Regulation, Table 3.1., updated 9 March 2016: http://echa.europa.eu/documents/10162/13626/annex_vi_clp_table_en.xlsx
	Hazard Class and Category Code(s)	**Hazard Class and Category Code(s)**	
	Carc. 1B	H350	
	Repr. 2	H361f	
	STOT RE 1	H372 (lungs)	
Cadmium	CLP Classification (Table 3.1)		http://echa.europa.eu/information-on-chemicals/cl-inventory-database/-/discli/details/51061
	Classification		
	Hazard Class and Category Code(s)	Hazard Statement Code(s)	
	Pyr. Sol. 1	H250	
	Acute Tox. 2 *	H330	
	Muta. 2	H341	
	Carc. 1B	H350	
	Repr. 2	H361fd	
	STOT RE 1	H372	
	Aquatic Acute 1	H400	
	Aquatic Chronic 1	H410	
Cadmium	**Classification**		Comment: cadmium compounds, with the exception of cadmium sulphoselenide (xCdS.yCdSe), reaction mass of cadmium sulphide with zinc sulphide (xCdS.yZnS), reaction mass of cadmium sulphide with mercury sulphide (xCdS.yHgS), and those specified elsewhere in this
	Hazard Class and Category Code(s)	**Hazard Class and Category Code(s)**	
	Acute Tox. 4 *	H332	
	Acute Tox. 4 *	H312	
	Acute Tox. 4 *	H302	
	Aquatic Acute 1	H400	
	Aquatic Chronic 1	H410	

[92] See http://echa.europa.eu/information-on-chemicals/registered-substances?p_p_id=dissregisteredsubstances_WAR_dissregsubsportlet&p_p_lifecycle=1&p_p_state=normal&p_p_mode=view&p_p_col_id=column-1&p_p_col_pos=1&p_p_col_count=2&_dissregisteredsubstances_WAR_dissregsubsportlet_javax.portlet.action=dissRegisteredSubstancesAction

Compound	Statements related to classification		Comments and source
			Annex: Source: Annex VI of CLP Regulation, Table 3.1., updated 9 March 2016: http://echa.europa.eu/documents/10162/13626/annex_vi_clp_table_en.xlsx
Selenium	**Classification**		Comment: Classification for selenium compounds with the exception of cadmium sulphoselenide and those specified elsewhere in this Annex Source: Annex VI of CLP Regulation, Table 3.1., updated 9 March 2016: http://echa.europa.eu/documents/10162/13626/annex_vi_clp_table_en.xlsx
	Hazard Class and Category Code(s)	**Hazard Statement Code(s)**	
	Acute Tox. 3 * Acute Tox. 3 * STOT RE 2 Aquatic Acute 1 Aquatic Chronic 1	H331 H301 H373 ** H400 H410	

In general it is noted that cadmium selenide currently does not have a harmonised classification and it is assumed that classification used by suppliers for marking and producing data sheets are thus based on separate classification statements of the substances cadmium and selenide.

The availability of information as to the toxicity of CdSe and InP does not allow a conclusive comparison of their toxicity nor deriving a conclusion as to which would be of higher concern in the application at hand.

5.6.4.3 Resource Use and Recycling

In relation to indium it is argued among others that the use of this substance should be a concern in relation to insufficient recycling methods at end of life. This is also raised against its being identified as a critical material in terms of its availability as a resource. In this respect it should, however, be kept in mind that indium is used in displays in other components, and thus developing suitable technologies for its recycling is of concern, regardless of the possible use of In-based Qds. In an Oeko-Institute report of 2012 concerning the recycling of critical raw materials from waste electronic equipment, Buchert et al. (2012) [93] state the following:

> *"Indium is used in the form of indium tin oxide (ITO) as electrode material in flat screens. The advantage of indium tin oxide is that it is transparent, conductive and largely heat-resistant. The ITO layers applied in screens consist of 90% In_2O_3 and 10% SnO_2, corresponding to a percent by weight of indium of 78% (Böni & Widmer 2011). Whilst two layers of ITO are applied to LCD displays, OLED displays*

[93] Buchert et al. (2012), Buchert, M.; Bleher, D.; Manhart, A.; Pingel, D.; Oeko-Institute, Recycling critical raw materials from waste electronic equipment [Recycling kritischer Rohstoffe aus Elektronikaltgeräten] Commissioned by: North Rhine-Westphalian State Agency for Nature Conservation, Environmental Affairs and Consumer Protection (LANUV), Recklinghausen, available under: http://www.oeko.de/oekodoc/1375/2012-010-en.pdf

only have one layer. The literature gives different and often very contradictory data on the film thickness and indium content of flat screens… In LCD displays with LED background illumination, indium is also used as a component of the LED semiconductor chip which is largely composed of indium gallium nitride."

Buchert et al. estimate the quantity of In per display in relation to display size, reproduced in Table 5-19.

Table 5-19: Mean Indium Content of Different Display Devices

	Mean screen area [cm^2]	Mean In content per device [mg]
Notebooks	552	39
Computer monitors	1,126	79
Televisions	3,626	254

Source: Buchert et al. (2012)

A further aspect to be understood in relation to environmental and health impacts is related to the achieved colour performance of specific display applications. It is observed that currently CdQds seem to be closest to achieving the high colour gamut addressed in Rec. 2020 whereas in some areas of application, it can be followed that the colour performance can be critical to achieve certain environmental or health benefits. Such would be the case in the design of displays to be used for medical diagnostics or for monitoring and control of environmental impacts. In such cases the high colour gamut can thus be understood to possibly create subsequent benefits for the environment or for health.

5.6.5 Stakeholder Contributions

Various aspects are raised by stakeholders both in support and in objection to the requests at hand. Some of these aspects are similar in nature to those detailed in the various sections of this report and thus are not referred to here again.

A number of the stakeholders mention the purpose of the RoHS Directive in supporting a transition of the market away from the substances restricted therein. This can be understood to support the revoke of exemption 39 and to restrict further placing on the market of displays and lighting containing Cd QDs. In some cases such statements are made in relation to the availability of Cd-free alternatives providing similar functions, and in others these statements are made along with explanations as to the scope of exemptions that should be defined more precisely. These statements raise various viable aspects, for example in relation to the purpose of the RoHS Directive or as to the expected low significance of possible socio-economic impacts to incur should the exemptions be denied. However, the consultants understand the three primary criteria specified in Article 5(1)(a) to constitute the core mandate of this evaluation. Where the available information allows understanding that there are technical advantages to a certain technology, the consultants understand this to be the base for conclusions of this evaluation. Where other aspects are of concern, such as of social nature, these can be taken into consideration in the duration of a possible exemption. However further consideration of such aspects, beyond that which has been undertaken is understood to be beyond the mandate of the consultants.

From the various contributions, it becomes apparent that a core question in the background of this evaluation is related to how an alternative and the baseline are respectively defined. When considering both display and lighting products, it is clear that alternative displays and alternative lighting applications both based on other technologies are available. Displays with lower colour gamut are available and are purchased by consumers, as are light sources with CRI below 90. The understanding that a wide range of display types are still purchased, shows that consumers have different preferences in relation to this product, not all attributing highest priority to colour gamut performance. The fact that such products are purchased, shows that consumers are willing to accept the lack of certain functions or properties. Though consumers may be willing to purchase products with additional properties, they cannot weigh the benefit from such functions against the technology or the substances it contains to provide such functions.

It may thus be worthwhile to consider whether the use of a RoHS restricted substance to provide certain functions in the products at hand is acceptable. The criteria specified in Article 5(1)(a) are understood to mean that where significant environmental, health and consumer safety benefits would be derived from the added function, that this could justify an exemption (depending as to how these benefits are to be weighed with total costs and benefits). However where technical aspects are enabled that do not relate to environment, health and consumer safety, RoHS does not specify if and how such impacts are to be considered. Where exemptions were issued when RoHS came into force, this is understood to have been done with the understanding that such exemptions would provide a transition period until products could comply with the substance restriction. However when a new product or a product with a new function and enhanced performance parameters is developed, there is no specification in RoHS as to whether and to how such functions should be taken into account. The evaluation can review whether a RoHS restricted substance supports a certain function, and if this is a significant difference in comparison to similar products on the market. However the evaluation cannot determine if the use of a RoHS restricted substance is an acceptable “cost” for the provision of a certain new function. In the exemption request at hand this is the case of the function colour gamut understood to be supported by the use of Cd QDs.

It further needs to be noted that though for some products a single function may be the main factor influencing consumer choice; this is not always the case. For example, for medical diagnostics devices, it can be assumed that all medical facilities shall prefer a device, which enables better diagnostics, should this be possible with higher colour gamut. Though some facilities may not be able to afford such a device in lack of sufficient finances, it is assumed that at least for most facilities, better diagnostics shall be the key function influencing product choice. In contrast, as is apparent by the wide range of displays for sale, different consumers can be expected to have very different preferences in relation to displays.

Though such questions are understood to be of importance, they are beyond a scientifically based assessment of the exemption and thus could only be taken into consideration in the course of the decision process of the EC and of the European Parliament, related to the requested exemptions.

As for aspects raised by KEMI, as to how the comparison of products should be undertaken, the consultants generally agree that a technology needs to be evaluated in the context of the product in which it is being used. However, in the consultants' perspective the "swap" comparisons made enable an understanding of the comparative potential of Cd-free and Cd-based QDs in displays and are thus understood to support the significant difference between each technology's performance capabilities. The swap method allows understanding the potential of a technology within a specific product, and in this sense serves its purpose. However, for other technologies, comparisons of this sort are more complicated as it is not straightforward to distinguish between the functions enabled by the technology and by functions enabled or supported by other components. In such cases it seems that at present only a comparison on the product level is appropriate. Provided information shows that some of the other technologies may provide sufficient alternatives in terms of colour gamut. However, the current inability to compare energy efficiency aspects as well as other aspects that may be of importance does not allow the consultants to conclude, which of the display types would be understood to have a significantly improved performance in relation to all relevant aspects. Thus the basis of available data, does not support other conclusions than those specified.

5.6.6 Exemption Wording Formulation

When asked as to the wording proposed by the consultants in the 2013-2014 report, 3M DMSD[94] stated that it agrees with a split of the exemption according to application field (between SSL and display lighting applications). They specify the following wording as one that best covers the display lighting application:

> "*Cadmium in downshifting cadmium based semiconductor nanocrystal quantum dots for use in display lighting applications (< 0.2 µg Cd per mm² of display screen area)*"

3M DMSD further raises the "repeated delays of QD manufacturers to bring a non-Cd solution to the market" and the lacking availability of non-Cd QDs on the open market to support a 5 year termed exemption duration. It is further explained that 5 years will be needed for development of film formulations and reliability and performance testing (of the film and in devices such as televisions), once non-Cd QD materials become freely available on the market in sufficient quantities.

In this respect, the consultants would like to note that both applicants have specified that CdQDs currently in use in displays on the market all use CdSe. In this sense the

[94] Op. cit. 3M DMSD (2016a)

exemption could be specified to CdSe, as all provided comparisons are understood to be relevant for displays using CdSe QDs. Though the current Cd QD configurations result in significantly different amounts of Cd in the final product, in the consultants' view, if an exemption is to be granted, it should not be limited to a certain configuration. This aspect was discussed in the initial review and is also supported by QD Vision's statement, that:

> *"on-edge cannot serve all markets. Display trends, including the desire for thinner bezels and HDR with its prescribed higher luminance requirements, are driving a strong market shift to direct-lit backlight technology – which requires the use of an on-surface QD configuration… Beyond televisions and monitors, most hand held-devices also place a premium on thin form-factors and bezels. And while QD Vision is working to miniaturise its on-edge technology, the implementation is unlikely to be sufficiently thin for such important applications. Until the advent of an on-chip solution – which could come out of our on-edge development – such displays require the availability of an on-surface solution."*[95]

5.6.7 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- 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;
- the **reliability** of substitutes is not ensured;
- 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.

For the first criteria, **elimination or substitution**, the colour gamut performance is understood to be the function differentiating between various types of displays. The information made available shows that CdSe quantum dots can be applied in displays, resulting in higher performance in terms of colour gamut. This is based on the results of a number of "swap" comparisons, in which the performance of a TV using a CdSe QD film was compared with that of the same TV using a InP QD film. In this sense, it can be concluded that in such cases the CdSe QD film used showed advantages related to the performance criteria colour gamut over the InP QD film used.

On this basis it is observed that CdSe QDs can be used in displays to provide higher colour performance, however these results need to be considered with caution. Comparing results shows that the standard used for comparison may affect the results or at least their significance. From results of the "swap" comparisons it can be concluded

[95] Op. cit. QD Vision (2016c)

that when CdSe QD films and InP QD films are compared in the same displays, that CdSe QDs always have a higher colour gamut performance. However the significance of this performance depends on the standards used for the comparison and is more significant in two cases (NTSC and Rec 2020) and less significant in another (DCI-P3). Results of general display comparisons can be used to understand this aspect in relation to other technologies (i.e., other than quantum dot technologies). On the basis of available information it was concluded in the evaluation of 2013-2014 that Cd QD technologies showed a colour gamut preference in comparison to other technologies available at the time. However, results of general comparisons made available at present show that there are some new technologies that may provide comparable or better performance. The NTSC results for TriGain phosphor, ß-sialon phosphor and $SrGa_2S_4$ phosphor show a comparability or a preference. The DCI-P3 results show comparability for IPS quantum and for Hi-performance phosphors. However as already stated above, it has been observed that higher performance in relation to one standard does not guarantee higher performance in others. Thus it is difficult to conclude as to the colour gamut performance of CD QD technologies in relation to such newer technologies. Furthermore, all of these technologies are understood to be relatively new and it is not clear if all are in use in products currently available on the market. Where results relate to actual displays (iMac, LG 4 smart-phone), these are of smaller sizes, possibly affecting comparability as the scalability of such technologies is not clear, nor are other performance aspects. This hinders further comparison in relation to the other criteria (for example reliability, environmental impacts).

As is apparent from data both for these phosphors and for the various QD displays, the market is observed to be very dynamic and the preference of a certain technology today should not be assumed to remain a constant for the long term.

Though for some cases it is observed that CdSe QDs provide better performance than other technologies, it is neither possible to conclude whether this is relevant only for InP QD technologies or for all other technologies, nor whether the difference in performance is significant enough to justify an exemption on its own.

As for the second criterion, in terms of **reliability**, the available data and particularly the market availability of displays using various technologies suggests that their reliability is sufficient for placing a product on the market, though it cannot be concluded from available data if the reliability is comparable for all displays in terms of expected service life. The applicants also both refer to long service lives of the CdQD components (films, optical tubes) of 30,000 hrs and above. In this sense, it is assumed that even if the display life is in some cases shorter, this could not necessarily be attributed to the use of the QD technology within the display.

The third criteria relates to **possible impacts on consumer safety, on health and on the environment**. These are to be compared between the application relevant to the request and its possible alternatives.

In relation to **consumer safety**, the Engler et al. LCA states "…*These loading levels of Cd overstate the exposure potential to a toxic form of Cd. Unlike CFL light sources, there is no mechanism for the release of the QD material from the display itself. The QD* *materials are non-volatile and are further incorporated into a polymer matrix as a homogenous material (and then either placed between low-permeability barrier films or in the case of the on-edge optic manufactured by QD Vision, encapsulated in a hermetically-sealed glass tube)*."[96] Nanoco[97] points out for example that "*There is still a risk to the worker/consumer/environment if the device becomes damaged, e.g. (for QD Vision's technology) if the fragile glass capillary component breaks, in a house fire, or in landfill*." However, the consultants understand the case of a "house fire", in which a Cd QD display is damaged and results in emissions and possible impacts on consumer safety, health and the environment to have a relatively low likelihood. In relation to consumer safety the consultants can follow QD Vision's statement that "the risks of InP and CdSe should not be exaggerated – particularly in the QD form that they have they present no hazard to the user" [98].

