Response to Public Consultation Questionnaire Regarding Cadmium QD Exemptions

Questions and Responses

1. The two applicants originally requested exemptions with different wording formulations, however in the course of the first evaluation it was understood that both exemptions are to allow placing Cd QD technologies on the EU market in various products. During the first evaluation the applicants were asked to confirm if the following formulation would cover the applications for which the exemptions had been requested:

> *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 µg/mm²*

This formulation was later used as a basis to separate between display lighting and solid-state lighting applications in the context of a possible exemption. If the exemption is to be recommended, a split shall most likely be proposed between the use of such cadmium components in solid state lighting applications and in display lighting applications.

a. Do you agree that the formulation above covers the cadmium quantum dot technologies addressed in the two exemption requests? If not, please explain why.

No, we would not agree that this wording is appropriate to cover both lighting and display applications. By expressing the maximum cadmium in relation to display screen area, the definition is clearly only applicable to display applications and not to lighting. It does seem logical that the maximum amount of cadmium in a display, if this is permitted at all, is linked to the display screen area. For lighting applications a different measurement would be needed that could be applied across lighting products in general, perhaps based on the power used by the LEDs that generate the light. However, the Applicants have not submitted any significant information for lighting products and the lack of any commercial Cd QD lighting products in the EU market indicates that an exemption for such products is unnecessary and unjustified. This was the conclusion of the previous review in section 7.7 of the final report:

"Concerning the use of Cd QDs in solid state lighting, the information provided does not allow a conclusion that such an exemption would be justified at present. The consultants therefore recommend not granting an exemption for Cd in QD applications to be used in solid state lighting."

The only change to the situation since then is that cadmium-free QD lighting products have now been commercially launched in the EU market, further reinforcing that an Exemption for lighting products is not justified.

b. If the exemption is to be split according to application field (SSL and display lighting) please specify what wording formulation would best cover each of the application areas.

The following formulation for display products would be logical:

46 Grafton Street, Manchester M13 9NT, United Kingdom
Phone: +44 (0)161 603 7900 Fax: +44 (0)161 603 7901
www.nanocotechnologies.com
Registered in England and Wales. Registered No 04206123

Cadmium in components for LCD display lighting applications, containing downshifting cadmium based semiconductor nanocrystal quantum dots, where the cadmium per display screen area is limited to less than X µg/cm²

- All the information supplied by the Applicants relates to LCD displays, so the formulation should reflect this limitation.
- It is misleading to use *mm²* as the unit of area when the Applicants mainly refer to large display screens up to 55" and even greater. Expressing the limit in *µg/cm²* is therefore more meaningful.

However, it should be noted that, in our view, any such Exemption could not be justified now that cadmium-free QD display technology is commercially available in the EU market and has already gained the leading market share for high colour gamut displays, proving that it meets the market requirements.

The following formulation for lighting products might be logical:

Cadmium in components for LED lighting applications (excluding display lighting applications), containing downshifting cadmium based semiconductor nanocrystal quantum dots, where the cadmium per lighting device is limited to less than X µg per Watt of power used by the LED light.

However, it should be noted that in our view, any such Exemption could not be justified now that cadmium-free QD lighting technology is commercially available in the EU market, while cadmium QD products are not available and the Applicants have not submitted any significant information for commercial lighting products.

c. Please suggest an alternative wording and explain your proposal, if you do not agree with the proposed exemption wording or with the proposed split.

See answers to a. and b. above

d. Please explain why you either support the applicant's request or object to it. To support your views, please provide detailed technical argumentation / evidence in line with the criteria in Art. 5(1) (a) to support your statement.

We comprehensively object to the applicant's request to extend the use of toxic cadmium-based materials in lighting and display products, and to the supporting requests from Philips Lumiled and Lighting Europe.

Ex.39 should have ended in 2014. The recommendations of the last Öko Institut review were not followed in the formulation by the European Commission of the Delegated Acts for Ex.39a and Ex.39b, which were then rejected by an overwhelming majority (618 to 33) of MEPs in May 2015. The European Parliament based its decision[1] on the fact that the European Commission's "justification is manifestly incorrect", given that the cadmium-free QD technology for displays "has become widely available on the Union market, on offer by well-known major retailers". We therefore believe that it is self-evident that a further continuation of Ex.39 in any form is no longer necessary or justified.

[1] P8_TA-PROV(2015)0205, Objection to a delegated act: exemption for cadmium in illumination and display lighting applications, European Parliament resolution of 20 May 2015

We further believe that the spirit and purpose of the RoHS Directive is being reversed through the continuation of Ex.39. The purpose of RoHS is to restrict the use of cadmium and other listed substances from use in electrical and electronic equipment (EEE) because of the hazards they are known to pose to consumers, workers and the environment. In particular, RoHS (5) states that *"the use of cadmium should be limited to cases where suitable alternatives do not exist."* The intention of the Exemption system is to allow for these materials to continue to be used in existing essential products where no suitable alternatives have been developed. However, the exemptions are deliberately time limited to encourage the development of acceptable alternative technologies as soon as possible. RoHS is therefore intended to promote innovation in substitutes and RoHS compliant new technologies and **not** to promote the innovation and development of new products using cadmium or other restricted materials. However, it is clear from the documents submitted by both the Applicants and by supporters including Lighting Europe and Philips Lumiled that they expect the RoHS Exemption process to be carried out to promote the further development and re-introduction of cadmium QD technology in displays (where few exist today with a much smaller market share than cadmium-free QD displays), and the development and introduction of entirely new cadmium QD technology in the case of lighting products where none exist today. We believe that any decision to further extend Ex39 would therefore be diametrically opposed to the entire purpose of RoHS and is not legally permitted.

Under the terms of Article 5(1)(a), an Exemption for such uses of cadmium is only permitted where:

I. Its elimination or substitution is scientifically or technically impracticable
II. The reliability of substitutes is not ensured
III. The total negative environmental, health and consumer safety impacts caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits of its use.

And any decisions must take into account:

a. The availability of substitutes
b. The socio-economic impact of substitution
c. The potential adverse impacts on innovation

and under the Preamble (18)

d. Should take specific account of the situation of SMEs

We will address these criteria though answering the following questions:

Q1 Is the substitution of cadmium-based QDs scientifically and technically practical?
Q2 Is the reliability of practical substitutes ensured?
Q3 Do the substitutes have an overall negative impact on the environment, health and consumer safety compared to continued cadmium use?
Q4 Are the substitutes available?
Q5 Will the substitutes have a negative socio-economic impact?
Q6 What is the impact on innovation of extending the use of cadmium?
Q7 What is the impact on SMEs of extending the use of cadmium?

However, we would first like to emphasise that in the case of lighting the assessment of the criteria under Article 5(1)(a) RoHS is not possible as cadmium QD lighting products have not been fully developed as yet and are not available to assess.

Q1 Practicality

The wide availability of commercial cadmium-free QD 'SUHD' displays from Samsung, the world's leading display manufacturer, clearly demonstrates that this alternative technology is practical. This technology has been a commercial success with rapid sales growth, and now has the leading market share for high colour gamut displays in EU and globally. Sales are expected to increase by up to 10 times in 2016 and Samsung are already launching new, higher performance models[2]. The proven commercial success of this technology, and its preferential selection by the world No1 manufacturer, clearly demonstrates that it is able to meet the technical performance requirement for the display market.

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[3]. As we discuss in 2.c. below, 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. Indeed, their performance can be confidently predicted to improve more rapidly than for cadmium QDs which are much more mature and are no longer showing rapid improvement. 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.

There are also some significant challenges with adopting such a high gamut standard, since it will significantly increase energy consumption (>20%) compared to established and market leading alternatives such as DCI-P3. This applies whatever QD/phosphor technology is used, since it is determined by the physics of light and the brightness perception of the human eye. The display industry will have to carefully consider the marginal benefits in colour performance as perceived by consumers compared to the significant inherent penalty in energy efficiency that will be incurred.

Cadmium-free QD technology will continue to improve with 2nd and 3rd generation products that will meet future standards as they are adopted over the next 5-10 years. This is indicated by the rate of improvement of Nanoco CFQD® cadmium-free QD technology compared to cadmium QD technology shown in Fig.1 below:

[2] http://news.samsung.com/global/samsung-reveals-spectacular-2016-suhd-tv-lineup-to-begin-a-new-decade-of-global-tv-leadership

[3] http://www.samsung.com/us/aboutsamsung/sustainability/environment/chemicalmanagement/policyontargetsubstances.html

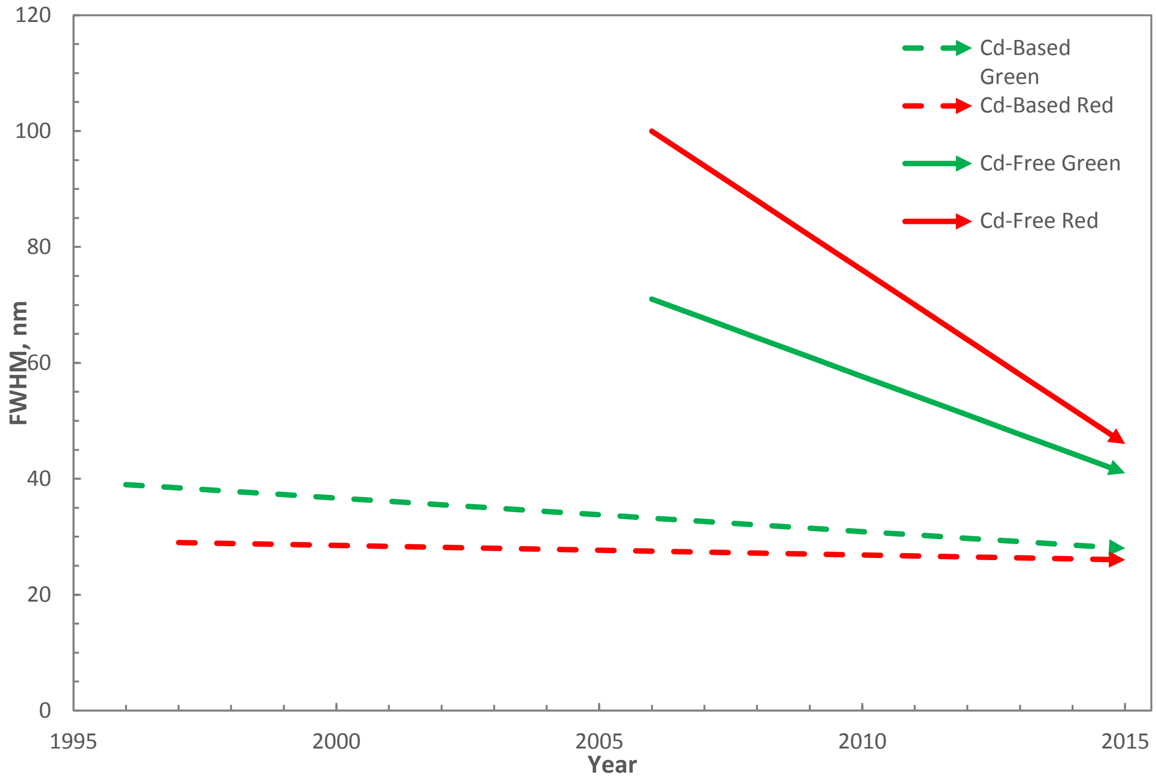


Figure 1: Comparison of improvements in the full-width at half-maximum (FWHM) of CFQD® cadmium-free quantum dots and cadmium-based quantum dots.[4]

Nanoco and Dow are the producers of TREVISTA™ quantum dot film containing CFQD® technology, which can be used in displays in a similar way to SUHD film. Commercial TVs using this technology are expected to be launched in 2016. Nanoco has carried out technical performance tests which show that TREVISTA™ quantum dot film delivers a similar level of colour performance and energy efficiency to Samsung's existing and commercialized SUHD film using cadmium free quantum dot technology.