As for **health** aspects, from the data available as to toxicity, it is difficult to differentiate between InP and CdSe QD applications in terms of the risks of possible health impacts. A comparison with other technologies is currently not possible on the basis of available data, as it would require knowledge as to substances used in relevant components and the risks of emissions thereof. In contrast, it can be followed that in some cases, the colour gamut function can serve to create environmental benefits, i.e., when these technologies are used to improve medical diagnostic capabilities. In other words where colour gamut can be achieved by a display technology in medical diagnostics devices, possible benefits to health could also be considered. As it can be understood that additional technologies may also achieve good colour gamut, it can however not be concluded whether such benefits could only be attributed to displays using CdSe QDs.

Finally, in terms of **environmental** impacts, it is observed that for displays where data is available, that the use of CdSe QD films can result in higher energy efficiency which could lead to lower emissions, thereunder Cd emissions, from energy supply. Though comparing different displays on the market, as a product, shows that in some cases InP QD film displays perform better in this regard than some CdSe displays, the "swap" comparison allows concluding that these differences are related to other components of the display design and not to the different technologies themselves. In "swap" comparisons CdSe QD films showed consistent results in terms of higher energy efficiency, though the difference varied between different displays (between 22% to 28% lower consumption displays of varying sizes). On this basis it can be concluded that CdSe QD can provide higher energy savings in comparison to InP QDs when used in a certain display. As for other display technologies, though there appear to be display technologies that could compare with Cd Qds in terms of colour gamut, the data made available does not allow concluding if these technologies would also have a similar potential to reduce energy consumption or if the opposite would occur. Data has not

[96] Op. cit. Engler et al. (2015)
[97] Op. cit. Nanoco (2016a)
[98] Op. cit. QD Vision (2015)

been made available for such technologies and a conclusion in this respect is not possible at present.

It can be understood that there are displays on the market with better performance in terms of energy consumption, when comparing displays of different sizes and of different colour performance. However when these aspects are held constant and particularly for consumers looking to purchase a display with higher colour gamut performance, the available information suggests that the use of CdSe QDs could allow reducing the energy consumption of the display. It has been demonstrated that this reduction is significant when comparing displays using CdSe QD technologies and displays using InP QD technologies. It is currently not possible to conclude whether this reduction would also be relevant (or significant) in comparison to all other technologies. The 2013-2014 evaluation showed energy benefits of above 10% in relation to other technologies available at the time[99]. It is apparent that there may be some new technologies with comparable colour gamut performance, which are starting to emerge in products on the market. Available data however does not allow a conclusion as to the energy efficiency of such technologies in comparison to Cd QD displays.

On the basis of available information and data it can be concluded that the use of CdSe QD technologies in displays can provide a higher colour gamut performance and a higher energy efficiency. This conclusion can be drawn in relation to older technologies available on the market and in relation to InP quantum dot technologies (though the significance of colour gamut performance differences may vary). As for newer technologies, information is only available as to colour gamut performance and does not allow a comprehensive conclusion at present. As such technologies can be understood to be in their first market stages (used in first products) or still in development and as data does not allow comparing aspects such as reliability, scalability and energy efficiency, it is recommended to grant a short term exemption, to allow monitoring the suitability of such technologies as alternatives in the near future.

Further thought may also need to be given to how an alternative and the baseline respectively are defined. Where it can be followed that the colour gamut function has a significant influence on consumer preferences, this aspect may serve to define what types of displays are to be considered as appropriate alternatives in relation to the first criteria, which relates in the end to the functionality.

It is beyond the scientifically based assessment mandate of the exemption evaluation to conclude whether the use of cadmium as a RoHS restricted substance to enable a certain function or property (colour gamut) is an acceptable cost therefor. There is a wide variety of displays used in other categories (televisions, telecommunications and displays of other EEE) and the fact that a certain function could be added does not allow concluding whether this function would comprise the main preference influencing consumers purchasing choices. Though this aspect is beyond the scope of this review, in

[99] Op. cit. Baron et al. (2014)

the consultants' opinion it is an aspect to be considered as part of the decision process on whether to grant the requested exemption or not and what its duration should be.

6.0 Cadmium Quantum Dots in Lighting Applications

In the 2013-2014 evaluation of these requests, it was mentioned that QD were being developed for use for solid state lighting (SSL) applications. At the time it had been stated that there were no articles on the market using either Cd-based or Cd-free QD, however it was stated that these should come onto the market shortly. As lighting applications have a very wide range of applications (form and dimension, power rating, lumen output, efficacy, colour performance, area of application, CRI etc.), it was concluded at the time that without understanding the area of applicability, a comparison of parameters would not enable understanding whether QD lighting technologies had advantages over conventional ones. The applicants and stakeholders have thus been requested to provide information as to changes in the market status of these technologies and as to the comparative performance thereof. Information made available in this respect is presented in the following sections.

6.1 Technical Background

According to Lumileds[100], conventional solid-state lighting technology is based on blue LEDs exciting a garnet and red phosphor (phosphorescent light downconverter) to generate green, yellow and some red light, which is mixed to form white light for illumination purposes. To create warm white light (CCT<3500K) with a high quality of light (CRI>90) it is necessary to add a significantly higher amount of red phosphor of longer wavelengths to produce the warm tones missing from the garnet phosphor spectrum. The problem with conventional red phosphors is that they have a broad spectrum and are therefore less efficient than green phosphors. LEDs with CRI>90 have lower luminous efficiency than LEDs with CRI of 80 because of the greater fraction of LED emission spectra needed in the far-red wavelength region. The broad spectrum of conventional red phosphors exacerbates the drop in luminous efficacy as the emission further reaches deep red and infrared wavelengths where the eye sensitivity is low. Similar to incandescent bulbs, a significant part of the generated light is wasted as infrared radiation.

[100] Lumileds (2015a), Lumileds Germany GmbH, Input for stakeholder consultation for RoHS exemption requests 2013-2 and 2013-5, submitted 14.12.2016, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/20151214_Oeko_Institut_consultation.pdf

Lumileds contends that quantum dots (QDs) are a relatively new material class that, like phosphors, down-convert light from higher energy wavelengths of typically blue light to lower energy wavelengths of green or red light. Key characteristics of quantum dots are their potentially very high efficiency, their narrow emission spectrum, and that their emission frequency can be accurately tuned across the entire visible spectrum. The narrow emission spectrum prevents the needless generation of invisible infrared radiation. No other downconverter exists which exhibits narrow emission (<35 nm FWHM), is emission tunable to within a wavelength in the range of few nm, and has extremely high photoluminescence quantum efficiencies, both at room temperature and LED operating temperatures.[101]

Lumileds[102] explains that QD LED packages are relevant for lighting areas where colours are to be rendered accurately, i.e. when we want our surroundings to look natural and realistic. High colour rendering / quality of light is not limited to a specific application. Examples of specific applications are for example:

- Bathrooms (to be able to accurately apply makeup, to accurately see the colour of your skin, teeth etc. in the mirror);
- Living rooms, dining rooms (to accurately see the colour of food, artwork, people);
- Museums (to accurately see the colour of paintings);
- Retail/shops (to accurately and appealingly reproduce the colour of objects for sale);
- Hospitality/hotels (to appealingly represent the colours of artwork, furniture, and people);
- Stadium lighting (to accurately represent the colours of the athletes both to the audience and the TV cameras); and
- Surgical lighting (To ensure the colours of tissue are accurately represented indicating to the surgeon the oxygenation level of tissue. In this instance high efficiency lighting has added importance beyond simply energy savings; it means the surgeon does not sweat under the heat of the lamps generating the intense light required for surgery).

Lumileds Cd QD LEDs are intended to be used in retrofit lamps, LED modules and LED luminaires such as A-style bulbs, candle lamps, spotlights, downlights, troffers, and tube LEDs (TLEDs). [103]

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[101] Op. cit. Lumileds (2015a)
[102] Lumileds (2016b), Answers to 1st Clarification Questionnaire Regarding CdQD Exemptions, submitted 18.4.2016
[103] Op. cit. Lumileds (2016b)

6.1.1 Standards and Methods for Comparing Lighting Performance

According to Nanoco[104], the main measures for comparison of LED lighting products are:

- Correlated Colour Temperature (CCT). The colour temperature of the light emitted from an ideal black body is defined as its surface temperature in Kelvin. Standard incandescent lamps have a CCT of around 2400K. Standard LED and fluorescent lights usually have a much higher CCT, which gives a bluer light.
- Colour Rendering Index (CRI) is a quantitative measure in % terms of the ability of a light source to show the colours of various objects correctly in comparison with an ideal or natural light source.
- Luminous Efficacy (LES) is the amount of light flux produced for the electrical power consumed, measured in Lumens per Watt (Lm/W).
- The R_9 value is a measure of the red component in a light, which is essential for producing more natural colours from artificial lights. The R9 value is not included in the standard CRI index.

Nanoco explains that when designing spectra for general lighting purposes, there is often a trade off in the lamp efficiency (LES) and the CRI R_a[105]. LES is calculated by multiplying the spectral power distribution (SPD) of the measured lamp source by the human eye sensitivity curve, which is particularly sensitive in the green part of the spectrum around 555nm, but tails off rapidly in the blue and red regions. CRI R_a on the other hand has particular sensitivity at different parts of the visible spectrum and in particular a significant component in the red region. This sensitivity also changes as the effective colour (CCT) of the emitted light changes. In addition to the CRI R_a sensitivity, a particular component of the metric known as the R_9, which represents the ability of a light source to accurately represent deep red colour tones is also gaining prevalence in the lighting industry, with regulations such as Energy Star[106] requiring that this specific figure is quoted. R_9 is far more sensitive than the CRI Ra metric, particularly in the red region of the spectrum. This means that in order to maximize the colour rendering properties of a light source (CRI values >90) the LES must be sacrificed as wavelengths in the red part of the spectrum need to be covered, where the eye is less sensitive. [107]

According to Lumileds[108], in the case of lamps producing white light for general illumination, product performance is measured by the following parameters. All four

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[104] Op. cit. Nanoco (2015a)
[105] Referenced in Nanoco (2016b) as Y. Ohno, "Spectral design considerations for white LED colour rendering," Opt. Eng., vol. 44, no. 11, p. 111302, 2005.
[106] Referenced in Nanoco (2016b) as Energy Star, "ENERGY STAR® Program Requirements for Televisions Partner Commitments," 2008
[107] Op. cit. Nanoco (2016b)
[108] Op. cit. Lumileds (2015a)

parameters, CCT, CRI, efficacy and luminous flux, should be measured according to the international standard CIE S 025, issued by the International Commission on Illumination.

- Luminous flux (the amount of visible light generated by the lamp);
- Luminous efficacy (the luminous flux divided by the electric input power);
- Colour temperature (CCT, how warm or cold/blue-ish the light appears); and
- Colour rendering index (CRI, how well a light source reproduces the colours of the objects it illuminates).

Lumileds[109] notes that there is an inherent trade-off between colour temperature (CCT), colour rendering index (CRI) and luminous efficacy. This is due to the fact that the human eye is not equally sensitive to all wavelengths, i.e. to all colours of light. Going from CRI 80 to CRI 90, all other parameters being equal is thought to result in a 20% decrease in luminous flux[110].

Lumileds states that a suitable colour temperature for benchmarking is 2700K (warm white), which is equivalent to the colour temperature of incandescent light bulbs and is frequently recommended for residential use[111]. CRI values of 90 and an R9 value of 50 are appropriate. The EU regulation 1194/2012 requires a minimum CRI of 80 (for residential use), but better colour rendering properties are recommended[111]. Lumileds agrees with the parameters provided by Nanoco. Luminous efficacy (in lm/W) is the key environmental parameter. CRI, CCT and R9 describe product performance, and only products with equal performance should be compared. [112]

6.2 The Market Availability of Quantum Dot Lighting

The applicants, QD Vision and 3M DMSD have not provided detailed information as to lighting applications in their recent documents.

Nanoco[113] provides some detail as to lighting applications containing QDs that are available on the EU market.

Table 6-1: Lighting Applications Containing QDs that are Available on the EU Market

Device	Vendor	Technology	CCT	CRI	LES	Availability	Source
Par 30 LED	Nexus Lighting	Cd-based QD	2700	90	65	discontinued	http://www.qdvision.com/release-05052009
Zylight F8-D LED Fresnel	Prokit	Cd-based QD	3200 & 5600	up to 97 and 95	not specified	now	https://www.prokit.com/zylight-f8-d-led-fresnel/)
Orion QD	MARL	Cd-free QD	2250	90	53	now	http://www.leds.co.uk/products/lighting/architectural_lighting#Orion QD

[109] Op. cit. Lumileds (2015a)
[110] Referred to in Lumileds (2015a) as http://www.ledsmagazine.com/articles/2013/01/lighting-coalition-asks-epa-to-lower-energy-star-efficacy-specsfor-high-cri-lamps.html
[111] Referred to in Lumileds (2015a) as US Department of Energy, "Energy Efficiency of LEDs," 2013
[112] Op. cit. Lumileds (2015a)
[113] Op. cit. Nanoco (2015a)

Notes: The Nexus Par 30 LED was discontinued in 2013.The Zylight F8-D LED Fresnel is the only Cd-based lighting product we have found available in the EU. However, this is a very expensive (>€2000ea) specialist theatrical spotlight for professional use only.
Source: Nanoco (2015a)

Nanoco also states that it demonstrated 4 different product ranges at the Lux Live exhibition this year. A panel lamp, a strip light and a spot light for domestic and commercial use were shown, each of which will be available in 3 colour temperatures. A horticultural lamp was shown in a strip light version and a panel lamp version is also being developed. [114]

Lumileds[115] manufactures LED modules and not Cd QD materials or Cd QD lighting end-products (i.e. lamps or luminaires to be sold to the final consumer). Lumileds is not aware of any additional lighting products employing quantum dot technology having been placed on the market. LED products using quantum dot technology – with or without cadmium – are currently not widely available. Lumileds intends to launch LED packages containing cadmium-based quantum dots in 2016. However, the uncertainty around this exemption leads to reluctance by lamp and luminaire manufacturers to invest into the technology, to explore its full potential and to develop products.

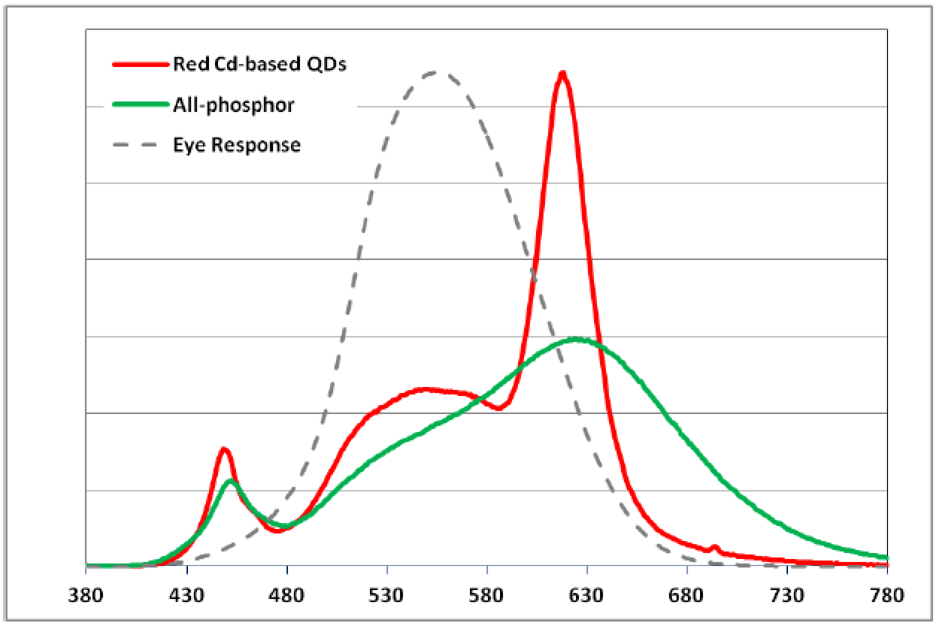
Lumileds expects that its LED packages shall be used in a wide range of lamps and luminaires. However, as a component supplier Lumileds cannot comment on the exact uses of such applications. [116]

6.3 Comparative Performance of Quantum Dot Lighting

CREE, Inc.[117] supports the request in relation to lighting applications. CREE has fabricated and tested a variety of white LEDs (i.e. those with colour points on or near the black-body locus) which contain red-emitting (600-630nm) Cd-based QDs. An example spectrum of a warm-white (~2700K) QD-LED is compared with that of a conventional 90 CRI (colour rendering index) all-phosphor LED in Figure 6-1. CREE explains the spectral efficiency of the QD-LED is ~18% higher than its all-phosphor counterpart, which translates into a corresponding efficacy gain when the QD quantum yield is comparable to that of the phosphors.

[114] Op. cit. Nanoco (2016a)
[115] Op. cit. Lumileds (2015a)
[116] Op. cit. Lumileds (2016b)
[117] CREE (2016), CREE Inc., Santa Barbara Technology Center, Consultation Questionnaire Regarding Cd Exemptions, submitted 11.1.2016, available under: http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/CREE__RoHS_Cd_exemption_consultation.pdf

Figure 6-1: Spectrum of a Warm-white (2700K, 92 CRI) LED Containing Cd-based QDs (red line), vs. an LED with Conventional Red Phosphor (Green Line) at the Same Colour Temperature and CRI



CREE notes that the human eye response is overlaid for reference. The QD-containing LED has a ~18% higher spectral efficiency due to its low emission in the near-infrared.

Source: CREE (2016)

CREE[118] claims to have evaluated both Cd-based and Cd-free QDs which emit red light. CREE explains that synthesized Cd-based QDs currently have quantum yield (blue to red light down-conversion efficiency) values of >90%, which is on par with conventional green/yellow and red phosphors. Meanwhile according to CREE, Cd-free QDs (e.g. InP-based) have been observed to have quantum yield values of <75%, which, combined with their broader (>45 nm FWHM) peak width, results in lower LED efficacy compared to Cd-based QDs. Given the current state of Cd-free QDs and their rate of development, CREE estimates that they will be precluded from practical use in SSL applications for the next >5 years. CREE values luminous efficacy as the most appropriate metric for evaluating the economic and environmental impacts of emerging solid-state lighting technologies, and provides Table 6-2 to compare luminous efficacy of various light sources they have tested.

[118] Op. cit. CREE (2016)

Table 6-2: Input Efficacy Values for Calculation of Cd Emissions Reductions, for LEDs at 3000K CCT and 90 CRI Ra & 50 CRI R_9

Type	Efficacy	Source
Linear Fluorescent (baseline)	75 lm/W	"Energy Savings Forecast of SSL in General Illumination Applications", Table D.2; Prepared for U.S. DOE by Navigant Consulting, August 2014.
Phosphor-converted LED	109 lm/W	Cree XP-L datasheet, U3 flux bin at 1 W/mm^2, 3000K/90 CRI
Cd-based QD-LED	149 lm/W	Cree R&D measurement at 1 W/mm^2
Cd-free QD-LED	132 lm/W	Simulation adapted from Cd-based QD meas., with 45nm FWHM and 75% quantum yield

Source: CREE (2016)

According to Nanoco[119], QDs are most effective in lighting applications where a high degree of spectral tunability is required, due the inherent increased emission tunability of the QD nanocrystals compared to other lighting technologies. For white lighting applications, QDs can be used to tune the colour temperature, for example to replicate natural daylight or to produce "mood lighting", for example in shops and restaurants.

Nanoco[120] provides comparative data as to the efficacy and colour performance of various QD lighting applications, reproduced in Table 6-3.

Table 6-3: Comparison of Products Available in the EU

Device	Vendor	Technology	CCT Kelvin	CRI %	LES Lum/W	Availability	Source
Par 30 LED	Nexus Lighting	Cd-based QD	2700	90	65	discontinued	http://www.qdvision.com/release-05052009
Zylight F8-D LED Fresnel	Prokit	Cd QD ? No Cd detected	3200 & 5600	up to 97 and 95	36.7 measured	now	https://www.prokit.com/zylight-f8-d-led-fresnel/)
Orion QD	MARL	Cd-free QD	2250	90	53	now	http://www.leds.co.uk/products/lighting/architectural_lighting#Orion QD
Cropmaster QD Propagator LED	Budmaster	Cd-free QD	N/A	N/A	N/A	now	http://www.budmaster.co.uk/cropmaster-qd-propagator-led.html

The Nexxus Par 30 LED was discontinued in 2013 and never replaced. The Zylight F8-D LED Fresnel is the only non-Nanoco lighting product we have found available in the EU that has claimed to use QDs. This is a very expensive (>€2000ea) specialist theatrical spotlight for professional use only. However, when a sample was tested by Nanoco it was found to contain no cadmium. It was found to contain significant levels of Aluminium, Yttrium, Gallium and Calcium. The spectrum of the light showed broad emission, other than for the blue from the LED, rather than the narrow peaks associated with QDs.
Source: Nanoco (2016a)

In a later communication, Nanoco[121] provides additional comparisons reproduced in the following tables. Table 6-4 shows a comparison of two of the lamps shown in Table 6-3

[119] Op. cit. Nanoco (2016b)
[120] Op. cit. Nanoco (2016a)
[121] Op. cit. Nanoco (2016b)

with an OLED lamp, which has similar performance parameters. Table 6-5 shows a comparison of a Cd-free QD LED with an HPS lamp, which has similar performance parameters.

Table 6-4: Comparison of Lighting Products with Similar CCTs, Similar to that of Daylight

TECHNOLOGY	DEVICE	CCT, K	CRI	LES, lm/W	NOTES
Cd-Based QD	Nexxus Par 30 LED	2,700	90	65	Discontinued [20]
Cd-Free QD	Marl Orion QD	2,250	90	53	[21]
OLED	LG LL030RS1-62P1-OY1	2,700	> 87	60	[22]

Source: Nanoco (2016b)

Table 6-5: Comparison of a High Pressure Sodium Lamp (HPS) with an Alternative Developed by Nanoco

TECHNOLOGY	DEVICE	CCT, K	CRI	LES, lm/W	NOTES
Hi-Pressure Sodium HPS	Phillips Master Colour	6,600	92	76	Ref [23]
Cd-Free QD	Nanoco CFQD®	6,314	95.7	105.9	Ref [24]

Source: Nanoco (2016b)

Nanoco[122] also states that high performance phosphors are also being investigated for lighting applications. One paper demonstrates that Sr[LiAl3N4]:Eu2+ phosphor can provide a 14 % improvement in luminous efficacy compared to a commercially available high CRI LED, while GE claims a 32 % improvement in luminous efficacy at a CCT of 4,000 K for its TriGain™ phosphor, compared to a conventional high CRI LED. The device with a CCT of 4,000 K had a high CRI of 90, a luminous efficacy of 168 lm/W and an R_9 value > 90.

Nanoco[123] provides further details as to Cd-free QDs used in alternatives for high pressure sodium (HPS) lamps and for horticultural lighting. As detailed information is not available to allow a comparison of CdQD lighting applications for these applications, the information is reproduced in Appendix A.2.0.

Nanoco[124] argues that, while cadmium-based QDs could be used to give similar lighting performance and characteristics, the RoHS Directive makes it clear that such restricted materials should not be used where alternatives exist. The current situation is that there are no cadmium QD lighting products on the EU market, while cadmium-free QD

[122] Op. cit. Nanoco (2016b)
[123] Op. cit. Nanoco (2016b)
[124] Op. cit. Nanoco (2016b)

products have already been launched. Nanoco believes that in this situation, there is no justification for extending Ex. 39 for all LED lighting products as this would only serve to promote the development and introduction of new cadmium based products – the precise opposite of what the RoHS Directive is intended to achieve. It would, of course, still be possible for manufacturers to develop cadmium QD lighting technology aimed at specific commercial lighting applications where they can positively prove that suitable alternatives do not yet exist and therefor apply for new, specific exemptions for those products in line with the RoHS Directive requirements.

Lumileds[125] confirms that they are currently not aware of any products on the market containing CdQds, though they expect such products to come on the market in 2016. Lumileds claims that luminous efficacy improvements are especially significant for warm-white lamps with a high quality of light (i.e. good colour rendering properties). The higher the CRI, the larger the red content and the greater the visual impact and benefit of the quantum dots. Based on internal data, Lumileds expects that the efficacy improvements presented in Table 6-6 can be achieved within the next two years (at a given CCT/CRI combination, relative to current conventional phosphors).

In a later communication, Lumileds[126] explains the advantage of Cd QD LEDs is not the spectral output in itself, but the higher luminous efficacy at given CCT/CRI combinations. The same spectral output can also be reached with conventional phosphor technology. This creates hardly visible red and invisible infrared light and wastes energy. With conventional phosphors it is currently not possible to avoid this completely, and therefore the luminous efficacy is lower compared to the Cd QD LEDs. The luminous efficacy gains (of Cd QD LEDs compared to conventional phosphor LEDs) will therefore be highest at lower CCT and higher CRI values. Table 6-6 shows that also at higher CCT (4000K / neutral white) there is still a significant luminous efficacy gain vs. conventional phosphor LEDs.

Table 6-6: Expected Efficacy Improvements that can be Achieved within the Next Two Years in CdQD SSL

		CCT		
CRI	**R9**	2700K	3000K	4000K
80	0	4.5%* (6.5%**)	5%**	3%**
90	50	25%*	22%**	16%**

*experimentally validated; **expected performance from modeling.

Source: Lumileds (2015a)

Lumileds[127] further provides data comparing two LEDs, with and without Cd QDs to a similar 60W incandescent lamp (CCT of 2700K, CRI of 90), which is reproduced in

[125] Op. cit. Lumileds (2015a)
[126] Op. cit. Lumileds (2016b)
[127] Op. cit. Lumileds (2015a)

Table 6-7. The data shows the power consumption of the LED lamp containing quantum dots to be 2.20 W lower than that of the LED lamp using conventional phosphors. Lumileds states that the resulting savings by far outweigh any potential negative health, safety and environmental effects that cadmium inside the products may have.

Table 6-7: Performance of two LED Lamps (with and without quantum dots) with a Similar Performance 60W Incandescent Lamp

	LED lamp using conventional phosphors	LED lamp using quantum dots
Light output	843lm	843lm
Number of LED packages	12	12
LED package efficacy	92lm/W	115lm/W
Amount of cadmium per LED package		2.55µg
Amount of cadmium per LED lamp		30.6µg
Efficiency losses due to drivers/optics	15%	15%
Lamp efficacy	78lm/W	98lm/W
Lamp power consumption	10.8W	8.60W

Source: Lumileds (2015a)

In terms of reliability, Lumileds[128] explains that until now, quantum dots could not be used directly in LED packages because their reliability and performance at the high operating temperatures encountered in LED packages was not sufficient. However, new developments allow quantum dots to be placed inside the LED package, directly on top of the semiconductor material (i.e. the LED die), which will finally enable their use in LED lighting. At the moment, the only type of quantum dot that can be used in this configuration and has the aforementioned advantageous properties is a cadmium containing quantum dot.

Lumileds was asked to substantiate its information to allow a better understanding of the applications for which Cd-QDs are expected to be developed, i.e., areas of application where the advantages in terms of warmer light and higher efficiency are significant in relation to existing applications. Lumileds[129] provided the Table 6-8 to allow a better understanding of the parameters compared in their initial documents. In this respect Lumileds explains that the efficiency gains from the use of quantum dots are biggest for warm-white, high CRI products with a high quality of light, i.e. with similar light quality properties as that of a 60W incandescent lamp (CCT of 2700K, CRI of almost 100). This used to be the most common lamp until it was phased out by legislation, and many consumers are still trying to find replacement lamps with equal light properties. Though the data is given for an example lamp, it is explained that it is derived from the single LED package. The LED packages used in this reference lamp determine the performance improvement associated with the use of Cd QD LEDs. They can be used in other lamp/luminaire configurations without any changes to the LED package.

[128] Op. cit. Lumileds (2015a)
[129] Op. cit. Lumileds (2016b)

Table 6-8: Parameter Specification for Conventional LED and Cd QD LED Used in Lumiled LCA Comparison

Parameter	Conventional LED lamp	Cd QD LED Gen 1	Cd QD LED Gen 2
Nominal input voltage	230V	230V	230V
Nominal input power/wattage	10.81W	9.65W	8.65W
Light output	843lm	843lm	843lm
Luminous efficacy (of the complete lamp)	78lm/W	87lm/W	98lm/W
Colour temperature	2700K	2700K	2700K
Colour rendering index (CRI)	90	90	90
R9	50	50	50
Number of LED packages used	12	12	12
Weight of heatsink	17.4g	12.6g	7.3g

Source: Lumileds (2016b)

Lumileds[130] explains that the parameters are specified on the basis of their research and testing. Lumileds produces LED packages and not final applications. In this sense, Lumileds confirms that it has not tested lamps, but rather LED modules. These had CCT of 3000K, CRI of 90 and R9 of 50. Light output is 495lm. The test results of the engineering samples confirm the expected gains in luminous efficacy and thereby confirm that the reference lamp is also representative (in terms of expected luminous efficacy gains) for other types of lamps and luminaires in different configurations, with similar light quality properties.

6.3.1 Environmental Arguments

Lumileds[131] quotes UNEP[132], explaining that "*Electricity for lighting accounts for between 15% (UNEP, 2014) and 19% (IEA, 2006) of global electricity consumption and between 5 and 6% of worldwide CO_2 emissions. A global transition to widely available efficient*

[130] Op. cit. Lumileds (2016b)
[131] Op. cit. Lumileds (2015a)
[132] Refered to in Lumileds (2015a) as Sustainable Energy for All Initiative, United Nations, "Global Energy Efficiency Accelerator Platform – Lighting", http://www.se4all.org/energyefficiencyplatform/lighting/, accessed November 25, 2015

solutions in all lighting sectors (residential, commercial/industrial and outdoor) by 2030 could reduce electricity demand for lighting by more than 32%, and avoid 3.5 Gt of CO_2. If the world leapfrogged to LED lamps in all sectors, it would reduce global electricity consumption for lighting by more than 52% and avoid 735 million tonnes of CO_2 emissions each year". In this respect Lumileds states that the application of quantum dot technology will accelerate this transition and further increase the potential savings of current LED lamps in electricity consumption and resulting CO_2 emissions, as outlined below.