In order to compare the colour performance of cadmium and cadmium-free QD TVs, Nanoco obtained four commercially available samples of 55" 4K HD TVs. 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. 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. This is used because the CIE1931 colour space is not the best method since this colour space is not uniform with respect to green light and hence can produce exaggerated results. Comparison in the more uniform CIE1976 colour space is a more rigorous approach and one that is recommended[5]. All sets have similar 'white points', which allows a fair comparison between the sets:

[4] Cd-based QD data: 1996: green CdSe/ZnS: M.A. Hines and P. Guyot-Sionnest, *J. Phys. Chem. C*, 1996, **100**, 468; 1997: red CdSe/ZnS: B.O. Dabbousi *et al.*, *J. Phys. Chem. B*, 1997, **101**, 9463; 2014 – 2015: red and green Cd-based QDs measured internally from Sony Bravia KDL-40W905A and Thomson 55UA9806 TVs

[5] ["The NTSC Color Triangle Is Obsolete, But No One Seems to Know", Seyno Slutyerman, SID 5/06 p8-9

		CIE 1976				
Manufacturer	**Type**	Rec 709/ sRGB Coverage	DCI-P3 Coverage	Adobe RGB Coverage	NTSC 1953 Coverage	Rec 2020 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%

The current standard is Rec 709/sRGB and all 4 deliver >95%, but only the Samsung and Thomson achieve full 100% coverage. DCI-P3 is the market leading standard for high colour gamut and all 4 deliver good coverage of >90%, but again the Samsung and Thomson are best at >95%. All 4 deliver >90% of Adobe RGB which is mainly aimed at high fidelity computer monitors. The Samsung is a little lower than the others because of being optimised for DCI-P3, but still achieves an effective 92%. NTSC 1953 is now an outdated standard but is included only for reference as cadmium QD manufacturers appear to have optimised their displays towards its. All 3 did achieve >90%, but the Samsung was very close at 87% despite having been optimised for DCI-P3. Rec 2020 is included for interest only as it is still under development. However, the Samsung is as good as or better than 2 out of 3 of the cadmium QD TVs. Even the Thomson is well under the minimum 90% of coverage that would be needed to effectively meet the standard.

Overall, we believe that this data clearly demonstrates that 1st generation cadmium-free QD displays can already deliver high colour performance to effectively meet current standards and compare favourably with 2nd generation cadmium QD displays.

In addition to cadmium-free QD technology from Nanoco and Samsung, other alternative cadmium-free QD and non-QD technologies continue to be developed and are increasingly available commercially – detailed further in section 6. For example, Apple have 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[6].

In relation to lighting products, the substitution question does not arise since there are no cadmium QD lighting products available. In contrast, two cadmium-free QD lighting products have already been launched and more will follow in 2016 – see section 4. for details. There is also evidence that cadmium-free QD and high performance phosphor technologies are able to meet the performance requirements for improved colour rendering by LED lighting (CRI and R9) while achieving improved energy efficiency compared with similar colour performance LEDs using conventional phosphor technology (see section 6.).

Furthermore, performance in relation to substitution is a horizontal standard requirement and is not related to individual quality or performance criteria of specific products, e.g. colour gamut or energy efficiency. The latter may be subjective consumer choice criteria determining the market success of

[6] https://medium.com/backchannel/exclusive-why-apple-is-still-sweating-the-details-on-imac-531a95e50c91#.zadzbp28j

a specific TV. This is confirmed by the Institute's practice, including in the previous assessment of Exemption 39b: "*Furthermore, even if such products* (i.e. alternative cadmium-free QD) *may result in a certain decrease in performance (colour gamut; energy efficiency) as soon as this alternative is viewed to be available, it should be considered if a certain level of lesser performance would be acceptable, to allow the elimination of a RoHS regulated hazardous substance".*[7]

This is also confirmed in other previous Institute Opinions that never considered quality or energy efficiency as a stand-alone argument[8], well to the contrary. In the Opinion on 'lead in decorative ceramic lamps'[9], the Institute stated that *"lead and cadmium cannot be fully substituted in glazes and colours of these ceramic parts without some impact on the quality and variety of colours that can be achieved. However from a technical standpoint, the substitution or elimination of lead and cadmium in this application is technically practicable. Aesthetically, the result of the elimination and substitution is not equivalent, as not all glazes and colours may be reproduced on an equivalent basis to that accomplished with lead and cadmium. However the consultant does not find this aspect to be crucial to the functionality and therefore does not believe this aspect could justify an exemption in line with Article 5(1)(a) of the Directive."* Thus, even in case of a product with a crucial decorative function, the fact that the aesthetic and colour result is not equivalent did not prevail as it is not 'crucial to the functionality'.

Another Opinion recommended an exemption because a technology had a 'reliability to overcome harsh environmental conditions' (lead solders in ignition modules[10]). In our view, this confirms that only elements that are 'crucial to the functionality' should be assessed.

Q2 Reliability

The reliability of substitutes is demonstrated by the existence of commercial products. By definition, the technology has already met the reliability standards required by the device manufacturers and is

---

[7] Institute Report of 22/04/2014, page 40 and following.

[8] This being said, in the exemption for Mercury in lamps, the Institute stated on LEDs as possible substitutes to mercury lamps that "*"When analysing the possibilities of using LED as a Hg-free substitute, the following question needs to be answered: on a life-cycle based approach, what are the environmental impacts of LED-based lamps compared to current lighting applications (e.g. energy needed for production, efficacy, lifetime, …)? Since currently there seems to be no reliable data and information available in this respect, it is not possible to evaluate whether or not LED-based lamps can be considered as substitute with overall environmental benefit".*

The Institute concluded that:

"The consultant thus proposes not to consider LED as a possible substitute for lighting applications in general due to unknown environmental effects. Since overall environmental policy goal is to both reduce the amount of hazardous substances in EEE and at the same time to ensure high efficiency in order to reduce energy consumption, LED are considered as possible substitutes, only once they have reached higher or equal efficiency and lifetime. Therefore, this technology should be evaluated again during the next RoHS revision cycle in 4 years".

However, in our view, this case is different from the case at hand. First, LED were not considered as a possible substitute because of the lack of data. Second, the general statement by the Institute on a possible future suitability of this technology mentioned <u>both</u> energy efficiency and lifetime.

[9] Institute Report of 25/03/2013, Final Report, Page 117

[10] Institute Report of 30/09/2013, Final Report, page 91

now meeting the reliability expectations of consumers and retailers in the EU market. This is abundantly clear in the case of cadmium-free QDs for displays, where this technology has been applied by Samsung, the World No1 display company. Equally it is the case for CFQD® technology selected by well-established lighting companies Marl and Budmaster (see section 4).

The reliability case for cadmium QD products is less clear. The Sony TV, Amazon tablet and the Nexus light were all withdrawn from the market rather quickly after being launched and were not replaced. The reliability of cadmium QD lighting products cannot now be assessed at all since none exist.

Q3 Environment, health and consumer safety impact

According to the Institute Guidance, this criterion should be interpreted to mean that: *"The (negative environmental, health and consumer safety) impacts of substitution stand to be significantly higher than those attributed to the use of the restricted substance in the application in question, where environmental, health and consumer safety aspects are considered."*

In other words, because the purpose of RoHS is to phase-out the use of listed hazardous substances, only when the total negative environmental/health/safety impacts of substitution are significantly higher than those of the use of cadmium can the use of cadmium be continued.

Cadmium is, among other hazards, a presumed carcinogen and suspected reproductive toxin and mutagen. It is also very toxic to aquatic environment, with both acute and chronic effects[11]. The main human exposure to cadmium occurs in waste recycling facilities (see e.g. paper from German Federal Agency for Workers Protection 2011[12] stating that concentration in the air of cadmium from electronics recycling is above the acceptable risk level). Environmental pollution with cadmium is another main concern: *"cadmium pollution poses a complex and difficult problem since it is a 'multimedia' form of pollution, affecting all environmental sectors; whereas cadmium may be emitted into the environment at numerous points in the production, manufacturing, use and waste disposal processes, and can readily migrate between environmental sectors."*[13]

In weighing potential alleged energy savings attributed to cadmium quantum dot products against cadmium workers safety and environmental pollution issues, RoHS clearly allocates priority to the phase-out of hazardous substances. In particular Recital 13 to RoHS provides that Directive 2009/125 (Eco-design Directive) is without prejudice to Union waste management legislation, including RoHS. Thus, the Union's interest in phasing-out hazardous substances supersedes the desire to improve the energy efficiency of electronic products. This is confirmed by the Institute's practice. As stated above, there is not a single exemption granted under RoHS in which the Institute took account of energy efficiency of the final products as a stand-alone or heavily weighted argument to support an exemption.

[11] See Part 3 of Annex VI to Regulation 1272/2008 (CLP Regulation).

[12] https://www.baua.de/de/Themen-von-A-Z/Gefahrstoffe/Arbeiten-mit-Gefahrstoffen/pdf/Elektronikschrottrecycling.pdf?__blob=publicationFile&v=2

[13] Council Resolution of 25 January 1988.

In the exemption for 'Luminous Discharge Tubes (HLDT) used for signs, decorative or general lighting'[14], the Institute stated that *"though it can be understood that LEDs* (i.e. the alternatives) *do not provide an equivalent outcome, the fact that their use in signs is becoming prevalent deems them to be an acceptable alternative in many cases. Although the case may still be debated as to whether there may be instances in which HLDTs are indispensable, information has not been provided that gives credence to this argument".*

Thus, the fact that an alternative technology has become widely used speaks against granting an exemption even if there is no equivalent outcome. This is applicable in this case where cadmium-free QD displays are already far more widely available and sold in much higher numbers than cadmium QD displays, and no cadmium QD lighting products exist at all when 2 cadmium-free QD products have already been launched.