According to Lumileds[133], as with any other technology, the environmental impact of LED light sources is measured by the material and energy resources used over the entire life-cycle of the product (production, use, recycling and/or disposal). In the case of all lighting technologies (incandescent, fluorescent, discharge, LED), the total life-cycle consumption is dominated by the electricity consumption during the use phase[134]. As noted by the U.S. Department of Energy, "*the greatest environmental impact after energy in-use for the LED sources is the aluminium heat sink, which would be reduced in size as the efficacy increases, and more of the input wattage is converted to useful lumens of light (instead of waste heat)*."[135] Most other parameters will not change significantly due to the introduction of quantum dots (e.g. energy consumption of LED die and package production, material use for LED lamp). Consequently, the most important parameter by far for assessing environmental performance of a light source is its luminous efficacy, i.e. the ratio of visible light output (luminous flux, measured in lumens) and power consumption (in watts). [136]

Lumileds[137] explains that as quantum dots LEDs show an increase in efficacy compared to current conventional phosphor LEDs, more of the input wattage is converted to useful lumens of light (instead of waste heat), resulting in a decrease in the heat sink size. The thermal management of current conventional phosphor and quantum dots LED lamps have been modelled to estimate the volume, as well as the weight of the heat sink needed to dissipate this heat, and is reproduced in Figure 6-2.

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[133] Lumileds (2016a), Comparative life cycle assessment of LED lamps based on cadmium containing quantum dots and conventional phosphors prepared for Lumileds, submitted 8.1.2016, available under http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_Pack_10/Cd_Quantum_Dot_Evaluation/Lumileds_20160108_LCA_Results_final.pdf

[134] Referred to in Lumileds (2015a) as US Department of Energy, "Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products", 2013

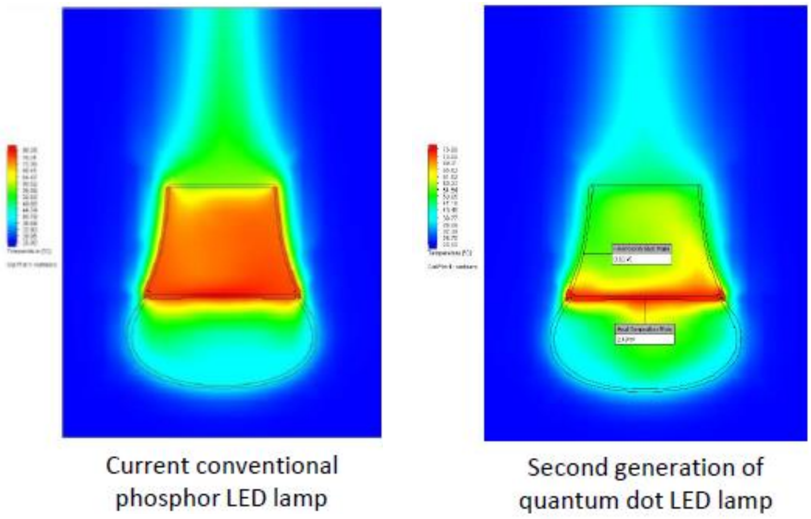
[135] Referred to in Lumileds (2015a) as US Department of Energy, "Life-Cycle Assessment of Energy and Environmental Impacts of LED Lighting Products - Part 2: LED Manufacturing and Performance", 2012

[136] Op. cit. Lumileds (2016a)

[137] Op. cit. Lumileds (2015a)

Figure 6-2: Comparison of Waste Heat and Waste Sink Weights of LED Lamps

Weights of the heat sink used in the LCA:	Weight heatsink (g)
Current conventional phosphor LED lamp	17.4
First generation of quantum dot LED lamp	12.6
Second generation of quantum dot LED lamp	7.3



Source: Lumileds (2015a)

CREE[138] also explains that emerging quantum dot materials in solid state lighting will raise luminous efficacy by up to 20% over conventional phosphor-down-converted LEDs, thereby resulting in lowered cost of ownership and greatly reduced pollutant emissions from electricity generation. CREE estimates that the reduction in Cd emissions enabled by QDs in LEDs used for a 10-year warranty period could be >18 times that of the Cd content sequestered in the LEDs themselves. CREE declines to comment on display applications. However, noting that the efficacy gains enabled by QDs in LEDs for solid-state lighting will also benefit display (e.g. large-format TV) efficiency, since most LCD displays are backlit with LEDs.

[138] Op. cit. CREE (2016)

6.4 Exemption Scope and Wording Formulation

Lumileds[139] states that the following wording is understood to be adequate:

> *"Cadmium in components for lighting applications and display lighting applications, containing downshifting cadmium based semiconductor nanocrystal quantum dots, where the cadmium per display screen area is limited to less than 0.2 ug/mm².”*

Lumileds understands the concentration limit of 0.2 µg/mm² to be applicable only to display products and believes that, if a maximum limit for lighting applications were to be proposed, the exact definition and limit value would need to be reconsidered as the definition of display screen area is not applicable to lighting products. In Lumileds perspective, the terms “nanocrystal” and “quantum dot” seem redundant. At least one of the two terms should be removed. In addition, both terms are not clearly defined within the context of this regulation. This may lead to unnecessary uncertainty and misunderstandings. For the reasons stated in the letter of LightingEurope in response to consultations 2013-2 and 2013-5 (dated November 11, 2013)[140], Lumileds believes it is preferable not to specify a maximum concentration and thus proposes the following wording:

> *“Cadmium in light control materials used for lighting devices”*

CREE[141] supports the use of the LED component-specific language proposed in the 2013-2 application, namely “*Cadmium in II-VI colour converting material (< 10 µg Cd per mm² of light-emitting area) for LEDs for use in solid state illumination or display systems*”. CREE proposes that the LED light-emitting area be defined as the combined surface area of region(s) on an LED component where light down-conversion may occur.

6.5 Critical Review

6.5.1 REACH Compliance - Relation to the REACH Regulation

See review in Section 5.6.1.

6.5.2 Scientific and Technical Practicability of Substitution

The stakeholders describe the advantages of using quantum dot technologies for lighting. The main advantage of QD LED packages is understood to be that they can be used to produce light sources, with a warmer light and higher colour rendering properties, which are more efficient than other sources in terms of energy consumption.

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[139] Op. cit. Lumileds (2015a)

[140] Referred to in Lumileds (2015a) as http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_IX/Request_2013-2/20131111_Lighting_Europe_WG_Material_support_letter_RoHSexemption39_Ex_Re_2013-2-5_final.pdf

[141] Op. cit. CREE (2016)

As the light emission of QDs can be tuned to produce a narrow and accurate spectral output, it is understood that light sources can be designed to emit more light in the relevant spectral output range of visible light, while decreasing losses to the invisible light range.

In cases where warmer light and higher colour rendering are needed, a spectral output is usually sought stretching in to the range of red wavelengths. In conventional light sources, though the light source shall be designed to emit light in the visible red wavelength range, there shall also be light emitted in the non-visible range, some of which results in heat being radiated from the lamp and not just light. From the available information, it can be understand that QDs can be tuned, determining the wavelengths of the emitted light more accurately. This allows reducing the spectral output in the non-visible range and thus also reducing losses to radiation (i.e. waste heat). Respectively, more of the power input is used to produce visible light and less is lost as non-visible light and heat, increasing the total efficiency of the lamp. As the waste heat is reduced, the size and weight of the lamp heat sink can also be reduced, this providing a further advantage in terms of the resources needed to manufacture the light source.

The consultants can follow that in certain areas of application, where a spectral output in the red wavelength range is required, that QD LED packages may allow designing the spectral output more efficiently, reducing emissions in the non-visible light range and reducing waste heat of the light source. To establish however the magnitude if this advantage, it is necessary to compare between QD LED light sources and between other light sources, however, as described below, it is apparent that this needs to be done in a certain way, depending on the area of application.

From the review of the information available, the consultants note when making comparisons, the application being compared is of importance to deduce how the light sources should be compared:

- When a QD LED package is expected to be a substitute for lighting applications, which are also designed on the basis of LED packages, then a comparison on the component level of LED packages may suffice. This is based on the understanding that the packages shall be applied to the product in the same way (the same array) in order to produce a similar type of lighting. In this sense, the LED package can be seen as a smaller building block of the application, where both applications contain the same number of packages in the same array.
- When however two LED products are being compared, which are assembled differently, it is possible that the number of packages used per product may differ and that the light output and light distribution from the two products may be different. In such cases it would not suffice to compare two modules, but rather the two products would need to be compared, taking into consideration the module comparison, but also the number and array of packages and the resulting light and its parameters. In such cases, the comparison needs to take into consideration that the light source may be different in terms of the resources (materials) from which it is composed.

However the use of LED packages may simplify the comparison to some degree, in so far that there will be similarities in resource use related to the materials comprising the LED packages.

- For similar reasons, where a QD LED package is expected to be a substitute for other light technologies (i.e., conventional technologies such as discharge lamps, but also more innovative technologies such as OLEDs), a comparison between the QD LED product and the product being replaced would be of relevance. The only exception to this rule would be in areas where the lamp technology to be replaced has been, or is about to be phased out. In such cases the comparison would be with other possible replacement alternatives and would be performed depending on their technology.

With the different aspects related to light source comparison in mind, the data and information provided by Nanoco and Lumileds can be viewed with an aim to determine whether the advantages of Cd QD LED packages would justify an exemption from the RoHS substance restrictions.

Nanoco provides data as to the performance of a number of Cd-free QD LED lighting products already available on the market. Nanoco also details a number of applications of relevance for Cd-free QD LED light sources, namely in horticultural lighting, as a substitute for HPS lamps and as panel lamps, strip lights and spot lights for domestic and commercial uses. As these lamps are understood to use other than Cd QDs, it is understood that they can be placed on the market regardless of whether the exemption is to be approved or denied. However, such light sources are an alternative that could be compared to Cd QD LEDs. Since they also use quantum technology to determine the spectral output, it can be assumed that the spectral output of light sources can also result in lower spectral losses and heat losses, thus enabling the production of more efficient lamps, at least in some areas of application.

As Lumileds demonstrates, the energy efficiency advantage is not absolute but rather its magnitude is tied to the parameters of the designed light source. As is apparent from Table 6-9, the efficacy improvements for higher CRI and R9 values are significantly larger than for lower values. The efficacy also changes in relation to CCT, with higher efficacies expected for warmer light (or light with a lower colour temperature).

Table 6-9: Expected Efficacy Improvements that can be Achieved within the Next Two Years in CdQD SSL

		CCT		
CRI	**R9**	2700K	3000K	4000K
80	0	4.5%* (6.5%**)	5%**	3%**
90	50	25%*	22%**	16%**

*experimentally validated; **expected performance from modeling.

Source: Lumileds (2015a)

This further supports that to Cd QD LED sources need to be evaluated in relation to the specific application, for which they are to be used. As observed from the table, in some areas, significant reductions of energy consumption could justify the use of a substance restricted by RoHS. However in others, where energy performance of light sources is comparable or where differences are less significant, this may not be the case. Thus the evaluation needs to consider the area of application. The data currently available, however does not allow a comprehensive comparison. In this respect, two types of comparison are understood to be of relevance at present. A comparison of Cd-based and Cd-free QD LED packages and a comparison of light sources based on QD LED packages with alternative light sources in relation to a specific application.

Since both of these are quantum dot technologies a comparison on the package level could be relevant for establishing whether the technologies are comparable or whether one provides performance superior to that of the other. However the data currently available would not allow such a comparison as it is not available for both technologies in relation to the LED package.

The data provided by Lumileds and by Nanoco would also not allow comparing Cd-based and Cd-free QD LEDs for a certain application as the two stakeholders have not provided data for a similar application. Even if this comparison were currently possible, a second stage would be to compare the applications in terms of the number of modules used and the various materials and resources used to manufacture the light source, as it could currently not be assumed that the light source is identical in all respects aside from the LED packages used.

Finally, even if one could currently determine the superiority of one of these QD technologies, it would still be of importance to understand the planned area of application of the LED packages, as this shall determine what products are currently used for the same purpose on the market. Alternative light sources of the specific application area would need to be reviewed to understand their comparability with QD LED light sources. For example, Nanoco provides detail of a Cd-free LED light source that could be used as an HPS replacement. However the data compares lamps with CRI above 90, whereas as HPS lamps with much lower CRI values are also used, for example in street lighting (see for example Ex. 4b and Ex. 4c of Annex III of the RoHS Directive).

6.5.3 Conclusions

Article 5(1)(a) provides that an exemption can be justified if at least one of the following criteria is fulfilled:

- 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;
- the **reliability** of substitutes is not ensured;
- 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.

It can be understood that quantum dots can be used to produce light sources with a warmer light and higher colour rendering properties. The stakeholders argue that such light sources have fewer losses in the spectral non-visible infra-red range, thus also resulting in products with lower waste heat. The consultants can follow that in some areas of application where warmer light and high colour rendering is required, that such technologies may provide energy savings in comparison to other available light sources. However it is currently not possible to clarify relevant areas of application at a level, which would allow comparing QD light source performance to the performance of other light sources. The current information may suggest that an exemption could be restricted to light sources above a certain CRI, however in order to establish if such an exemption would be justified, it would further be necessary to substantiate information and data as to the following aspects in order to allow a comprehensive comparison and a conclusive evaluation:

- The area of application in terms of the purpose of the light source and its required light parameters (i.e., CRI, CCT, R_9, light output, etc.);
- The characteristics of the light sources being compared (as relevant to package comparison/lamp comparison / luminaire comparison) and the parameters of relevance thereto (for example, number of LED packages, bill of materials, data on heat sink components, etc.). Here the detail of a comparison would depend on the products being compared;
- The characteristic performance parameters of the light sources being compared (luminous efficiency, input power, etc.).

At present, it is understood that a general exemption is requested for the use of Cd in quantum dot application in solid state lighting. However it is clear from the available information that in some areas the unique properties of Cd QD LED light sources are not relevant to the scope of an exemption. For example, energy consumption benefits can be understood to be significant above certain CRI and R9 values and at lower CCT values (warmer light temperatures). However below such values there would be negligible or possibly no benefits and the exemption would not be justified as other light sources can achieve the same function without the use of Cd.

At present it is also not possible to demarcate a more narrow scope where the exemption would be justified. Though some parameters have been clarified to be of relevance to such a demarcation (CRI, CCT, R_9, etc.), it has not yet been possible to determine the values at which benefits can be expected. It also seems probably that such values would be application sensitive and would therefor only justify exemptions for the use of the technology in certain application areas, which are yet to be defined. Finally, it is apparent that there may be substance alternatives, which may prove to be substitutes for Cd within the quantum dot application. For such cases, the performance of the two technologies needs to be compared either on an LED package basis (should this be possible from available data) or on a product/application sensitive basis (where package data cannot be obtained in the public realm).

Once a comparison can be performed in relation to the aspects above, it shall be possible to determine for various applications if an exemption is justified in line with the

5(1)(a) criteria – if substitutes are available that provide a comparable reliability and for which environmental and health benefits would not outweigh those of Cd QD LED light sources.

7.0 Recommendation

The information and data made available shows that CdSe QDs can be used in displays to provide higher colour gamut and to reduce energy consumption. Though there are displays using CdSe with lower performance in this respect, “swap” comparisons of QD films allow concluding that differences would be related to the performance of other display components, whereas when these are held constant, CdSe show better performance in comparison with InP QDs. In this sense an exemption would be understood to be justified due to benefits that CdSe QDs could provide in terms of energy efficiency and in some cases also in relation to colour gamut, at least where InP QD displays are assumed to be the only appropriate alternative. In parallel, it is apparent that the display market is a highly dynamic one, and other technologies have been observed showing similar colour gamut. For these technologies energy efficiency performance was not specified and it cannot be concluded if their performance would be comparable or not. As such products are understood to be relatively new technologies in terms of their use in products on the market, the consultants recommend providing a short termed exemption so that changes in products on the market can be observed.

In parallel, it is beyond the scientifically based assessment mandate of the exemption evaluation to conclude whether the use of a RoHS restricted substance to enable a certain function or property is an acceptable cost therefor. Though in some cases functions may be related to environmental, health or consumer safety benefits, this only seems to be the case for products of categories 8 and 9. There is a wide variety of displays used in other categories (televisions, telecommunications and displays of other EEE) and the fact that a certain function could be added does not allow concluding whether this function would be critical for other consumers. Though this aspect is beyond the scope of this review, in the consultants opinion it is an aspect to be considered as part of the decision process on deciding whether to grant the requested exemption or not and what its duration should be.

At present it is not recommended to grant an exemption for the use of Cd QDs in lighting applications. Though this technology may have environmental benefits in certain application areas, the available information shows that an exemption would not be justified in all areas of lighting applications. In contrast, the information currently available does not allow demarcating applications of relevance for an exemption with a more narrow scope. Nor can the possible extent of relevant environmental benefits, such as energy saving, be understood for such applications so that it is not yet possible to understand in what areas an exemption would be justified and in what areas it would not. Nonetheless, where manufacturers can show that Cd QD light sources for specific application areas have benefits over other light source alternatives, it would still be possible to submit a request for exemption in the future.

Exemption 39	**Duration***
Cadmium selenide in downshifting cadmium based semiconductor nanocrystal quantum dots for use in display lighting applications (< 0.2 µg Cd per mm^2 of display screen area)	*An exemption should be granted for three years*

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APPENDICES

A.1.0 Appendix 1: Relevant REACH Regulation Entries

Relevant annexes and processes related to the REACH Regulation have been cross-checked to clarify:

- In what cases granting an exemption could "weaken the environmental and health protection afforded by Regulation (EC) No 1907/2006" (Article 5(1)(a), pg.1)
- Where processes related to the REACH regulation should be followed to understand where such cases may become relevant in the future;

The last consolidated version has been consulted in this respect, published on 2 February 2016. Compiled information in this respect has been included, with short clarifications where relevant, in the following tables:

Table A. 1 lists those substances appearing in Annex XIV, subject to Authorisation, which are relevant to the RoHS substances dealt with in the requests evaluated in this project. As can be seen, at present, exemptions have not been granted for the use of these substances.

Table A. 1: Relevant Entries from Annex XIV: The List of Substances Subject to Authorization

Designation of the substance, of the group of substances, or of the mixture	Transitional arrangements		Exempted (categories of) uses
	Latest application date (1)	Sunset date (2)	
4. Bis(2-ethylhexyl) phthalate (DEHP) **EC No: 204-211-0** **CAS No: 117-81-7**	21 August 2013	21 February 2015	Uses in the immediate packaging of medicinal products covered under Regulation (EC) No 726/2004, Directive 2001/82/EC, and/or Directive 2001/83/EC.
5. Benzyl butyl phthalate (BBP) **EC No: 201-622-7** **CAS No: 85-68-7**	21 August 2013	21 February 2015	Uses in the immediate packaging of medicinal products covered under Regulation (EC) No 726/2004, Directive 2001/82/EC, and/or Directive 2001/83/EC.
6. Dibutyl phthalate (DBP) **EC No: 201-557-4** **CAS No: 84-74-2**	21 August 2013	21 February 2015	Uses in the immediate packaging of medicinal products covered under Regulation (EC) No 726/2004, Directive 2001/82/EC, and/or Directive 2001/83/EC.
7. Diisobutyl phthalate (DIBP) **EC No: 201-553-2** **CAS No: 84-69-5**	21 August 2013	21 February 2015	
10. Lead chromate	21 November 2013	21 May 2015	-

Designation of the substance, of the group of substances, or of the mixture	Transitional arrangements		Exempted (categories of) uses
	Latest application date (1)	Sunset date (2)	
EC No: 231-846-0 **CAS No: 7758-97-6**			
11. Lead sulfochromate yellow **(C.I. Pigment Yellow 34)** **EC No: 215-693-7** **CAS No: 1344-37-2**	21 November 2013	21 May 2015	-
12. Lead chromate molybdate sulphate red **(C.I. Pigment Red 104)** **EC No: 235-759-9** **CAS No: 12656-85-8**	21 November 2013	21 May 2015	-
16. Chromium trioxide **EC No: 215-607-8** **CAS No: 1333-82-0**	21 March 2016	21 September 2017	-
17. Acids generated from chromium trioxide and their oligomers **Group containing:** **Chromic acid** **EC No: 231-801-5** **CAS No: 7738-94-5** **Dichromic acid** **EC No: 236-881-5** **CAS No: 13530-68-2** **Oligomers of chromic acid and dichromic acid** **EC No: not yet assigned** **CAS No: not yet assigned**	21 March 2016	21 September 2017	-
18. Sodium dichromate **EC No: 234-190-3** **CAS No: 7789-12-0** **10588-01-9**	21 March 2016	21 September 2017	-
19. Potassium dichromate **EC No: 231-906-6** **CAS No: 7778-50-9**	21 March 2016	21 September 2017	-
20. Ammonium dichromate **EC No: 232-143-1** **CAS No: 7789-09-5**	21 March 2016	21 September 2017	-
21. Potassium chromate **EC No: 232-140-5** **CAS No: 7789-00-6**	21 March 2016	21 September 2017	
22. Sodium chromate **EC No: 231-889-5** **CAS No: 7775-11-3**	21 March 2016	21 September 2017	
28. Dichromium tris(-chromate) **EC No: 246-356-2** **CAS No: 24613-89-6**	22. July 2017	22 January 2019	
29. Strontium chromate **EC No: 232-142-6 CAS** **No: 7789-06-2**	22 July 2017	22 January 2019	
30. Potassium hydroxyoctaoxodizincatedichromate **EC No: 234-329-8** **CAS No: 11103-86-9**	22 July 2017	22 January 2019	
31. Pentazinc chromate octahydroxide **EC No: 256-418-0** **CAS No: 49663-84-5**	22 July 2017	22 January 2019	

For the substances currently restricted according to RoHS Annex II: cadmium, hexavalent chromium, lead, mercury, polybrominated biphenyls and polybrominated diphenyl ethers and their compounds, we have found that some relevant entries are listed in Annex XVII of the REACH Regulation. The conditions of restriction are presented in Table

A. 2 below. Additionally, some amendments have been decided upon, and are still to be included in the concise version. These may be seen in Table A. 3.

Table A. 2: Conditions of Restriction in REACH Annex XVII for RoHS Substances and Compounds

Designation of the substance, of the group of substances or of the mixture	Conditions of restriction
8. Polybromobiphenyls; Polybrominatedbiphenyls (PBB) CAS No 59536-65-1	1. Shall not be used in textile articles, such as garments, undergarments and linen, intended to come into contact with the skin. 2. Articles not complying with paragraph 1 shall not be placed on the market.
16. Lead carbonates: **(a) Neutral anhydrous carbonate ($PbCO_3$)** **CAS No 598-63-0** **EC No 209-943-4** **(b) Trilead-bis(carbonate)-dihydroxide $2PbCO_3$-$Pb(OH)_2$** **CAS No 1319-46-6** **EC No 215-290-6**	Shall not be placed on the market, or used, as substances or in mixtures, where the substance or mixture is intended for use as paint. However, Member States may, in accordance with the provisions of International Labour Organization (ILO) Convention 13, permit the use on their territory of the substance or mixture for the restoration and maintenance of works of art and historic buildings and their interiors, as well as the placing on the market for such use. Where a Member State makes use of this derogation, it shall inform the Commission thereof.
17. Lead sulphates: **(a) $PbSO_4$** **CAS No 7446-14-2** **EC No 231-198-9** **(b) $Pb_x SO_4$** **CAS No 15739-80-7** **EC No 239-831-0**	Shall not be placed on the market, or used, as substances or in mixtures, where the substance or mixture is intended for use as paint. However, Member States may, in accordance with the provisions of International Labour Organization (ILO) Convention 13, permit the use on their territory of the substance or mixture for the restoration and maintenance of works of art and historic buildings and their interiors, as well as the placing on the market for such use. Where a Member State makes use of this derogation, it shall inform the Commission thereof.
18. Mercury compounds	Shall not be placed on the market, or used, as substances or in mixtures where the substance or mixture is intended for use: (a) to prevent the fouling by micro-organisms, plants or animals of: — the hulls of boats, — cages, floats, nets and any other appliances or equipment used for fish or shellfish farming, — any totally or partly submerged appliances or equipment; (b) in the preservation of wood; (c) in the impregnation of heavy-duty industrial textiles and yarn intended for their manufacture; (d) in the treatment of industrial waters, irrespective of their use.
18a. Mercury **CAS No 7439-97-6** **EC No 231-106-7**	1. Shall not be placed on the market: (a) in fever thermometers; (b) in other measuring devices intended for sale to the general public (such as manometers, barometers, sphygmomanometers, thermometers other than fever thermometers). 2. The restriction in paragraph 1 shall not apply to measuring devices that were in use in the Community before 3 April 2009. However Member States may restrict or prohibit the placing on the market of such measuring devices. 3. The restriction in paragraph 1(b) shall not apply to: (a) measuring devices more than 50 years old on 3 October 2007; (b) barometers (except barometers within point (a)) until 3 October 2009. 5. The following mercury-containing measuring devices intended for industrial and professional uses shall not be placed on the market after 10 April 2014: (a) barometers; (b) hygrometers; (c) manometers; (d) sphygmomanometers; (e) strain gauges to be used with plethysmographs;

	(f) tensiometers; (g) thermometers and other non-electrical thermometric applications. The restriction shall also apply to measuring devices under points (a) to (g) which are placed on the market empty if intended to be filled with mercury. 6. The restriction in paragraph 5 shall not apply to: (a) sphygmomanometers to be used: i. in epidemiological studies which are ongoing on 10 October 2012; ii. as reference standards in clinical validation studies of mercury-free sphygmomanometers; (b) thermometers exclusively intended to perform tests according to standards that require the use of mercury thermometers until 10 October 2017; (c) mercury triple point cells which are used for the calibration of platinum resistance thermometers. 7. The following mercury-using measuring devices intended for professional and industrial uses shall not be placed on the market after 10 April 2014: (a) mercury pycnometers; (b) mercury metering devices for determination of the softening point. 8. The restrictions in paragraphs 5 and 7 shall not apply to: (a) measuring devices more than 50 years old on 3 October 2007; (b) measuring devices which are to be displayed in public exhibitions for cultural and historical purposes.
23. Cadmium and its compounds **CAS No 7440-43-9** **EC No 231-152-8**	For the purpose of this entry, the codes and chapters indicated in square brackets are the codes and chapters of the tariff and statistical nomenclature of Common Customs Tariff as established by Council Regulation (EEC) No 2658/87 (1). 1. Shall not be used in mixtures and articles produced from the following synthetic organic polymers (hereafter referred to as plastic material): — polymers or copolymers of vinyl chloride (PVC) [3904 10] [3904 21] — polyurethane (PUR) [3909 50] — low-density polyethylene (LDPE), with the exception of low-density polyethylene used for the production of coloured masterbatch [3901 10] — cellulose acetate (CA) [3912 11] — cellulose acetate butyrate (CAB) [3912 11] — epoxy resins [3907 30] — melamine-formaldehyde (MF) resins [3909 20] — urea-formaldehyde (UF) resins [3909 10] — unsaturated polyesters (UP) [3907 91] — polyethylene terephthalate (PET) [3907 60] — polybutylene terephthalate (PBT) — transparent/general-purpose polystyrene [3903 11] — acrylonitrile methylmethacrylate (AMMA) — cross-linked polyethylene (VPE) — high-impact polystyrene — polypropylene (PP) [3902 10] Mixtures and articles produced from plastic material as listed above shall not be placed on the market if the concentration of cadmium (expressed as Cd metal) is equal to or greater than 0,01 % by weight of the plastic material. By way of derogation, the second subparagraph shall not apply to articles placed on the market before 10 December 2011. The first and second subparagraphs apply without prejudice to Council Directive 94/62/EC (13) and acts adopted on its basis. By 19 November 2012, in accordance with Article 69, the Commission shall ask the European Chemicals Agency to prepare a dossier conforming to the requirements of Annex XV in order to assess whether the use of cadmium and its compounds in plastic material, other than that listed in subparagraph 1, should be restricted. 2. Shall not be used in paints [3208] [3209]. For paints with a zinc content exceeding 10 % by weight of the paint, the concentration of cadmium (expressed as Cd metal) shall not be equal to or greater than 0,1 % by weight. Painted articles shall not be placed on the market if the concentration of cadmium (expressed as Cd metal) is equal to or greater than 0,1 % by weight of the paint on the

painted article.

3. By way of derogation, paragraphs 1 and 2 shall not apply to articles coloured with mixtures containing cadmium for safety reasons.

4. By way of derogation, paragraph 1, second subparagraph shall not apply to:

— mixtures produced from PVC waste, hereinafter referred to as ‘recovered PVC’,

— mixtures and articles containing recovered PVC if their concentration of cadmium (expressed as Cd metal) does not exceed 0,1 % by weight of the plastic material in the following rigid PVC applications:

—

(a) profiles and rigid sheets for building applications;

(b) doors, windows, shutters, walls, blinds, fences, and roof gutters;

(c) decks and terraces;

(d) cable ducts;

(e) pipes for non-drinking water if the recovered PVC is used in the middle layer of a multilayer pipe and is entirely covered with a layer of newly produced PVC in compliance with paragraph 1 above.

Suppliers shall ensure, before the placing on the market of mixtures and articles containing recovered PVC for the first time, that these are visibly, legibly and indelibly marked as follows: ‘*Contains recovered PVC*’ or with the following pictogram:

In accordance with Article 69 of this Regulation, the derogation granted in paragraph 4 will be reviewed, in particular with a view to reducing the limit value for cadmium and to reassess the derogation for the applications listed in points (a) to (e), by 31 December 2017.

5. For the purpose of this entry, ‘cadmium plating’ means any deposit or coating of metallic cadmium on a metallic surface.

Shall not be used for cadmium plating metallic articles or components of the articles used in the following sectors/applications:

(a) equipment and machinery for:

— food production [8210] [8417 20] [8419 81] [8421 11] [8421 22] [8422] [8435] [8437] [8438] [8476 11]

— agriculture [8419 31] [8424 81] [8432] [8433] [8434] [8436]

— cooling and freezing [8418]

— printing and book-binding [8440] [8442] [8443]

(b) equipment and machinery for the production of:

— household goods [7321] [8421 12] [8450] [8509] [8516]

— furniture [8465] [8466] [9401] [9402] [9403] [9404]

— sanitary ware [7324]

— central heating and air conditioning plant [7322] [8403] [8404] [8415]

In any case, whatever their use or intended final purpose, the placing on the market of cadmium-plated articles or components of such articles used in the sectors/applications listed in points (a) and (b) above and of articles manufactured in the sectors listed in point (b) above is prohibited.