In the exemption for 'Lead in platinized platinum electrodes for measurement instruments'[15], the Institute recommended an exemption because of the lack of suitable alternatives. However this was not due to the environmental impact of alternatives. To the contrary: the Institute did not consider as negative environmental impacts of the alternatives (as claimed by the applicant) the fact that (i) the alternative technology will require bigger electrodes and thus bigger size of the final products which impacts on their eco-design, and (ii) that alternative cannot cover the full measuring range, requiring compilation of measurement data from several sources.

In the exemption for Tin Lead Solder in audio-visual applications[16], the Institute did not recommend an exemption for lead because of the existence of an alternative, and this despite the fact that *"it is an inherent characteristic of innovative technology that there is no in-the-field long-term reliability experience."*

In the application for prolongation of the exemption for mercury in fluorescent lamps[17] ('CFLs') (which was rejected in this case), the Institute accepted that as a result of the use of mercury, there is an energy saving which leads to the reduction in the emission of mercury. The Institute however stated*: "however, the goal of the RoHS Directive should be to restrict the amount of mercury used in the lamps as much as possible. This is currently the case as the allowed maximum limit is decreased gradually. In this respect, further environmental advantages within the different CFLs would need to be analysed carefully and compared to the possible negative impacts with regard to the environment, consumer safety and health. Here it has to be stated that LCA analysis has so far confirmed that the main environmental impacts of CFLs are associated with their energy need during use".* Thus: (i) the fact that less mercury is released due to the mercury technology under exemption is not relevant as RoHS aims at the restriction of restricted substances, (ii) the fact that a technology has a positive effect on energy consumption is not sufficient to overcome the other negative impact from the continued use of the restricted substance.

Finally, settled case law on RoHS (e.g. Joined Cases C 14/06 and C 295/06) provide: *"as regards the objectives of Directive 2002/95 (*RoHS 1*), it is clear (...) that the intention of the legislature is to prohibit products referred to in the directive and to grant exemptions only in accordance with carefully defined*

[14] Institute Report of 30/09/2013, Pack 2-Final Report, Page 114.
[15] Institute Report of 30/09/2013, Pack 2-Final Report, Page 63.
[16] Institute Report of 28/07/2006, Final Report, Page 97.
[17] Institute Report of 30/05/2011, Final Report, Page 33.

conditions. Such an objective, in compliance with Article 152 EC, according to which a high level of human health protection is to be ensured in the definition and implementation of all Community policies and activities (...) and in compliance with Article 174(2) EC, according to which Community policy on the environment is to aim at a high level of protection and is based on the principles of precaution and preventive action (...) justifies the strict interpretation of the conditions for exemption."

The Applicants have sought to downplay the toxic nature of their cadmium based materials, claiming that they are a relatively harmless form of cadmium. However, this is not relevant in the context of RoHS restrictions which relate equally to all forms of cadmium (which is also the case e.g. of the REACH cadmium Restriction (No. 23) that identifies 'cadmium' as 'EC No 231-152-8 and its compounds'). This is correct as it is cadmium as an element which is the source of the hazard and cadmium atoms remain the same whatever compounds they are used in. Cadmium accumulates in the body, so that even low-level exposure builds up over time to dangerous levels. Cadmium and its compounds are highly toxic and exposure to this element is known to cause cancer and targets the body's cardiovascular, renal, gastrointestinal, neurological, reproductive, and respiratory systems. In addition, the WHO International Agency for Research on Cancer (IARC) report on the toxicity of cadmium and its compounds concludes: *"There is sufficient evidence in humans for the carcinogenicity of cadmium and cadmium compounds. Cadmium and cadmium compounds cause cancer of the lung. Also, positive associations have been observed between exposure to cadmium and cadmium compounds and cancer of the kidney and of the prostate."* and: *"Cadmium and cadmium compounds are carcinogenic to humans (Group 1)."*

The Applicants' claims that cadmium selenide (CdSe) is relatively less harmful in QD due to low solubility are also incorrect. A recent study has compared the toxicity of CdSe QDs with highly soluble cadmium chloride ($CdCl_2$)[18]. Though the harmful effects of CdSe QDs were observed at higher levels than those of $CdCl_2$, CdSe QDs nevertheless induced toxic and genotoxic effects, along with changes to the level of oxidative stress and in the expression of different genes involved in stress response. They concluded that: *"Cd based QDs are toxic, and induce oxidative stress and deregulation of gene expression as well as damage to DNA … The increased use of [Cd-based] QDs may affect human health after short- and long-term exposures."*

The safety data sheet[19] supplied with cadmium selenide by a leading material supplier in Europe shows the following hazards:

- Acute toxicity, Oral (Category 3), H301
- Acute toxicity, Inhalation (Category 3), H331
- Acute toxicity, Dermal (Category 4), H312
- Carcinogenicity (Category 1A), H350
- Specific target organ toxicity - repeated exposure (Category 2), H373
- Acute aquatic toxicity (Category 1), H400
- Chronic aquatic toxicity (Category 1), H410

Similarly, claims that the amounts of cadmium involved and their encapsulation eliminate the hazards are not correct. There is still a risk to the worker/consumer/environment if the device becomes

[18] M. Alaraby, E. Demir, A. Hernández, R. Marcos, Assessing potential harmful effects of CdSe quantum dots by using Drosophila melanogaster as in vivo model, Science of the Total Environment 530–531 (2015) 66–75

[19] http://www.sigmaaldrich.com/MSDS/MSDS/DisplayMSDSPage.do?country=GB&language=en&productNumber=244600&brand=ALDRICH&PageToGoToURL=http%3A%2F%2Fwww.sigmaaldrich.com%2Fcatalog%2Fproduct%2Faldrich%2F244600%3Flang%3Den

damaged, *e.g.* (for QD Vision's technology) if the fragile glass capillary component breaks, in a house fire, or in landfill. Data from QD Vision's Quantum Light™ optic, comprising CdSe/ZnS QDs embedded in acrylate polymer and encapsulated between borosilicate glass showed that exposure to 1 M nitric and gastric acids may destroy the ZnS shell, facilitating the acid etching of the CdSe core to liberate Cd[20]. A Cd release of 1.10 – 1.20 mg/g polymer was observed. It is envisaged that similar conditions could be encountered in a landfill environment. It also should be noted that inhalation of cadmium oxide from burning cadmium compounds, as could occur in a house fire or in poorly controlled waste disposal/recycling operations, is rapidly fatal at a dose of only 20 mg for an adult.[21] This is only 1/10th of the 200 mg limit that Ex.39(b) allowed for in a large (1m^2) TV, so there could be enough cadmium in a TV to kill 10 people.

See also the evidence that exposure to cadmium occurs in waste recycling facilities (see e.g. paper from German Federal Agency for Workers Protection 2011[22] stating that concentration in the air of cadmium from electronics recycling is above the acceptable risk level).

The applicants have also questioned the use of indium phosphide (InP) as a substitute, claiming that it is as great a hazard as cadmium. This is clearly not the case. InP is not restricted under RoHS or REACH and it is only a 4th priority substance for possible future review under RoHS. A review has not yet been scheduled and the outcome should not legally be pre-judged. Also, InP is a compound composed of indium and phosphorus. When InP is burned or dissolved, the indium and phosphorus are separated and form different compounds that are not classified as carcinogenic, so the hazard is already neutralised before exposure can occur.

A number of studies have directly compared the toxic effects of CdSe QDs with InP QDs, and of cadmium with indium. The results have consistently shown CdSe QDs to be much more toxic that InP QDs, and that cadmium is much more toxic than indium. See section 5. for details.

Nanoco CFQD® quantum dots are not made from InP, but from alloys containing indium and other metallic and non-metallic elements. Therefore, the hazards of the material are not the same as for InP. Accredited toxicology testing has shown Nanoco CFQD® quantum dots to be, according to EU GHS – CLP: EC1272/2008, "Not classified" for acute (oral) toxicity, skin and eye irritation, acute fish toxicity and acute daphnia toxicity. Ames and micronucleus testing has not shown any genotoxicity or mutagenicity, which would be the key concerns for any similarity to InP carcinogenicity. The organic content was also shown to be readily biodegradable. Classification of CFQD® quantum dots is limited to Skin Sensitisation (Category 1b) based on a weak positive result for Red CFQD® quantum dots only.

The Applicants have also sought to justify the continued use of cadmium on the basis of claiming significant reductions in energy consumption from the use of their products, and that this reduction in energy consumption would lead to an overall net reduction of cadmium in the environment by reducing emissions from coal burning power stations. As argued from the legislation and precedents above, the admissibility of these arguments is already rejected. However, even if these factors are considered they are not supported by the facts for commercial products.

---

[20] J. Liu, J. Katahara, G. Li, S. Coe-Sullivan and R.H. Hunt, *Environ. Sci. Technol.*, 2012, **46**, 3220

[21] Derived from NIOSH fatal dose data: http://www.cdc.gov/niosh/idlh/7440439.html and adult respiration rate data from Californian EPA : http://www.arb.ca.gov/research/resnotes/notes/94-11.htm

[22] https://www.baua.de/de/Themen-von-A-Z/Gefahrstoffe/Arbeiten-mit-Gefahrstoffen/pdf/Elektronikschrottrecycling.pdf?__blob=publicationFile&v=2

The primary comparison of power consumption by different types of displays should be based on published manufacturer's data – in accordance with EU consumer energy rating test conditions – where these are available. The following tables compare 55" and 65" 4k TVs using cadmium QD, cadmium-free QD, OLED and conventional LED technology (both are required in order to compare the withdrawn Sony model and the 2 available cadmium QD TVs as they are different sizes with only 1 model each). There is also a comparison of 27" monitors between cadmium QD and conventional LED technology.

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
LG EG960V	OLED	55"	196	134	B	http://www.johnlewis.com/lg-55eg960v-curved-4k-ultra-hd-oled-3d-smart-tv-55-with-freeview-hd-built-in-wi-fi-harman-kardon-audio-2x-3d-glasses/p1921663
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

Considering first the 55" displays:

- The cadmium-free QD Samsung JS9000 is 'A' rated for energy efficiency with an energy consumption of 110W, which is even less than comparable TVs with conventional lower colour gamut screens (115W for the 'A' rated Sony KD55X85).
- The Sony model was the only cadmium QD TV ever to be sold in the EU before 2015 and was withdrawn in 2014. It was rated 'B' for energy efficiency and had a consumption of 155W, or **41% higher** than the Samsung.
- The Thomson UA9806 is 'A' rated for energy efficiency with an energy consumption of 112W, which is better than the non-QD Sony, but still **2% higher** than the Samsung.
- OLED technology has continued to improve, but the LG EG960V as an example is only 'B' rated with an energy consumption of 134W, which is 17% than higher the non-QD Sony.

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

Considering secondly the 65" displays:

- The cadmium-free QD Samsung JS8500 is 'A+' rated for energy efficiency with an energy consumption of 116W, which is significantly (up to 22%) less than comparable TVs with conventional lower colour gamut screens (149W for the 'A' rated Sony KD65X85).
- The Hisense XT910 is 'A' rated for energy efficiency but with an energy consumption of 285W, which is significantly higher than the non-QD Sony, and **146% higher** than the Samsung.
- OLED technology shows better performance at this size as shown by the 65" version of the LG EG960V. This is 'A' rated with an energy consumption of 142W, which is 5% lower than the non-QD Sony, and 22% higher than the Samsung.

Device	Type	Screen size	Energy Consumption kWh/annum	On-mode Consumption W	EU energy rating	Source
BenQ SW2700PT	Cd-based QD	27"	n/a	65 or 36.7	n/a	http://shop.benq.eu/store/benqeu/en_GB/DisplayProductDetailsPage/ThemeID.19795600/productID.325771300/categoryID.57154900
ACER H277H	Non-QD	27"	n/a	27	n/a	http://www.pcworld.co.uk/gbuk/computing/pc-monitors/pc-monitors/acer-h277hsmidx-full-hd-27-ips-led-monitor-10135222-pdt.html

The comparison for the BenQ monitor is not so clear because the EU version of the BenQ website gives a power consumption of 65W, while the BenQ.com website states 36.7W. Possibly this is due to measurements made according to a different standard for the EU market. However, whichever number is used it is clear that the power consumption is much higher than a 27" HD LCD monitor using conventional LED technology, such as the Acer H277H rated at only 27W. Depending on which figure is used for the BenQ, its power consumption is either **36% or 141% higher**.

It is clear from these comparisons using manufacturers' published test data for products to European standards that commercial cadmium QD displays **do not** offer the significant energy savings claimed by the applicants when compared to cadmium-free QD and conventional LED technology in LCD displays. Cadmium QDs should in theory be able to offer similar energy performance compared to cadmium-free QDs in LCD displays, but commercially available products do not seem able to deliver this at the moment, even though they are 2nd generation compared to the 1st generation SUHD models from Samsung. Hence there is no possible argument that life-cycle benefits from reducing energy consumption can be used to justify a continued Exemption for cadmium QDs in display product.

A further argument that the Applicants propose is that claimed energy savings from using cadmium QDs in displays will lead to an overall reduction in cadmium in the environment. Obviously this logic cannot apply given the absence of convincing evidence that commercial products deliver any energy savings. However, it is also worth noting that the logic and figures used for the calculation of reducing cadmium emissions appear to have a number of flaws. A precise evaluation of the argument is made difficult because the details appear to be from a report that has not been publicly submitted by the Applicant[23]. However, some key points and figures can be taken from the supplemental Life Cycle Assessment by Acta Group LLC on behalf of QD Vision. This claims that:

i) Cadmium QD TVs would use 25% less energy than cadmium-free QD TVs
ii) Lifetime energy saving per TV would be 436 kg CO_2 equivalent over a 20.5 year lifetime
iii) That an average TV would contain 1.5mg of Cd
iv) Cadmium emissions overall would be reduced by 1.3mg, so a reduction emissions from power generation by 2.8mg is implied - equivalent to 0.0064 mg Cd/kgCO_2)

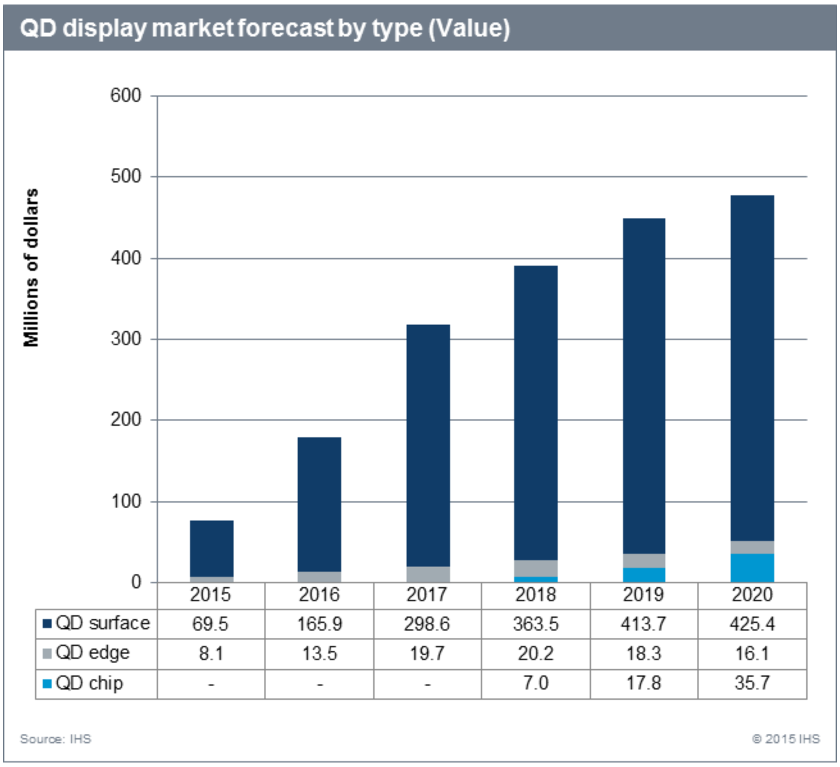
Considering each of these points:

i) As we have shown above the evidence based on EU standard test data on comparable commercial displays shows that there is no evidence to support the claim of 25% power saving. In fact, the evidence available tends to show the opposite.

ii) The assumption of a 20.5 year lifetime for an LCD TV or computer monitor does not seem to be credible. Consumers change their display product much more frequently than this and a 5-10 year lifetime would seem to be more appropriate. This would reduce the amount of energy saved to about 1/3 of that claimed. It also assumes that the display is used for 4 hours a day, which also seems to be excessive as families are tending to use multiple smaller devices and rely less on watching the main TV in the home. It seems likely that the average usage will reduce to 2 or 3 hours a day, reducing the energy saving by a further 25-50%.

iii) The claim that an average cadmium QD TV would contain only 1.5mg of cadmium appears to relate to smaller models than those currently available (32” to 60” is quoted), so the amount used in a 55” TV is likely to be greater. Also this figure relates only to TVs using ‘on-edge’ designs from QD Vision, when the majority of available QD TVs use ‘on-surface’ designs, including the QDEF film from the Applicant 3M. According to QD Vision, these film designs would use from 8.5 to 162 mg Cd for this range of sizes. This also aligns with Exemption 39b that would have permitted up to 200mg in a TV with 1m^2 of screen area (60”). Clearly, even the claimed saving of 2.8mg in power emissions over the life of a TV would make little impact for those using the film design – as the majority do now and are likely to continue doing in future. This view is supported by market forecasts from IHS, which show the current dominance of ‘on-surface’ design continuing through to 2020, even including the potential appearance of ‘on-chip’ designs from 2018 – see graphic below:

[23] Risk & Policy Analysts. (2015): Cadmium Selenide Quantum Dots – RoHS Exemption Supporting Arguments. Final Report. *Not submitted as a public document by QD Vision*.



iv) To assess the accuracy of the emission figures used by the Applicants, Nanoco commissioned a review by an independent consultant (BiPRO GMBH) of available emissions data in the EU[24]. Based on E-PRTR data for 2013, they calculated a value of 0.00675 mg Cd/kg CO_2, which is indeed close to the 0.0064 figure used by the Applicants. However, this only includes data from 20% of the big coal fired plants in the EU, so it is only partial. It is also striking that there is a huge variation in emissions according to the country and the level of abatement technology and enforcement applied. In Germany, the best performing, the emission rate is only 0.000498 mg Cd/kg CO_2, or 7.4% of the average. Meanwhile Czech Republic is at 0.029 mg Cd/kg CO_2, or 4.3 times the average. It is clear from EU policy that the percentage of coal in the energy mix will reduce in coming years to meet carbon reduction targets: by 2020 it is scheduled to drop from 27% to 20%, falling to only 7% by 2050. Also, the mix of remaining plants will shift in favour of more modern plants using improved emission controls, as seen in Germany. Given these trends, the average emission rate of cadmium per kg of CO_2 will fall sharply in coming years. By 2030 for example, if the coal usage rate drops from 27% to 12 % and plant emissions are improved on average by 50% to 0.0125 mg Cd/kg CO_2 (still 10 times the current German emission standard) then overall emissions would drop to 0.0015 mg Cd/kg CO_2. This would mean a reduction in cadmium 'savings' of **77.8%** compared to the figures proposed by QD Vision.

In conclusion, the assessment of the reduction of cadmium emissions from power generation provided by QD Vision is factually incorrect and greatly exaggerates the potential reductions even if any energy were to be saved compared to cadmium-free QD technology (which is a claim that is not supported by the fact from commercial products). Even if all of their claims were correct, the savings would be

[24] 'Airborne cadmium emissions from coal fired electricity generation in the European Union', BiPRO GMBH, 7th January 2016.

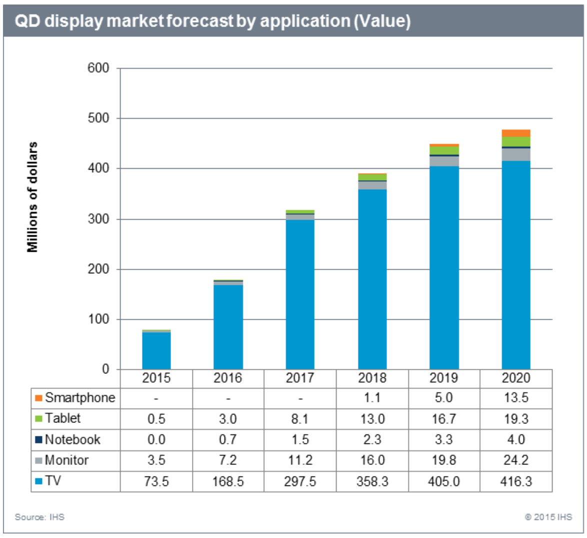
small compared to the amount of cadmium used in the majority of cadmium QD displays, since they use film technology that requires much larger amounts of cadmium than 'on-edge' designs that are not preferred by display manufacturers.