6. The provisions referred to in paragraph 5 shall also be applicable to cadmium-plated articles or components of such articles when used in the sectors/applications listed in points (a) and (b) below and to articles manufactured in the sectors listed in (b) below:

(a) equipment and machinery for the production of:

— paper and board [8419 32] [8439] [8441] textiles and clothing [8444] [8445] [8447] [8448] [8449] [8451] [8452]

(b) equipment and machinery for the production of:

— industrial handling equipment and machinery [8425] [8426] [8427] [8428] [8429] [8430] [8431]

	— road and agricultural vehicles [chapter 87] — rolling stock [chapter 86] — vessels [chapter 89] 7. However, the restrictions in paragraphs 5 and 6 shall not apply to: — articles and components of the articles used in the aeronautical, aerospace, mining, offshore and nuclear sectors whose applications require high safety standards and in safety devices in road and agricultural vehicles, rolling stock and vessels, — electrical contacts in any sector of use, where that is necessary to ensure the reliability required of the apparatus on which they are installed. 8. Shall not be used in brazing fillers in concentration equal to or greater than 0,01 % by weight. Brazing fillers shall not be placed on the market if the concentration of cadmium (expressed as Cd metal) is equal to or greater than 0,01 % by weight. For the purpose of this paragraph brazing shall mean a joining technique using alloys and undertaken at temperatures above 450 °C. 9. By way of derogation, paragraph 8 shall not apply to brazing fillers used in defence and aerospace applications and to brazing fillers used for safety reasons. 10. Shall not be used or placed on the market if the concentration is equal to or greater than 0,01 % by weight of the metal in: (i) metal beads and other metal components for jewellery making; (ii) metal parts of jewellery and imitation jewellery articles and hair accessories, including: — bracelets, necklaces and rings, — piercing jewellery, — wrist-watches and wrist-wear, — brooches and cufflinks. 11. By way of derogation, paragraph 10 shall not apply to articles placed on the market before 10 December 2011 and jewellery more than 50 years old on 10 December 2011.
28. **Substances which appear in Part 3 of Annex VI to Regulation (EC) No 1272/2008 classified as carcinogen category 1A or 1B (Table 3.1) or carcinogen category 1 or 2 (Table 3.2) and listed as follows:** **— Carcinogen category 1A (Table 3.1)/carcinogen category 1 (Table 3.2) listed in Appendix 1** **— Carcinogen category 1B (Table 3.1)/carcinogen category 2 (Table 3.2) listed in Appendix 2:** **Chromium (VI) trioxide** **Zinc chromates including zinc potassium chromate** **Nickel chromate** **Nickel dichromate** **Potassium dichromate** **Ammonium dichromate** **Sodium dichromate** **Chromyl dichloride; chromic oxychloride** **Potassium chromate** **Calcium chromate** **Strontium chromate** **Chromium (VI) compounds, with the exception of barium chromate and of compounds specified elsewhere in Annex VI to Regulation (EC) No 1272/2008** **Chromium III chromate; chromic chromate**	Without prejudice to the other parts of this Annex the following shall apply to entries 28 to 30: 1. Shall not be placed on the market, or used, — as substances, — as constituents of other substances, or, — in mixtures, for supply to the general public when the individual concentration in the substance or mixture is equal to or greater than: — either the relevant specific concentration limit specified in Part 3 of Annex VI to Regulation (EC) No 1272/2008, or, — the relevant generic concentration limit specified in Part 3 of Annex I of Regulation (EC) No 1272/2008. Without prejudice to the implementation of other Community provisions relating to the classification, packaging and labelling of substances and mixtures, suppliers shall ensure before the placing on the market that the packaging of such substances and mixtures is marked visibly, legibly and indelibly as follows: 2. By way of derogation, paragraph 1 shall not apply to: (a) medicinal or veterinary products as defined by Directive 2001/82/EC and Directive 2001/83/EC; (b) cosmetic products as defined by Directive 76/768/EEC; (c) the following fuels and oil products: — motor fuels which are covered by Directive 98/70/EC, — mineral oil products intended for use as fuel in mobile or fixed combustion plants, — fuels sold in closed systems (e.g. liquid gas bottles); (d) artists' paints covered by Regulation (EC) No 1272/2008; (e) the substances listed in Appendix 11, column 1, for the applications or uses listed in Appendix 11, column 2. Where a date is specified in column 2 of Appendix 11, the derogation shall apply until the said date.

Sodium chromate **Cadmium oxide** **Cadmium chloride** **Cadmium fluoride** **Cadmium Sulphate** **Cadmium sulphide** **Cadmium (pyrophoric)** **Chromium (VI) trioxide** **Lead Chromate** **Lead hydrogen arsenate** **Silicic acid, lead nickel salt Lead sulfochromate yellow; C.I. Pigment Yellow 34;** **Lead chromate molybdate sulfate red; C.I. Pigment Red 104;**	
29. **Substances which appear in Part 3 of Annex VI to Regulation (EC) No 1272/2008 classified as germ cell mutagen category 1A or 1B (Table 3.1) or mutagen category 1 or 2 (Table 3.2) and listed as follows:** **— Mutagen category 1A (Table 3.1)/mutagen category 1 (Table 3.2) listed in Appendix 3** **— Mutagen category 1B (Table 3.1)/mutagen category 2 (Table 3.2) listed in Appendix 4** **Cadmium chloride** **Cadmium fluoride** **Cadmium Sulphate** **Chromium (VI) trioxide** **Potassium dichromate** **Ammonium dichromate** **Sodium dichromate** **Chromyl dichloride; chromic oxychloride** **Potassium chromate** **Sodium chromate**	
30. **Substances which appear in Part 3 of Annex VI to Regulation (EC) No 1272/2008 classified as toxic to reproduction category 1A or 1B (Table 3.1) or toxic to reproduction category 1 or 2 (Table 3.2) and listed as follows:** **— Reproductive toxicant category 1A adverse effects on sexual function and fertility or on development (Table 3.1) or reproductive toxicant category 1 with R60 (May impair fertility) or R61 (May cause harm to the unborn child) (Table 3.2) listed in Appendix 5** **— Reproductive toxicant category 1B adverse effects on sexual function and fertility or on development (Table 3.1) or reproductive toxicant category 2 with R60 (May impair fertility) or R61 (May cause harm to the unborn child) (Table 3.2) listed in Appendix 6:**	

Bis(2-ethylhexyl) phthalate; di-(2-ethylhexyl) phthalate; DEHP **Benzyl butyl phthalate; BBP** **Dibutyl phthalate; DBP** **Diisobutyl phthalate** **Cadmium chloride** **Cadmium fluoride** **Cadmium Sulphate** **Potassium dichromate** **Ammonium dichromate** **Sodium dichromate** **Sodium chromate** **Nickel dichromate** **Lead compounds with the exception of those specified elsewhere in this Annex** **Lead hydrogen arsenate** **Lead acetate** **Lead alkyls** **Lead azide** **Lead Chromate** **Lead di(acetate)** **Lead hydrogen arsenate** **Lead 2,4,6-trinitroresorcinoxide, lead styphnate** **Lead(II) methane- sulphonate** **Trilead bis- (orthophosphate)** **Lead hexa-fluorosilicate** **Mercury** **Silicic acid, lead nickel salt**	
47. Chromium VI compounds	1. Cement and cement-containing mixtures shall not be placed on the market, or used, if they contain, when hydrated, more than 2 mg/kg (0,0002 %) soluble chromium VI of the total dry weight of the cement. 2. If reducing agents are used, then without prejudice to the application of other Community provisions on the classification, packaging and labelling of substances and mixtures, suppliers shall ensure before the placing on the market that the packaging of cement or cement-containing mixtures is visibly, legibly and indelibly marked with information on the packing date, as well as on the storage conditions and the storage period appropriate to maintaining the activity of the reducing agent and to keeping the content of soluble chromium VI below the limit indicated in paragraph 1. 3. By way of derogation, paragraphs 1 and 2 shall not apply to the placing on the market for, and use in, controlled closed and totally automated processes in which cement and cement-containing mixtures are handled solely by machines and in which there is no possibility of contact with the skin. 4. The standard adopted by the European Committee for Standardization (CEN) for testing the water-soluble chromium (VI) content of cement and cement-containing mixtures shall be used as the test method for demonstrating conformity with paragraph 1. 5. Leather articles coming into contact with the skin shall not be placed on the market where they contain chromium VI in concentrations equal to or greater than 3 mg/kg (0,0003 % by weight) of the total dry weight of the leather. 6. Articles containing leather parts coming into contact with the skin shall not be placed on the market where any of those leather parts contains chromium VI in concentrations equal to or greater than 3 mg/kg (0,0003 % by weight) of the total dry weight of that leather part. 7. Paragraphs 5 and 6 shall not apply to the placing on the market of second-hand articles which were in end-use in the Union before 1 May 2015.
51. The following phthalates (or other CAS and EC numbers covering the substance): **(a) Bis (2-ethylhexyl) phthalate (DEHP)** **CAS No 117-81-7** **EC No 204-211-0**	1. Shall not be used as substances or in mixtures, in concentrations greater than 0,1 % by weight of the plasticised material, in toys and childcare articles. 2. Toys and childcare articles containing these phthalates in a concentration greater than 0,1 % by weight of the plasticised material shall not be placed on the market. 4. For the purpose of this entry 'childcare article' shall mean any product intended to facilitate sleep, relaxation, hygiene, the feeding of children or sucking on the part of

(b) Dibutyl phthalate (DBP) **CAS No 84-74-2** **EC No 201-557-4** **(c) Benzyl butyl phthalate (BBP)** **CAS No 85-68-7** **EC No 201-622-7**	children.
63. Lead and its compounds **CAS No 7439-92-1 EC No 231-100-4**	1. Shall not be placed on the market or used in any individual part of jewellery articles if the concentration of lead (expressed as metal) in such a part is equal to or greater than 0,05 % by weight. 2. For the purposes of paragraph 1: (i) 'jewellery articles' shall include jewellery and imitation jewellery articles and hair accessories, including: (a) bracelets, necklaces and rings; (b) piercing jewellery; (c) wrist watches and wrist-wear; (d) brooches and cufflinks; (ii) 'any individual part' shall include the materials from which the jewellery is made, as well as the individual components of the jewellery articles. 3. Paragraph 1 shall also apply to individual parts when placed on the market or used for jewellery-making. 4. By way of derogation, paragraph 1 shall not apply to: (a) crystal glass as defined in Annex I (categories 1, 2, 3 and 4) to Council Directive 69/493/EEC (*); (b) internal components of watch timepieces inaccessible to consumers; (c) non-synthetic or reconstructed precious and semiprecious stones (CN code 7103, as established by Regulation (EEC) No 2658/87), unless they have been treated with lead or its compounds or mixtures containing these substances; (d) enamels, defined as vitrifiable mixtures resulting from the fusion, vitrification or sintering of minerals melted at a temperature of at least 500 °C. 5. By way of derogation, paragraph 1 shall not apply to jewellery articles placed on the market for the first time before 9 October 2013 and jewellery articles produced before 10 December 1961. 6. By 9 October 2017, the Commission shall re-evaluate paragraphs 1 to 5 of this entry in the light of new scientific information, including the availability of alternatives and the migration of lead from the articles referred to in paragraph 1 and, if appropriate, modify this entry accordingly. 7. Shall not be placed on the market or used in articles supplied to the general public, if the concentration of lead (expressed as metal) in those articles or accessible parts thereof is equal to or greater than 0,05 % by weight, and those articles or accessible parts thereof may, during normal or reasonably foreseeable conditions of use, be placed in the mouth by children. That limit shall not apply where it can be demonstrated that the rate of lead release from such an article or any such accessible part of an article, whether coated or uncoated, does not exceed 0,05 µg/cm 2 per hour (equivalent to 0,05 µg/g/h), and, for coated articles, that the coating is sufficient to ensure that this release rate is not exceeded for a period of at least two years of normal or reasonably foreseeable conditions of use of the article. For the purposes of this paragraph, it is considered that an article or accessible part of an article may be placed in the mouth by children if it is smaller than 5 cm in one dimension or has a detachable or protruding part of that size. 8. By way of derogation, paragraph 7 shall not apply to: (a) jewellery articles covered by paragraph 1; (b) crystal glass as defined in Annex I (categories 1, 2, 3 and 4) to Directive 69/493/ EEC; (c) non-synthetic or reconstructed precious and semi-precious stones (CN code 7103 as established by Regulation (EEC) No 2658/ 87) unless they have been treated with lead or its compounds or mixtures containing these substances; (d) enamels, defined as vitrifiable mixtures resulting from the fusion, vitrification or sintering of mineral melted at a temperature of at least 500 ° C; (e) keys and locks, including padlocks; (f) musical instruments; (g) articles and parts of articles comprising brass alloys, if the concentration of lead (expressed as metal) in the brass alloy does not exceed 0,5 % by weight;

	(h) the tips of writing instruments (i) religious articles; (j) portable zinc-carbon batteries and button cell batteries; (k) articles within the scope of: (i) Directive 94/62/EC; (ii) Regulation (EC) No 1935/2004; (iii) Directive 2009/48/EC of the European Parliament and of the Council (**); (iv) Directive 2011/65/EU of the European Parliament and of the Council (***) 9. By 1 July 2019, the Commission shall re-evaluate paragraphs 7 and 8(e), (f), (i) and (j) of this entry in the light of new scientific information, including the availability of alternatives and the migration of lead from the articles referred to in paragraph 7, including the requirement on coating integrity, and, if appropriate, modify this entry accordingly. 10. By way of derogation paragraph 7 shall not apply to articles placed on the market for the first time before 1 June 2016. (*) OJ L 326, 29.12.1969, p. 36. (**) Directive 2009/48/EC of the European Parliament and of the Council of 18 June 2009 on the safety of toys (OJ L 170, 30.6.2009, p. 1). (***) Directive 2011/65/EU of the European Parliament and of the Council of 8 June 2011 on the restriction of the use of certain hazardous substances in electrical and electronic equipment (OJ L 174, 1.7.2011, p. 88).