Q4 Availability

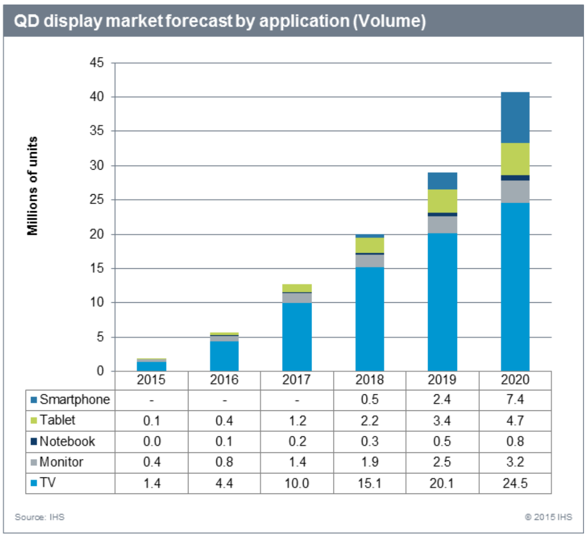
For displays, the commercial availability of cadmium-free QD materials and components is now well established:

- Samsung and their manufacturing partner Hansol have large scale commercial production capacity operational in Jeonju in Korea. These are used to supply the QD film components for Samsung's market leading range of SUHD display products, with 11 models available (see 2.a.). At the CES show, they have just announced the launch of a further 5 models with improved performance[25].
- Nanoco has commercial production of CFQD® cadmium-free QD technology at Runcorn in the UK.
- Dow have built and commissioned a large scale commercial plant in Cheonan in Korea to produce CFQD® QD technology.
- Several other QD companies have announced plans for Cd-free QD supply. These include one of the original applicants, Nanosys, who has recently stated[26] that 40% of their sales are already from Cd-free QDs. Nanosys have licensed their Cd-free QD technology to Samsung. They have manufacturing plants in Milpitas in California and Milwaukee in Wisconsin, USA. Another is Quantum Materials Corporation who recently announced an increase in their production capacity for cadmium-free QDs in San Marcos in Texas, USA[27].

Production capacity will continue to grow rapidly to meet the market demand as this new technology becomes more widely adopted in the next few years. The graphics below from IHS show how the market for QD displays is expected to grow up to 2020:



	2015	2016	2017	2018	2019	2020
Smartphone	-	-	-	1.1	5.0	13.5
Tablet	0.5	3.0	8.1	13.0	16.7	19.3
Notebook	0.0	0.7	1.5	2.3	3.3	4.0
Monitor	3.5	7.2	11.2	16.0	19.8	24.2
TV	73.5	168.5	297.5	358.3	405.0	416.3



	2015	2016	2017	2018	2019	2020
Smartphone	-	-	-	0.5	2.4	7.4
Tablet	0.1	0.4	1.2	2.2	3.4	4.7
Notebook	0.0	0.1	0.2	0.3	0.5	0.8
Monitor	0.4	0.8	1.4	1.9	2.5	3.2
TV	1.4	4.4	10.0	15.1	20.1	24.5

---

25 http://www.koreaherald.com/view.php?ud=20160105000966

26 Interview with Nanosys. http://www.displaydaily.com/content/videos/451-display-week-2015-video-news/24872-nanosys-calls-for-rec-2020-change-and-explains-cadmium-issue

27 http://www.qmcdots.com/press/press37.php

Other available 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. We believe that manufacturing costs for large OLED screens will continue to be significantly higher than for LED screens for the foreseeable future. LG has been promoting its OLED TVs strongly and recently announced a $9billion investment in a new OLED production plant[28].
- Other technologies continue to emerge. For example the IPS Quantum display technology used on the LG G4 mobile phone.

In contrast, it should be noted that at the time when the original Exemption 39 should have ended in July 2014, there were no Cd-based QD display products available in the EU market. Since then, four cadmium QD display products have been re-introduced, of which only the very recently launched Hisense 65" TV appears to have anything better than very limited availability (see section 2.a.). We therefore believe that at this time Cd-free QD displays have an overwhelming market share compared to Cd-based QD displays.

For lighting products, it remains the case that more than 6 years after Exemption 39 was enacted, there is not a single cadmium QD lighting product available in the EU market. In contrast, two cadmium-free QD lighting products have already been launched and more will follow in 2016 – see section 4. for details. In addition, higher colour performance LED lighting using improved cadmium-free phosphor technologies are becoming increasingly available as well.

Q5 Socio-economic impact

So far as the impact on employment in the EU is concerned, there will be a negative impact if Ex.39 is extended. This is because the Applicants are US based, both for research and development and for the manufacture of cadmium QD materials, whereas Nanoco is UK based for its R&D and direct manufacturing. Other EU companies that have based their business strategy in accordance with the RoHS Directive and focussed on developing and applying cadmium-free technologies will also be negatively affected. This could include, among others, NDF Special Light Products BV, who have also responded to the consultation, and Fraunhofer Institute who have publicly announced the development of cadmium-free quantum dot technology[29]. In fact, the R&D work into sustainable

---

[28] http://www.flatpanelshd.com/news.php?subaction=showfull&id=1448894534

[29] http://www.iap.fraunhofer.de/en/Forschungsbereiche/Funktionale_Polymersysteme/funktionsmaterialienundbauelemente.html

http://www.iap.fraunhofer.de/en/Forschungsbereiche/Funktionale_Polymersysteme/funktionsmaterialienundbauelemente/hocheffiziente-cadmiumfreie-quantenpunkte--fuer-qleds-und-solarz.html

http://www.rsc.org/chemistryworld/2015/10/environmentally-friendly-quantum-dots-indium-nanoparticles-lcd alternatives by Nanoco and others has in many cases been assisted by financial grants from the EU and Member States that have promoted sustainable innovation.

This would also set a very discouraging example for other companies investing or considering investing in sustainable innovation in Europe, based on the assumption of consistent policy from the EU to promote this desirable activity. The long term economic impact of undermining confidence in the consistency of EU policy in this area could be very significant.

Unfortunately, large scale manufacture of both lighting and display products has largely moved from EU to Asia. Hence the majority of consumer product manufacturing jobs will be in Asia whichever technology is used. Equally, the retail and distribution channels in Europe and associated employment will not be affected.

For the economic impact on consumers, market pressure will ensure that product pricing will remain competitive and will not be significantly affected. This is contrary to the arguments put forward by one of the Applicants, QD Vision (QDV). Even according to their own submission, the cost of a comparable 55" SUHD TV from Samsung and a Thomson UA9806 is the same at €1,790 – even though the Thomson uses QDV's supposedly cheaper technology. This is already good evidence that the choice of technology will not have a significant impact on the display unit cost.

QDV quotes a figure of $40 for one of their cadmium QD glass capillary components, but it does not say what size display this is for or even whether 2 components will be needed for larger screens (which are often lit from 2 edges). It also does not take into account the additional cost of modifying the display design to accommodate the extra component(s) or the handling difficulties of installation (they are very fragile). They quote a figure $120 for a film using cadmium-free QDs, although again they do not say what size. In Nanoco's experience, both cadmium QD (as produced by the other Applicant 3M) and cadmium-free QD films are currently priced at around $100-150 /m^2. A 60" display with 16:9 screen ratio is 0.99m^2, while a 27" display (larger computer monitor) is 0.20m^2. Clearly the film cost is proportional to the size of the panel, so that it is competitive in smaller, cheaper displays. In fact, at $20-25 for a 27" monitor screen, the film cost would already be less than the $40 quoted by QDV. In addition, there is no re-design or any additional components needed with the film design, it is easy to handle and it integrates easily with the existing optical film 'stack' in the display panel. It is also possible that it can act as a diffuser and replace or simplify other components in the panel to save costs. This is why it is the preferred design solution of many manufacturers, including the market leader Samsung.

Finally, it should be noted that, in line with general principles of mass production, the price of QD film is expected to reduce significantly as production volume increases. This will be achieved through reduced production and raw material costs at larger scale. Evidence of this is available already by reviewing the change in pricing across EU countries for Samsung SUHD models using cadmium-free QD films (see table below). The price points of these televisions have dropped on average by around 25% in the six month period from July to December 2015. Based on current trends this would mean a 50% drop in older models by the end of 2016. Such a drop would bring the price point of cadmium free TV's and the average price of similar size models using conventional LED technology into close proximity.