Table A. 3: Summary of Relevant Amendments to Annexes Not Updated in the Last Concise Version of the REACH Regulation

Designation of the substance, of the group of substances, or of the mixture	Conditions of restriction	Amended Annex	Amendment date
Addition of Entry 62 concerning: **(a) Phenylmercury acetate** **EC No: 200-532-5** **CAS No: 62-38-4** **(b) Phenylmercury propionate** **EC No: 203-094-3** **CAS No: 103-27-5** **(c) Phenylmercury 2-ethylhexanoate** **EC No: 236-326-7** **CAS No: 13302-00-6** **(d) Phenylmercury octanoate** **EC No: -** **CAS No: 13864-38-5** **(e) Phenylmercury neodecanoate** **EC No: 247-783-7** **CAS No: 26545-49-3**	1. Shall not be manufactured, placed on the market or used as substances or in mixtures after 10 October 2017 if the concentration of mercury in the mixtures is equal to or greater than 0,01% by weight. 2. Articles or any parts thereof containing one or more of these substances shall not be placed on the market after 10 October 2017 if the concentration of mercury in the articles or any part thereof is equal to or greater than 0,01% by weight.’	Annex XVII, entry 62	20 Sep 2012

As of 28 September 2015, the REACH Regulation Candidate list includes those substances relevant for RoHS listed in Table A. 4 (i.e. proceedings concerning the addition of these substances to the Authorisation list (Annex XIV) have begun and shall be followed by the evaluation team to determine possible discrepancies with future requests of exemption from RoHS (new exemptions, renewals and revocations))[142]:

Table A. 4: Summary of Relevant Substances Currently on the REACH Candidate List

Substance Name	EC No.	CAS No.	Date of Inclusion	Reason for inclusion
Cadmium fluoride	232-222-0	7790-79-6	17 December 2014	Carcinogenic (Article 57 a); Mutagenic (Article 57 b); Toxic for reproduction (Article 57 c); Equivalent level of concern having probable serious effects to human health (Article 57 f)
Cadmium sulphate	233-331-6	10124-36-4 31119-53-6	17 December 2014	Carcinogenic (Article 57 a); Mutagenic (Article 57 b); Toxic for reproduction (Article 57 c); Equivalent level of concern having probable serious effects to human health (Article 57 f)
Cadmium chloride	233-296-7	10108-64-2	16 June 2014	Carcinogenic (Article 57a);
Cadmium sulphide	215-147-8	1306-23-6	16 Dec 2013	Carcinogenic (Article 57a); Equivalent level of concern having probable serious effects to human health (Article 57 f)
Lead di(acetate)	206-104-4	301-04-2	16 Dec 2013	Toxic for reproduction (Article 57 c);
Cadmium	231-152-8	7440-43-9	20 Jun 2013	Carcinogenic (Article 57a); Equivalent level of concern having probable serious effects to human health (Article 57 f)
Cadmium oxide	215-146-2	1306-19-0	20 Jun 2013	Carcinogenic (Article 57a); Equivalent level of concern having probable serious effects to human health (Article 57 f)
Pyrochlore, antimony lead yellow	232-382-1	8012-00-8	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead bis(tetrafluoroborate)	237-486-0	13814-96-5	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead dinitrate	233-245-9	10099-74-8	19 Dec 2012	Toxic for reproduction (Article 57 c)
Silicic acid, lead salt	234-363-3	11120-22-2	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead titanium zirconium oxide	235-727-4	12626-81-2	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead monoxide (lead oxide)	215-267-0	1317-36-8	19 Dec 2012	Toxic for reproduction (Article 57 c)
Silicic acid ($H_2Si_2O_5$), barium salt (1:1), lead-doped ***[with lead (Pb) content above the applicable generic concentration limit for 'toxicity for reproduction' Repr. 1A (CLP) or category 1 (DSD); the substance is a member of the group entry of lead compounds, with index number 082-001-00-6 in Regulation (EC) No 1272/2008]***	272-271-5	68784-75-8	19 Dec 2012	Toxic for reproduction (Article 57 c)
Trilead bis(carbonate)dihydroxide	215-290-6	1319-46-6	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead oxide sulfate	234-853-7	12036-76-9	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead titanium trioxide	235-038-9	12060-00-3	19 Dec 2012	Toxic for reproduction (Article 57 c)
Acetic acid, lead salt, basic	257-175-3	51404-69-4	19 Dec 2012	Toxic for reproduction (Article 57 c)
[Phthalato(2-)]dioxotrilead	273-688-5	69011-06-9	19 Dec 2012	Toxic for reproduction (Article 57 c)
Tetralead trioxide sulphate	235-380-9	12202-17-4	19 Dec 2012	Toxic for reproduction (Article 57 c)
Dioxobis(stearato)trilead	235-702-8	12578-12-0	19 Dec 2012	Toxic for reproduction (Article 57 c)
Tetraethyllead	201-075-4	78-00-2	19 Dec 2012	Toxic for reproduction (Article 57 c)
Pentalead tetraoxide sulphate	235-067-7	12065-90-6	19 Dec 2012	Toxic for reproduction (Article 57 c)
Trilead dioxide phosphonate	235-252-2	12141-20-7	19 Dec 2012	Toxic for reproduction (Article 57 c)

142 Updated according to http://echa.europa.eu/web/guest/candidate-list-table

Substance Name	EC No.	CAS No.	Date of Inclusion	Reason for inclusion
Orange lead (lead tetroxide)	215-235-6	1314-41-6	19 Dec 2012	Toxic for reproduction (Article 57 c)
Sulfurous acid, lead salt, dibasic	263-467-1	62229-08-7	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead cyanamidate	244-073-9	20837-86-9	19 Dec 2012	Toxic for reproduction (Article 57 c)
Lead(II) bis(methanesulfonate)	401-750-5	17570-76-2	18 Jun 2012	Toxic for reproduction (Article 57 c)
Lead diazide, Lead azide	236-542-1	13424-46-9	19 Dec 2011	Toxic for reproduction (article 57 c),
Lead dipicrate	229-335-2	6477-64-1	19 Dec 2011	Toxic for reproduction (article 57 c)
Dichromium tris(chromate)	246-356-2	24613-89-6	19 Dec 2011	Carcinogenic (article 57 a)
Pentazinc chromate octahydroxide	256-418-0	49663-84-5	19 Dec 2011	Carcinogenic (article 57 a)
Potassium hydroxyoctaoxodizincatedichromate	234-329-8	11103-86-9	19 Dec 2011	Carcinogenic (article 57 a)
Lead styphnate	239-290-0	15245-44-0	19 Dec 2011	Toxic for reproduction (article 57 c)
Trilead diarsenate	222-979-5	3687-31-8	19 Dec 2011	Carcinogenic and toxic for reproduction (articles 57 a and 57 c)
Strontium chromate	232-142-6	7789-06-2	20 Jun 2011	Carcinogenic (article 57a)
Acids generated from chromium trioxide and their oligomers. Names of the acids and their oligomers: Chromic acid, Dichromic acid, Oligomers of chromic acid and dichromic acid.	231-801-5, 236-881-5	7738-94-5, 13530-68-2	15 Dec 2010	Carcinogenic (article 57a)
Chromium trioxide	215-607-8	1333-82-0	15 Dec 2010	Carcinogenic and mutagenic (articles 57 a and 57 b)
Potassium dichromate	231-906-6	7778-50-9	18 Jun 2010	Carcinogenic, mutagenic and toxic for reproduction (articles 57 a, 57 b and 57 c)
Ammonium dichromate	232-143-1	7789-09-5	18 Jun 2010	Carcinogenic, mutagenic and toxic for reproducetion (articles 57 a, 57 b and 57 c)
Sodium chromate	231-889-5	7775-11-3	18 Jun 2010	Carcinogenic, mutagenic and toxic for reproduction (articles 57 a, 57 b and 57 c)
Potassium chromate	232-140-5	7789-00-6	18 Jun 2010	Carcinogenic and mutagenic (articles 57 a and 57 b).
Lead sulfochromate yellow (C.I. Pigment Yellow 34)	215-693-7	1344-37-2	13 Jan 2010	Carcinogenic and toxic for reproduction (articles 57 a and 57 c))
Lead chromate molybdate sulphate red (C.I. Pigment Red 104)	235-759-9	12656-85-8	13 Jan 2010	Carcinogenic and toxic for reproduction (articles 57 a and 57 c)
Lead chromate	231-846-0	7758-97-6	13 Jan 2010	Carcinogenic and toxic for reproduction (articles 57 a and 57 c)
Lead hydrogen arsenate	232-064-2	7784-40-9	28 Oct 2008	Carcinogenic and toxic for reproduction (articles 57 a and 57 c)
Sodium dichromate	234-190-3	7789-12-0, 10588-01-9	28 Oct 2008	Carcinogenic, mutagenic and toxic for reproduction (articles 57a, 57b and 57c)

Additionally, Member States can register intentions to propose restrictions or to classify substances as SVHC. The first step is to announce such an intention. Once the respective dossier is submitted, it is reviewed and it is decided if the restriction or authorisation process should be further pursued or if the intention should be withdrawn.

As at the time of writing (Fall 2015), it cannot yet be foreseen how these procedures will conclude. It is thus not yet possible to determine if the protection afforded by REACH Regulation would in these cases consequently be weakened by approving the exemption requests dealt with in this report. For this reason, the implications of these decisions have not been considered in the review of the exemption requests dealt with in this report. However for the sake of future reviews, the latest authorisation or restriction process results shall be followed and carefully considered where relevant.[143]

As for registries of intentions to identify substances as SVHC, as of 28 September 2015, Sweden has submitted intentions regarding the classification of cadmium fluoride and cadmium sulphate as CMR, intending to submit dossiers in August 2014.None of the current registries of intentions to propose restrictions apply to RoHs regulated substances.[144]

As for prior registrations of intention, dossiers have been submitted for the substances listed in Table A. 5.

Table A. 5: Summary of Substances for which a Dossier has been submitted, following the initial registration of intention

Restriction / SVHC Classification	Substance Name	Submission Date	Submitted by	Comments
Restriction	Cadmium and its compounds	17 Jan 2014	Sweden	Artist paints
	Cadmium and its compounds	17 Oct 2013	ECHA	Amendment of the current restriction (entry 23) on use of paints with TARIC codes [3208] & [3209] containing cadmium and cadmium compounds to include placing on the market of such paints and a concentration limit.
	Lead and lead compounds	18 Jan 2013	Sweden	Placing on the market of consumer articles containing Lead and its compounds
	Chromium VI	20 Jan 2012	Denmark	Placing on the market of leather articles containing Chromium VI
	Phenylmercuric octanoate; Phenylmercury propionate; Phenylmercury 2-ethylhexanoate; Phenylmercury acetate; Phenylmercury	15 Jun 2010	Norway	Mercury compounds
	Mercury in measuring devices	15 Jun 2010	ECHA	Mercury compounds
	Lead and its compounds in jewellery	15 Apr 2010	France	Substances containing lead
SVHC Classification	Cadmium chloride	03 Feb 2014	Sweden	CMR; other;
	Cadmium sulphide	05 Aug 2013	Sweden	CMR; other;
	Lead di(acetate)	05 Aug 2013	Netherlands	CMR
	Cadmium	04 Feb 2013	Sweden	CMR; other;
	Cadmium oxide	04 Feb 2013	Sweden	Substances containing Cd CMR; other; Substances Containing Cd
	Trilead dioxide Phosphonate; Lead Monoxide (Lead Oxide);	30 Aug 2012	ECHA	CMR; substances Containing Lead

[143] European Chemicals Agency (ECHA), Registry of intentions to propose restrictions: http://echa.europa.eu/registry-of-current-restriction-proposal-intentions/-/substance/1402/search/+/term (28.09.2015)
[144] ECHA website, accessed 28.09.2015: http://echa.europa.eu/web/guest/addressing-chemicals-of-concern/registry-of-intentions

	Trilead bis(carbonate)dihydroxide; Lead Dinitrate; Lead Oxide Sulphate; Acetic acid, lead salt, basic; Dioxobis(stearato)trilead; Lead bis(tetrafluoroborate); Tetraethyllead; Pentalead tetraoxide sulphate; Lead cyanamidate; Lead titanium trioxide; Silicic acid ($H_2Si_2O_5$), barium salt (1:1), lead-doped; Silicic acid, lead salt; Sulfurous acid, lead salt, dibasic; Tetralead trioxide sulphate; [Phthalato(2-)]dioxotrilead; Orange lead (lead tetroxide); Fatty acids, C16-18, lead salts; Lead titanium zirconium oxide			
	Lead(II) bis(methanesulfonate)	30 Jan 2012	Netherlands	CMR; Amides
	Lead styphnate; Lead diazide; Lead azide; Lead dipicrate	01 Aug 2011	ECHA	CMR; Substances containing lead
	Trilead diarsenate			CMR; Arsenic compounds
	Strontium Chromate	24 Jan 2011	France	CMR; Substances containing chromate
	Acids generated from chromium trioxide and their oligomers: Chromic acid; Dichromic acid; Oligomers of chromic acid and dichromic acid	27 Aug 2010	Germany	CMR; Substances containing chromate
	Chromium Trioxide	02 Aug 2010	Germany	CMR; Substances containing chromate
	Sodium chromate; Potassium chromate; Potassium Dichromate	10 Feb 2010	France	CMR; Substances containing chromate
	Lead chromate molybdate sulfate red (C.I. Pigment Red 104); Lead sulfochromate yellow (C.I. Pigment Yellow 34)	03 Aug 2009	France	CMR; substances Containing Lead
	Lead Chromate	03 Aug 2009	France	CMR; Substances containing chromate
	Lead hydrogen arsenate	27 Jun 2008	Norway	CMR; Arsenic compounds
	Sodium dichromate	26 Jun 2008	France	CMR; Substances containing chromate

Concerning the above mentioned processes, as at present, it cannot be foreseen if, or when, new restrictions or identification as SVHC might be implemented as a result of this proposal; its implications have not been considered in the review of the exemption requests dealt with in this report. In future reviews, however, on-going research into restriction and identification as SVHC processes and the results of on-going proceedings shall be followed and carefully considered where relevant.

A.2.0 Appendix 2: Nanoco Information as to QD Alternatives for HPS Horticultural Lighting and for High Pressure Sodium Lighting

Source: Nanoco (2016b), Nanoco Technologies, Response to Additional Questionnaire (2nd Round) Regarding Cadmium QD Exemptions, submitted 20.4.2016

A.2.1 High Pressure Sodium Lighting

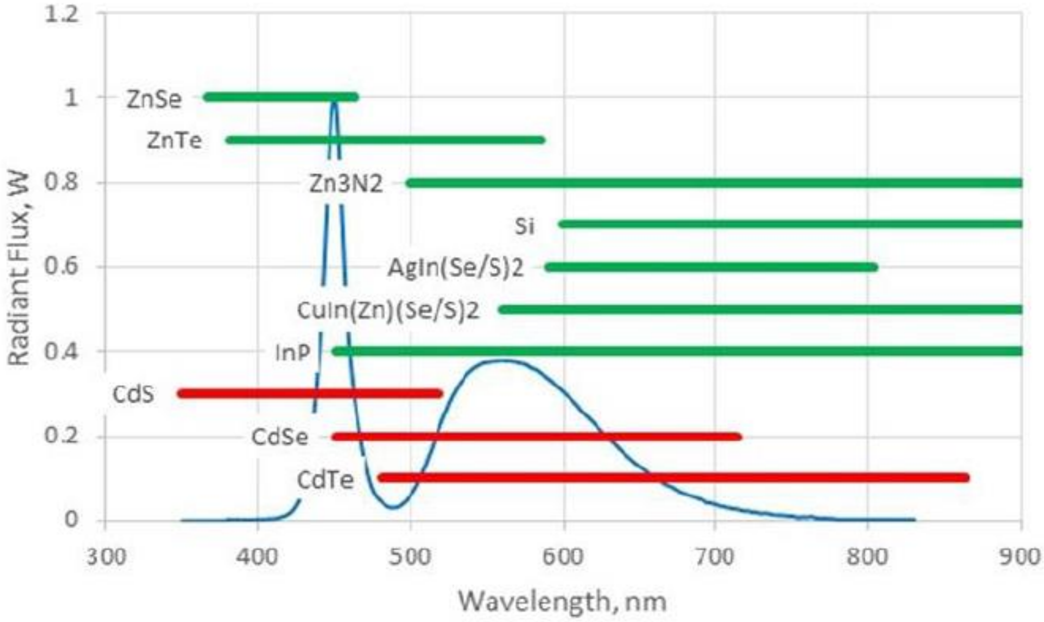
Nanoco explains that cadmium-free QD lighting is highly suitable as an alternative to **high pressure sodium (HPS) lamps**. HPS lamps typically have a high energy consumption (150 – 1,000 W), with some energy being wasted as heat. They also have short lifetimes. Cadmium-free QD lighting encompasses the energy efficiency properties and improved performance lifetimes of LED lighting, but can also be used to achieve a CCT closer to that of natural daylight than standard white LEDs, which tend to emit bluish light. HPS lighting systems are often designed to either maximize on CRI or on efficiency as demonstrated by the Philips Master Colour HPS series[145] which provide lamps at CCT 6600 K, CRI R_a 92, and LES 76 lm W^{-1}. This is due to the lack of tunability in the red region of the spectrum for HPS technology as only specific impurities can be used to adjust the emission colour, resulting in compromises in either the efficiency or colour rendering ability of a light source. QD emission spectra, however, are defined by the size and size distribution of the nanocrystals in the ensemble used for light colour conversion.[146] This allows for a high level of emission tunability using QDs with different species capable of producing emission across various parts of the visible spectrum (Figure A - 1), and also allows for narrow width of spectral emission by controlling the nanocrystal size distribution. This in turn means that QDs can be tuned to specifically hit the wavelengths required by light sources at differing CCT values to maximize both CRI R_a and R_9 values. In addition controlling the emission to be of narrow width also means that excess unnecessary wavelengths will not be emitted in the less eye sensitive red region of the

[145] Referenced in Nanoco (2016b) as Wesco, "Philips CDM250S50/V/O/4K-ALTO." [Online]. Available: https://buy.wesco.com/Standard-Light-Bulbs/PHILIPS/Metal-Halide-Light-Bulb-250-W-ED-18/CDM250S50-V-O-4K-ALTO/p/78667713093-1. [Accessed: 18-Apr-2016].