Country		UE48JS9000	% reduction	UE55JS9000	% reduction	UE65JS9000	% reduction	UE48JS8500	% reduction	UE55JS8500	% reduction	UE65JS8500	% reduction	UE65JS9500	% reduction	UE78JS9500	% reduction	UE88JS9500	% reduction
AT	Jul	2899.00		2884.02		4590.00		2199.00						5590.00					
	Dec	1999.99	31.01%	2470.59	14.34%	3830.92	16.54%	2521.00	-14.64%			4033.60		5042.01	9.80%	8571.42			
BE	Jul	2799.00		3499.00		5999.00		2699.00		2799.00		4499.00		5999.00		12499.00		24999.00	
	Dec	2299.00	17.86%	2998.00	14.32%	4499.00	25.00%	1998.00	25.97%	2498.00	10.75%	3798.00	15.58%	4998.00	16.69%	9999.00	20.00%	19999.00	20.00%
BG	Jul	4013.50		5492.20		8688.85		3893.97		3989.71		7490.96		9987.94		18977.48		39955.68	
	Dec	4199.00	-4.62%	4599.00	16.26%	6999.00	19.45%	3299.00	15.28%	3999.00	-0.23%	6899.00	7.90%	8499.00	14.91%	15499.00	18.33%		
CY	Jul			3499.00		5299.00													
	Dec			2699.00	22.86%	4599.00	13.21%												
CZ	Jul			99990.00				59990.00		84990.00		129990.00		179990.00		299990.00		549990.00	
	Dec			89990.00	10.00%			49990.00	16.67%	69990.00	17.65%	99990.00	23.08%	139999.00	22.22%	249990.00	16.67%	549990.00	0.00%
DE	Jul	3199.00		3799.00		5790.00				2599.00		4799.00		6799.00		12999.00		24999.00	
	Dec	2499.00	21.88%	3199.00	15.79%	4999.00	13.66%	2099.00		1875.00	27.86%	4299.00	10.42%	5799.00	14.71%	9999.00	23.08%	19999.00	20.00%
DK	Jul	23035.51		23326.54		40056.57		21035.87		20035.75		30049.89		55092.71		100163.82			
	Dec	11287.00	51.00%	0.00		19815.00	50.53%	9999.00	52.47%	12999.00	35.12%	19999.00	33.45%	32173.00	41.60%	61999.00	38.10%		
EL	Jul	2545.00		3429.00		4378.00		2199.00		2999.00		4499.00		5199.00		10999.00			
	Dec	1999.00	21.45%	2189.00	36.16%	3939.00	10.03%	1699.00	22.74%	1949.00	35.01%	3499.00	22.23%	4999.00	3.85%	9989.00	9.18%	17999.00	
ES	Jul	2699.00		0.00		5499.00		1735.00		2129.00				6499.00		11999.00			
	Dec	1699.00	37.05%	2199.00		3199.00	41.83%	1415.00	18.44%	1769.00	16.91%	2929.00		3999.00	38.47%	7499.00	37.50%	16999.00	
FI	Jul			2999.00		5299.00		2699.00		2999.00		5299.00		6399.00		12599.00			
	Dec			1999.00	33.34%	2979.00	43.78%	1749.00	35.20%	1899.00	36.68%	3299.00	37.74%	3399.00	46.88%	6799.00	46.04%		
FR	Jul			2999.00				1999.00		3490.00				5499.00		9999.00			
	Dec			2490.00	16.97%					1999.00	42.72%			3990.00	27.44%	9990.00	0.09%	24990.00	
HR	Jul	21751.95				34141.23		20743.07		18129.17									
	Dec					25999.00	23.85%	12499.00	39.74%	16999.00	6.23%	26999.00		35999.00					
HU	Jul			999899.00		1599999.00		729899.00						1899900.00		3499900.00			
	Dec			749999.00	24.99%			439989.00	39.72%	699999.00				1199900.00	36.84%	2500000.00	28.57%	3999990.00	
IE	Jul	3329.00		3729.00		4799.00		2659.00		3299.00		4399.00		8177.00		12699.00		25299.00	
	Dec	2049.00	38.45%	2699.00	27.62%	3999.00	16.67%	1799.00	32.34%	2399.00	27.28%	3299.00	25.01%	3699.00	54.76%	12699.00	0.00%	25299.00	0.00%
IT	Jul	2999.00		2999.00		5499.00		1949.00		2499.00				6499.00					
	Dec	2329.00	22.34%	2499.00	16.67%	4499.00	18.19%	1999.00	-2.57%	1499.00	40.02%	3499.00		5299.00	18.46%				
LT	Jul			2799.00		4389.00				2248.00		4499.00		4989.00					
	Dec	1762.00		2219.00	20.72%	3649.00	16.86%	1459.00		1899.00	15.52%	2989.00	33.56%	4299.00	13.83%				
LUX	Jul	2495.00		2999.00		4995.00													
	Dec	1995.00	20.04%	2395.00	20.14%	3495.00	30.03%												
LV	Jul											2199.00		6499.00					
	Dec			2199.00		3699.00		1699.00		1899.00		2999.00	-36.38%	4399.00	32.31%	7599.00			
MT	Jul							2499.00		2999.00				6499.00		11999.00		25000.00	
	Dec			2999.00				1999.00	20.01%	2499.00	16.67%			5499.00	15.39%	9999.00	16.67%	19999.00	20.00%
NL	Jul	3199.00		3299.00		4299.00				3199.00				6999.00				22999.00	
	Dec	2299.00	28.13%	2189.00	33.65%	3375.00	21.49%	1489.00		2499.00	21.88%	2799.00		4999.00	28.58%	7999.00		15999.00	30.44%
PL	Jul	9499.00		12499.00		18999.00		7999.00		10699.00				22999.00		41999.00		87999.00	
	Dec	6799.00	28.42%	8939.00	28.48%	12599.00	33.69%	6099.00	23.75%	7499.00	29.91%	11999.00		19999.00	13.04%	41999.00	0.00%	84999.00	3.41%
PT	Jul	2499.00		3499.00		4999.00		2499.00		2999.00				6999.00		11999.00			
	Dec	2299.00	8.00%	2399.00	31.44%	3599.00	28.01%	1124.00	55.02%	1699.00	43.35%	3299.00		4874.00	30.36%	8624.00	28.13%		
RO	Jul	9999.90		13999.90		19999.90		9999.90		11999.90		15999.90		22999.90		47999.90		99999.90	
	Dec	8999.90	10.00%			19999.90	0.00%			9499.90	20.83%	13999.90	12.50%	19999.90	13.04%	42999.90	10.42%	99999.90	0.00%
SE	Jul	21819.87		29759.36		54558.83								64478.62		118954.95		248040.54	
	Dec	16999.00	22.09%	18990.00	36.19%	34990.00	35.87%							44990.00	30.22%	98990.00	16.78%	190990.00	23.00%
SI	Jul	3499.00		3799.00		5999.00										13999.00			
	Dec			2499.00	34.22%	3999.00	33.34%			2499.00				4999.00					
SK	Jul			3599.00				2179.00		2999.00		4599.00		6499.00					
	Dec			2999.00	16.67%					2399.00	20.01%	3499.00	23.92%	5999.00	7.69%	9990.00		19999.00	
UK	Jul	2249.00		2849.00		3749.00		1749.00		2349.00				5799.00		9999.00		19999.00	
	Dec	1499.00	33.35%	1899.00	33.35%	2799.00	25.34%	1299.00	25.73%	1649.00	29.80%	2449.00		3999.00	31.04%	8999.00	10.00%	17999.00	10.00%
Price reduction			24.15%		24.01%		24.64%		25.37%		24.70%		17.42%		24.44%		18.80%		12.69%

QDV further claim that cost advantages for cadmium QDs will increase in the future due to being able to use them in smaller amounts in both 'on-edge' and 'on-chip' designs. However, this is both incorrect and speculative. Nanoco already has experience using cadmium-free QDs in 'on-edge' designs, but moved to focus on 'on-surface' film designs over 2 years ago based on the preference of display manufacturers for this design – a preference which is clearly supported by the fact that 3M also use a film design (QDEF™). Neither cadmium nor cadmium-free QDs are currently able to be used 'on-chip' although this remains an active research goal for both technologies. QDV's statement that this can only be achieved by cadmium QDs is purely speculative, and their claim that cadmium QDs use 40-400 times less material than cadmium-free QDs is not substantiated or on a like-for-like basis.

A further claim from both Applicants is for reduced running costs arising from reduced power consumption that can only be achieved by cadmium QD displays, and that these would be a significant economic benefit for EU consumers. However, as discussed in Q3 above, their claims for significant energy savings are not substantiated. Indeed, for some of the past and current cadmium QD displays (Sony TV and BENQ monitor) their power consumption has actually been significantly higher than comparable standard LCD displays and/or cadmium-free QD displays.

Our conclusion from the factors analysed above shows that the overall socio-economic impact of extending Ex.39 is likely to be negative for the EU.

Q6 Impact on innovation

Allowing (via the prolongation of an exemption) the development of a new lighting technology using cadmium should not be permitted because it will have an adverse impact on innovation, contrary to RoHS requirements. The Institute Guidance clarifies that the assessment should focus on *"impacts that the duration of an exemption may have on future efforts for developing possible substitutes."* This is in line with broader EU policies to promote sustainable innovation, of which the development of CFQD® technology by Nanoco, a UK based SME, is an excellent example.

Investment and research into cadmium-free lighting technology (both QD and non-QD) will be discouraged if the development of cadmium based quantum dot light technology is allowed via a prolonged exemption.

Furthermore, Annex V RoHS (entitled 'Applications for granting, renewing and revoking exemptions as referred to in Article 5') states that applications shall include: *"the proposed actions to develop, request the development and/or to apply possible alternatives including a timetable for such actions by the applicant."*

Thus, companies that apply for exemptions should also contribute to the development and application of alternatives.[30] This is the case in most other Exemption applications which typically contain a

[30] The character of RoHS exemptions is temporary and their purpose is a gradual phase-out of the use of hazardous substances (Recital 19 to RoHS). This is confirmed in the case at hand: Commission Decision 2010/122 which introduced Exemption 39 stated that *"research on cadmium-free technology is in progress and substitutes should become available within the next four to five years at the latest."* This is in line with Council Resolution of 25 January 1988 on a Community action program to combat environmental pollution by cadmium[30] which provides that the strategies adopted should include *"limitation of the uses of cadmium to cases where suitable*

timetable in which the applicant demonstrates his gradual shift to the alternative technology. However, the way in which the cadmium QD industry approaches this issue is very questionable.

In our view, both QD Vision and 3M in their 2013 Exemption 39 requests[31] did not substantiate their own R&D and thus why the exemption should continue. The recent paper submitted by Lighting Europe on December 9, 2015 during the current public consultation (and also previous contributions of other cadmium stakeholders) states that the cadmium industry should leverage their investments in cadmium containing quantum dot technology. The paper states that future new cadmium technologies will be 'stepping stones' once cadmium-free is commercially available, so that the EU benefits from possible improvements.

Thus, it would appear that the cadmium industry suggest that by improving cadmium based technologies, they will indirectly improve future cadmium-free technologies developed by other companies. In our view, however, there is a clear risk that there will be an opposite effect. It is likely that the providers of cadmium QD technology will seek to consolidate and expand a permanent position in the EU market. This is clearly against the spirit and purpose of RoHS and against the time-limited character of RoHS exemptions.

The principle that the applicant should be involved in the development of alternatives is confirmed in the "Institute Opinion on cadmium in photo-resistors applied in professional audio equipment"[32] which recommended granting of a limited exemption on the grounds that the applicants *"spend time and effort in developing and testing alternatives as was well presented in a roadmap suggesting that a RoHS-compliant solution is possible within the next years hence proposing an exemption limited to three additional years."* The Institute stated that the applicants *"consider that there are no known technically and scientifically feasible RoHS compliant substitutes and alternate processes at the moment"*. The Applicants are however *"continuously investigating new state of the art solutions to replace this component but however fail to provide any substantiated evidence on these activities."*

In several other cases (e.g. lead in glass of fluorescent tubes[33]), the applicants were granted a limited exemption as they had already developed an alternative technology, but still needed some additional time for its implementation, i.e. for phasing-out of the hazardous substance.

---

alternatives do not exist" and *"stimulation of research and development of substitutes and technological derivatives."*

[31]Institute Report of 22/04/2014, Final Report – Pack 4, Page 59
QD Vision stated: *"continue to believe that such alternatives will indeed be viable one day, however, our increased effort has also lead to an increased understanding of the practical technical difficulties of implementing such a material substitution. Our own research has not yet provided a III-V (Indium Phosphide) semiconductor material which demonstrates performance properties that match those of the current II-VI colour converting materials that contain cadmium".*

3M stated: *"that the replacement of Cd in commercial applications is to require a minimum of 7 years (by 2021). 3M estimates that Cd-free QD research (based on InP) shall reach the current colour quality and energy consumption performance with prototypes becoming available by 2019. Thus they expect full-scale commercialisation by July 2021".*

[32] Institute report of 30/05/2011, Final Report, page 12
[33] Institute report of 20/02/2009, Final Report, Page 52

In the present case however, the cadmium QD industry is apparently interested principally in developing cadmium technology, which under the principles above should not justify granting an exemption because it is contrary to Annex V(g) of RoHS. Moreover, since cadmium-free QD technology has now 'leap-frogged' cadmium QD to take a leading market position in both display and lighting, any argument that Exemption 39 should be extended to provide a 'stepping-stone' is clearly rendered obsolete.

Q7 Impact on SMEs

There would clearly be a negative impact on European SMEs if the exemption for the use of cadmium in lighting and display products were to continue.

Nanoco Technologies Ltd is a UK based SME that is a world leader in the development of CFQD® cadmium-free QD technology. Since 2004, Nanoco has turned its back on the use of toxic cadmium in response to the RoHS Directive, the concerns of responsible major manufacturers and its own environmental and safety policy. Nanoco has invested €75 million in research and development of cadmium-free QDs and continually promoted sustainable innovation in the application of QD technology in display, lighting and other markets. Nanoco has relied on the time limited nature of RoHS exemptions to ensure that the use of cadmium QDs would be withdrawn as soon as cadmium-free QDs were able to meet commercial levels of performance. However, Ex.39 has already been extended well beyond its scheduled expiry date and this creates uncertainty in the market that is potentially damaging to the growth prospects for Nanoco's cadmium-free technology.

Another example is NDF Special Light Products BV, who have also responded to the consultation. NDF are a Netherlands based SME producing high performance displays for aircraft, air traffic control, medical and industrial applications (among others). NDF have chosen to commit their research and development efforts to cadmium-free technologies, in response to RoHS regulations, their own health and environmental concerns and the expressed will of the European Parliament. The development and approval cycles for their products can be long and expensive, so their commitment is strategically significant for the future of their products.

2. At the time of the first review, difficulties regarding the comparison of Cd QDs in display applications and Cd-free QDs in display applications, did not allow making a well-balanced comparison of these technologies. In the meantime, it has become apparent that the market situation of these products has changed, possibly allowing a better comparison and evaluation as to the environmental performance of these technologies and other related aspects. The two applicants and a manufacturer of a substitute candidate have provided information regarding applications that are already on the market using the Cd based and Cd free technologies. Please review this information and comment:

a. Regarding the availability of Cd-based and Cd-free products for display applications using these technologies, please specify if you are aware of additional products that have become available since 2014 (display type, dimensions and other characteristic aspects for clarifying the performance class) other than those specified by the applicants and the substitute candidate manufacturer.

The Applicants have identified a number of cadmium QD products that they claim have become available. However, the scope of this consultation relates to the EU market and many of the products listed by the Applicants are not currently available in the EU, so the information is misleading.

Considering the products listed by QD Vision (QD Product List 20 October 2015.xlsx), there are 35 identified that use cadmium QD technology. However, the vast majority of these are discontinued and/or not available in the EU and some appear to be duplicate entries. Of this list of 35, we have only been able to find the following to be available in the EU:

1) Thomson 55UA9806, 55" Flat screen 4K HD : Very limited availability in only a few Member States and not available from www.boulanger.com as claimed.

QD Vision also claimed 2 other products as being currently available in EU in its submission:

2) Televisions to be launched in October/November 2015:
  a. Hisense : based on K7100
3) Current model monitor:
  a. Philips : 276E6.

However, the availability of this Hisense model cannot be confirmed as insufficient information is provided to identify it. The Hisense UK website identifies 1 available model as containing QD technology:

2) Hisense LTDN65XT910XWTSEU3D, 65” curved screen 4K HD : This has only very recently become available with some retailers in the UK and some other Member States.

Also, although originally announced as launching in October, the Philips monitor was still not available in the EU on the 7th January 2016 (well after the date of the QD Vision document) and it is not clear when it will actually be launched.

In strong contrast, a whole range of models using cadmium-free QD technology was launched in Q1 2015 in the EU by Samsung and has sold extremely well. Based on IHS forecasts for global sales in 2015[34], the sales for QD TVs will be split as shown below:

2015 Sales Forecast	Type	TVs (millions)	Market Share
Cadmium-free QD	Surface	1.0	77%
Cadmium QD	Surface	0.1	8%
Cadmium QD	Edge	0.2	15%
Total QD TV		**1.3**	**100%**

This implies a 77% share for SUHD cadmium-free QD TVs globally, and the share is likely to be higher in the EU market since Cadmium QD TVs were launched earlier in China and USA than in Europe. Cadmium-free display sales are also forecast to grow globally by 310% in 2016, compared to a growth of 88% in cadmium QD displays – so 3.5 times higher growth rate for cadmium-free QD technology. It is clear from these figures that cadmium-free QD technology is already established as the market leader for high colour gamut displays in the EU market and globally.

3M provides a table of cadmium QD products that they claim are available in their submission. 9 such products are listed, of which the Amazon tablet has been withdrawn and the Asus monitor is described as 'pending' but is not available in the EU. The only products we were able to find with any availability in the EU are:

i) ASUS Zenbook NX500JK 15.6": This has very limited availability only though specialist on-line retailers and only in a few Member States.

ii) Hisense LTDN65XT910XWTSEU3D : as above

iii) BENQ SW2700PT 27": This appears to be available through the manufacturer's website: http://benq.co.uk/product/monitor/sw2700pt/
It is also available through a limited number of mainly specialist on-line retailers in a number of Member States.
It is not clear from the website if this model uses cadmium QD technology. It should also be noted that it is Energy Efficiency Class 'C', with power on consumption of 65W according to the BenQ.eu website and 36.7W according to the BenQ.com website. In contrast, a 27" monitor from Asus has a power consumption of only 27W:
http://www.pcworld.co.uk/gbuk/computing/pc-monitors/pc-monitors/acer-h277hsmidx-full-hd-27-ips-led-monitor-10135222-pdt.html
So this BENQ uses **36% or 141% more power** than a standard 27" HD monitor.

[34] Quantum Dot Display Technology & Market Report – H2 2015, IHS Technology, August 2015

In summary:

Manufacturer	Model	Size	QD Type	Application	Availability
Sony	KDL-X9000A	55"	Cadmium QD	Glass tube	Withdrawn 2014
Kindle	Fire HDX	7"	Cadmium QD	QDEF Film	Withdrawn 2014
Asus	NX500	15.6"	Cadmium QD	QDEF Film	Very limited
Thomson	UA 9806	55"	Cadmium QD	Glass tube	Very limited
Hisense	XT910 ULED	65"	Cadmium QD	Glass tube	New : Part EU
BENQ	SW2700PT	27"	Cadmium QD ?	Not disclosed?	New : Part EU

It should be noted that at the time when the original Exemption 39 should have ended in July 2014, there were no cadmium QD display products available in the EU market.

Our conclusion is that the availability and sales volume of cadmium QD based display products in the EU market remains very small and has made very little impact on consumers. It is also noted that the data from the Applicants continues to be misleading concerning the real commercial availability of such products in the EU market.

This is in clear contrast to the current SUHD range of 11 cadmium-free QD display products[35]:

Manufacturer	Model	Size	QD Type	Application	Availability
Samsung	S9WAT	82"	Cd-free QD	SUHD Film	All EU
Samsung	JS8000	55"	Cd-free QD	SUHD Film	All EU
Samsung	JS8500	48"	Cd-free QD	SUHD Film	All EU
Samsung	JS8500	55"	Cd-free QD	SUHD Film	All EU
Samsung	JS8500	65"	Cd-free QD	SUHD Film	All EU
Samsung	JS9000	48"	Cd-free QD	SUHD Film	All EU
Samsung	JS9000	55"	Cd-free QD	SUHD Film	All EU
Samsung	JS9000	65"	Cd-free QD	SUHD Film	All EU
Samsung	JS9500	65"	Cd-free QD	SUHD Film	All EU
Samsung	JS9500	78"	Cd-free QD	SUHD Film	All EU
Samsung	JS9500	88"	Cd-free QD	SUHD Film	All EU

These are widely available from many major retailers across all Member States in the EU market. We understand that these products are leading the market for high colour gamut displays in the EU market and globally. They are also highly energy efficient, with most models scoring an 'A' rating or higher. We further understand that in response to market demand, sales in the EU are forecast to increase by up to 10 times during 2016.

b. Please state if you agree with the detailed parameters mentioned by the three actors as relevant for enabling a comprehensive comparison of performance of the technologies (general performance and environmental performance). Please explain your views and if relevant specify other parameters that should be considered.

[35] http://www.samsung.com/uk/consumer/tv-audio-video/televisions/

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 sRGB colour standard triangle, but only cover 85% of the position of the standard triangle. In this case the display would only be able to show 85% of the sRGB standard colours, so the 85% coverage is the relevant performance measure. To effectively operate to a particular colour standard, a coverage of 90% to 100% is recommended.

The other key point when considering coverage of a colour standard is the colour space coordinate system that is used for the calculation. The CIE1931 colour space is not the best method since this colour space is not uniform with respect to green light and hence can produce exaggerated results. Comparison in the more uniform CIE1976 colour space is a more rigorous approach and one that is recommended by experts[36].

Note that displays are usually designed to optimise performance against one of the possible standards (see next section below). 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.

In terms of the environmental performance of Cd and Cd-free products, the primary consideration should be restricting the use of Annex II (RoHS) listed substances, including cadmium. The primary purpose of the RoHS Directive is to reduce and eliminate the use of Annex II listed substances in this category of products.

The hazards, long term health and environmental impacts of cadmium salts are well documented and detailed in the CLP Regulation (EC/1272/2008 Annex VI). These were the basis for inclusion of all cadmium based materials in the original RoHS (2002) and for a 10 fold lower threshold (0.01%w) than for any other listed substances like mercury and lead. The use of cadmium presents serious risks throughout the life cycle of display and lighting products including manufacturing, distribution, consumer use and waste disposal/recycling.

Cadmium-free QDs are materials that are not restricted under RoHS, so the development and use of these materials instead of cadmium is permitted and encouraged under the RoHS Directive.

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.

Note that as energy efficiency is covered by separate EU legislation, it should only be regarded as a secondary factor in conducting a review under RoHS (see Recital 13 RoHS).