[146] Referenced in Nanoco (2016b) as X. Yang, D. Zhao, K. S. Leck, S. T. Tan, Y. X. Tang, J. Zhao, H. V. Demir, and X. W. Sun, "Full Visible Range Covering InP/ZnS Nanocrystals with High Photometric Performance and Their Application to White Quantum Dot Light-Emitting Diodes," *Adv. Mater.*, vol. 24, no. 30, pp. 4180–4185, 2012

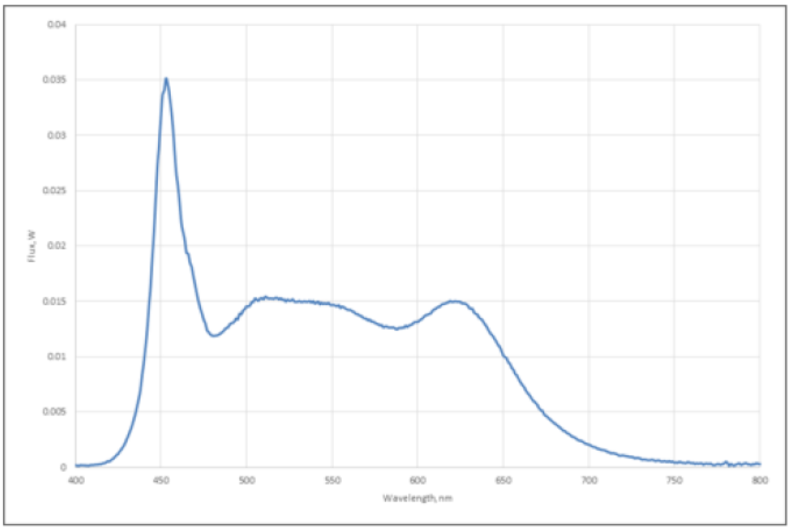
spectrum, maximizing the potential LES values for sources tuned to maximize CRI. Using such technology, Nanoco Lighting has managed to produce commercial luminaires with excellent colour rendering properties and competitive LES values, such as in the luminaire spectrum shown in Figure A - 2.

Figure A - 1: Emission Tunability of a Selection of Visible Light Emitting QDs Overlaid with a Spectral Power Distribution of a Commercially Available 6500 K White LED (Blue Line). Red Bars Indicate QDs Containing Toxic Cadmium



Source: Nanoco (2016b)

Figure A - 2: Measured Emission Spectrum of a Nanoco 6500KCCT300X300CDWT Model Luminaire (Left) with Accompanying Measured Characteristics (Right).



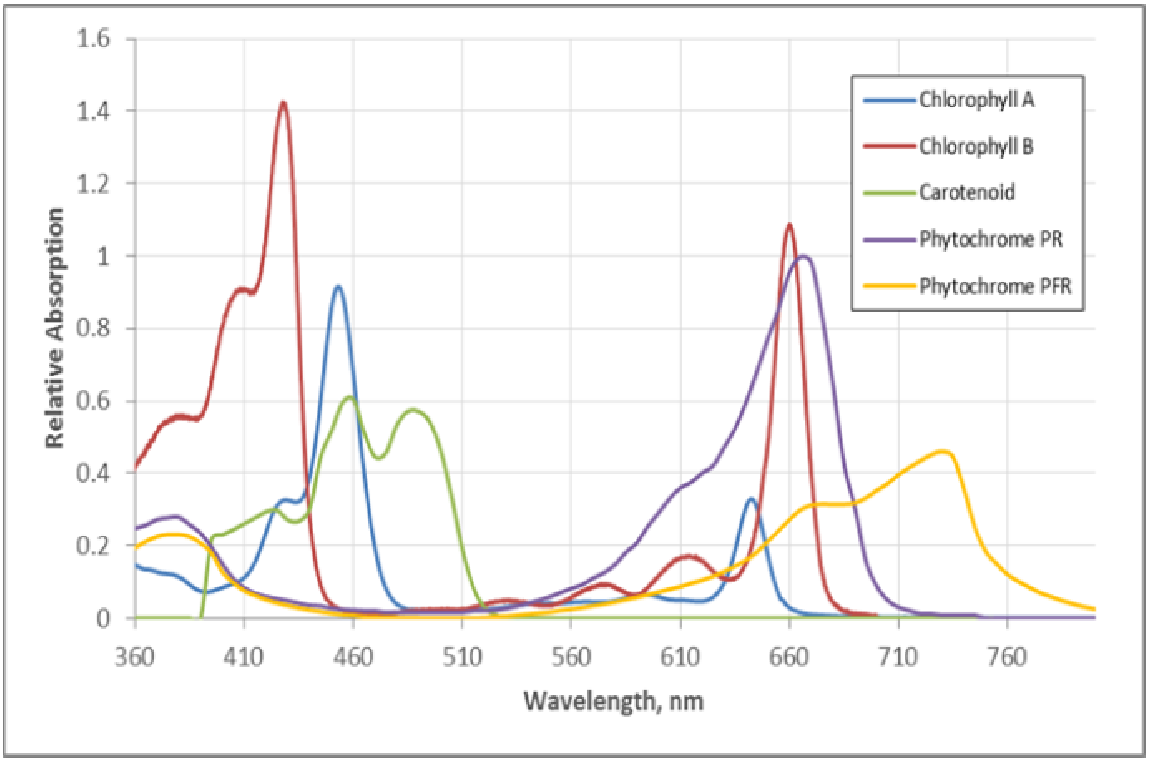
Drive Current, mA	276
Drive Voltage, V	35.15
x	0.316
y	0.327
CCT, K	6314
CRI (R_a)	95.7
R_9	92.9
Rad. Flux, W	3.64
Lum. Flux, lm	1027
LES, lm W^{-1}	105.9

Source: Nanoco (2016b)

A.2.2 Horticultural Lighting

"Horticultural lighting is used to supplement or replace natural sunlight during the plant growing process, typically in an indoor environments such as greenhouses or indoor vertical farms. Horticultural lighting is used to stimulate different molecular species within the plant of interest to encourage more efficient photosynthesis or adjust the plants circadian rhythm during the growing process. Each molecular species within the plant will have a slightly different light absorption profile as detailed in Figure A - 3.

Figure A - 3: Typical Absorption Profiles of Different Molecular Species Found in plants. Chlorophyll A and B along with Carotenoid are Responsible for Energy Absorption to Enable Photosynthesis, while Phytochrome PR and FPR are Responsible for Circadian Rhythm Control

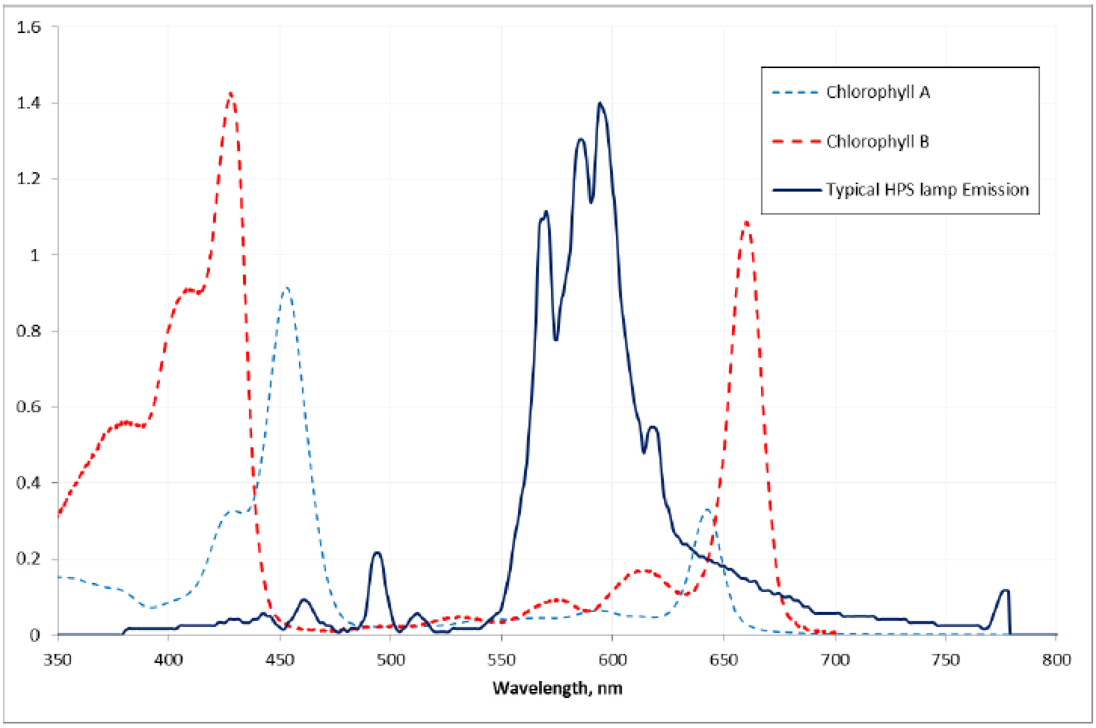


Source: Nanoco (2016b)

HPS lamps are currently commonly used for horticultural lighting due to their high energy efficiency. Their emission profile however does not coincide very well with the absorption profile of the targeted molecular species to encourage plant growth (see Figure A - 4), resulting in wasted energy at non-required wavelengths in the system. Also studies have shown that different plant species require specific ratios of red and blue excitation light for optimized growth[147] and, due to the lack of tunability in HPS lighting systems, this cannot be accommodated for.

[147] Quoted as P. Davis, “Lighting : The review,” *UHDB*, 2014

Figure A - 4: Typical Absorption Profiles of Chlorophyll A and B Overlaid with the Typical Emission Spectrum of a Commercial HPS Grow Light.

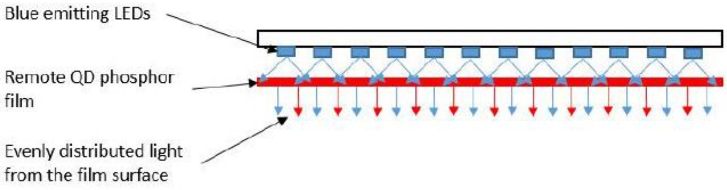


Source: Nanoco (2016b)

The current industry trend is moving away from HPS towards mixed LED lighting, where a combination of red and blue LEDs are used in a light fixture to generate the required emission at the required light colour ratios. These units solve the issue of wasted unnecessary light, allowing for more efficient growing systems. A further advantage of LED lighting is that it emits little energy as heat, allowing the lighting to be placed much closer to the growing plants. One downfall with mixed LED lighting, however, is the colour mixing of the independent red and blue sources before it hits the plant bed. This is particularly important in areas such as propagation in vertical farming applications, where full and even illumination of a seedbed is required over short distances in order to save space. Also, due to the very narrow emission width of the LEDs and limitations in available red wavelengths, only specific molecules can be targeted in plant, with little flexibility to stimulate different molecules or multiple molecules at the same time.

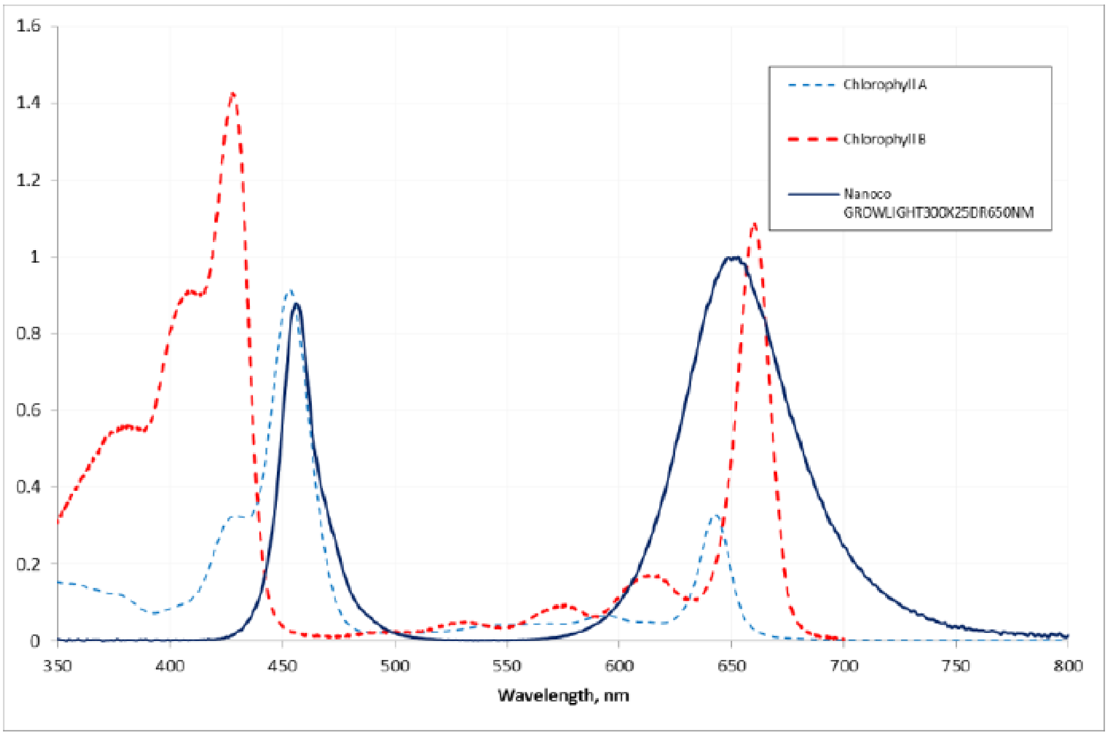
QD technology can be used to compliment LED technology in order to combat this issue for propagation beds by utilizing the QDs in a remote phosphor format (using QD film positioned above the blue LEDs). Remote phosphor allows for an even colour mixing of the light of light over a short distance, resulting in a uniform distribution of Photosynthetically Active Radiation (PAR) over distances as little as 6 inches (see Figure A - 5). Meanwhile the colour tunability of the QDs allows for specific positioning of the red peak position to stimulate the desired molecules in the plant for the desired growth stage, while the control over the emission width also leads to the ability to target several molecules at once using the same light source (see Figure A - 6).

Figure A - 5: Graphic to Show the Principle of Using a Remote QD Phosphor Film to Generate Even Light Emission (left), and a Photo Demonstrating the Even Emission for a Nanoco Propagator Lamp



Source: Nanoco (2016b)

Figure A - 6: Typical Absorption Profiles of Chlorophyll A and B Overlaid with the Typical Emission Spectrum of a Commercial Nanoco Propagation Lamp, Designed to Target Chlorophyll A and B within a Plant.



Source: Nanoco (2016b)

Please note that these are only 2 example areas where we have detailed performance data available in the time required for this consultation. A further example is in phototherapy applications, where QDs offer a further advantage in that they can be incorporated into a flexible film to form a lighting device that can be applied directly to a body part to be treated. There are many other potential applications where the tuneable emission characteristics of cadmium-free QDs allow for improved lighting performance in LED systems that are more energy efficient and flexible than alternative lighting technologies."