[36] "The NTSC Color Triangle Is Obsolete, But No One Seems to Know", Seyno Slutyerman, SID 5/06 p8-9

In addition, secondary effects of energy efficiency (such as associated emissions) should be excluded from the analysis. This is because these are covered by separate EU legislation, which is rapidly changing as the EU moves to a more sustainable energy policy (see Recital 13 RoHS). Also, in section 7.6.5 of the previous final report from Öko-Institut, the consultants criticised the calculation basis and logic concerning claimed energy savings, reductions in CO_2 and cadmium emissions put forward by the Applicants. In conclusion they noted that: *"In general, though the consultants can follow that benefits, in terms of emission reductions and benefits derived from lower energy consumption during use, might be possible for the Cd QD technologies, the provided information from both sources does not allow quantifying the degree of this benefit, nor comparing it with the respective benefit that is relevant for other display technologies."*

c. The various actors mention the following standards among others as relevant for comparing the technologies used in display applications: NTSC and Adobe RGB as well as the REC 2020 standard that is understood to be in adoption stages. Please comment as to the suitability of these standards for comparing QD technologies in display applications.

The relevant colour standards for displays are:

i. **sRGB / Rec. 709 (1990/1996)**
The standard most widely referred to by computer monitor manufacturers is sRGB. This has the same colour space as Rec. 709, which is the most widely used standard for TV media content, including High Definition (HD).

ii. **DCI-P3 (2012)**
The standard most widely referred to by leading TV manufacturers is DCI-P3, which has been developed for digital cinema[37] and widely adopted. This represents the highest quality media generally available. Samsung is the market leader in QD televisions and has optimised its SUHD range using the DCI standard. Hence DCI should be regarded as the market standard for high colour gamut displays today. World-leading computer company Apple has also chosen to focus on DCI-P3 as the colour standard for its new range of iMac products[38].

iii. **Adobe RGB (1998)**
Designed for computer displays to cover most of the colours achievable on CMYK colour printers. It improves on the gamut of the sRGB colour space mainly in green hues. It requires special software and a complex workflow in order to utilize its full range when the media content is recorded using sRGB. Generally this standard is more relevant for computer monitors than for televisions.

iv. **NTSC (1953)**
This is an outdated standard that was replaced by Rec. 709 for television media many years ago[39]. It is still referred to by some manufacturers, but media content is not recorded using this standard.

[37] http://www.dcimovies.com/
[38] https://medium.com/backchannel/exclusive-why-apple-is-still-sweating-the-details-on-imac-531a95e50c91#.zadzbp28j
[39] "The NTSC Color Triangle Is Obsolete, But No One Seems to Know", Seyno Slutyerman, SID 5/06 p8-9

Note 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.

The other standard that is sometimes referred to is Rec. 2020. However, this is a future standard that has not yet been adopted by the industry, and the colour standard for Rec. 2020 is still under development. Indeed, even cadmium QD manufacturers have been calling for changes to this colour standard to make it more achievable[40]. There are no commercially available cadmium QD TVs that achieve >90% of the currently proposed colour gamut for Rec. 2020.

In fact, the latest industry standard for televisions and recorded media, **Ultra HD Premium**, has just been announced by the UHD Alliance (UHDA)[41]. The UHDA membership includes leading display and media companies including Samsung, LG, Sony, Panasonic, TCL, Hisense, Philips, Disney, Universal, Warner Bros, Netflix and Amazon[42]. It also includes Nanosys, one of the previous Applicants. The new standard requires displays to achieve >90% of DCI-P3 colour gamut, providing further strong evidence that DCI-P3 will be the main focus for wide colour gamut display products in future.

---

[40] Interview with Nanosys. http://www.displaydaily.com/content/videos/451-display-week-2015-video-news/24872-nanosys-calls-for-rec-2020-change-and-explains-cadmium-issue

[41] http://arstechnica.co.uk/gadgets/2016/01/just-after-you-bought-a-4k-tv-for-christmas-uhd-alliance-announces-uhd-premium/

[42] http://www.uhdalliance.org/members/

3. Please specify on the basis of what regulations/standards a comparison of these technologies in relation to the performance of the relevant product (TV, display, tablet, mobile-phone, solid state illumination applications) can be made, in particular in relation to the consumption of energy during various use modes (standby and other operation modes, operation with different brightness/contrast settings; display of images with higher or lower contrast or differing hues; etc.)

- QD technologies only have impact on the active modes of operation in both display and lighting so standby modes can be discounted.
- Regarding display applications, colour performance should be compared against the Adobe RGB and DCI-P3 standards and the amount of coverage of the standard the display product can achieve. Displays optimised for Adobe RGB will likely have sub-optimal performance in DCI-P3 and vice versa due to the differing green peak wavelengths required by the two standards.
- Energy consumption comparison can be made via on mode consumption as determined by IEC62087-3.
- Regarding lighting applications, the following key parameter should be measured according to recognised international standards from CIE/IEC:
    - Correlated Colour Temperature (CCT) in Kelvin
    - Colour Rendering Index (CRI) (max. 100)
    - Luminous Efficacy (LES) in Lumens per Watt (lm/W).
    - The R9 index value (max. 100)
- Direct comparison of energy consumption per lumen of output should only be made of products with the same CCT and CRI. High CRI and high efficiency are conflicting requirements, so comparison of a high CRI product with one of lower CRI would not lead to a fair assessment. Note that R9 is an extension to the normal CRI index that measures the rendering of deeper red colours more accurately, which will again tend to reduce energy efficiency and should also be taken into account when comparing products.

4. At the time of the first review, it was understood from various stakeholders that the Cd-based and Cd-free quantum dot technologies were also being developed for possible future use in solid-state illumination applications. The two applicants and a manufacturer of a substitute candidate have provided information regarding applications that are already on the market using the Cd based and Cd free technologies. Please review this information and comment:

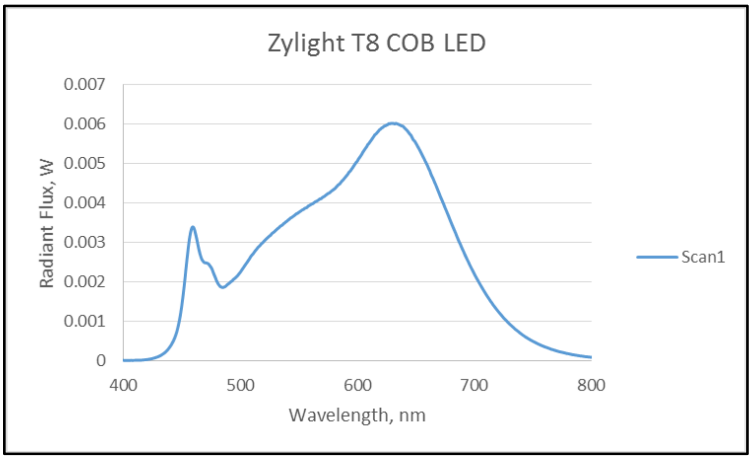
a. If additional lighting products (solid state illumination) have become available on the EU market since 2014.

Product availability that we are aware of in the EU is shown below:

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:



Our conclusion is that this light **does not use cadmium QD technology** and probably uses 1 or more non-QD phosphor materials. Also, when we tested a sample luminaire we found that it had a very low efficiency (LES) of only 36.7 lm/W.

At the Lux Live exhibition this year, Nanoco demonstrated 4 product ranges. 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. Lux listed the Orion QD light in its 'Top Ten' innovations in the show[43]. Lux also put Nanoco in its 2015 Global Hotlist of most exciting light firms[44].

Our conclusion is that there are **no** cadmium QD lighting products available in the EU market, whereas 2 commercial cadmium-free products are available and further products have been demonstrated publicly and are due to launch in 2016.

Submissions from Lighting Europe and Philips Lumiled have also been made to the consultation[45]. Both of these refer to the future introduction of cadmium QD lighting products into the EU market, possibly from some time in 2016. However, they also both confirm that there are **currently no commercial cadmium QD lighting products available to assess**, and not even any firm launch dates for possible future products.

b. Please clarify for Cd-based and Cd-free products as described in a), what parameters are relevant for enabling a comprehensive comparison of performance to clarify how the technologies compare in relation to performance in general and in particular to environmental performance;

The main measures for technical performance comparison of LED lighting products are:

I. **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.
II. **Colour Rendering Index (CRI)** is a quantitative measure (max. 100) of the ability of a light source to show the colours of various objects correctly in comparison with an ideal or natural light source.
III. **Luminous Efficacy (LES)** is the amount of light flux produced for the electrical power consumed, measured in Lumens per Watt (lm/W).
IV. **The R9 index value** (max. 100) is a measure of the red component in a light, which is essential for producing more natural looking colours from artificial lights. The R9 value is not included in the standard CRI index.

In relation to environmental performance, the issues are essentially the same as for the use of cadmium in display products. The primary consideration should be restricting the use of Annex II (RoHS) listed substances, including cadmium. The primary purpose of the RoHS Directive is to reduce and eliminate the use of Annex II listed substances in this category of products.

The hazards, long term health and environmental impacts of cadmium salts are well documented and detailed in the CLP Regulation (EC/1272/2008 Annex VI). These were the basis for inclusion of all cadmium based materials in the original RoHS (2002) and for a 10 fold lower threshold (0.01%w) than for any other listed substances like mercury and lead. The use of cadmium presents serious risks throughout the life cycle of display and lighting products including manufacturing, distribution, consumer use and waste disposal/recycling.

---

[43] http://luxreview.com/article/2015/09/10-product-innovations-to-look-out-for-at-luxlive-2015
[44] http://luxreview.com/article/2015/10/-global-hotlist-of-lighting-firms-unveiled-
[45] http://rohs.exemptions.oeko.info/index.php?id=265

Cadmium-free QDs use materials that are not restricted, so the development and use of these materials instead of cadmium is permitted under the RoHS Directive.

The secondary factor for the environmental life-cycle performance of displays is their energy efficiency (LES) for a comparable specification product. For general lighting products this should take into account the colour temperature (CCT), colour rendering index (CCT) and R9 value. Energy labelling is intended to encourage consumers to use more energy efficient products for a given quality of light. Note that for some specialised lighting products, such as horticultural lights, the performance and efficiency parameter will be different and unique to the application.

Note that as energy efficiency is covered by separate EU legislation, it should only be regarded as a secondary factor in conducting a review under RoHS (Recital 13 RoHS).

In addition, secondary effects of energy efficiency (such as associated emissions) should be excluded from the analysis. This is because these are covered by separate EU legislation, which is rapidly changing as the EU moves to a more sustainable energy policy (Recital 13 RoHS). Also, in section 7.6.5 of the previous final report from Öko-Institut, the consultants criticised the calculation basis and logic concerning claimed energy savings, reductions in CO_2 and cadmium emissions put forward by the Applicants. In conclusion they noted that: *"In general, though the consultants can follow that benefits, in terms of emission reductions and benefits derived from lower energy consumption during use, might be possible for the Cd QD technologies, the provided information from both sources does not allow quantifying the degree of this benefit, nor comparing it with the respective benefit that is relevant for other display technologies."*

c. Please state if you agree with the detailed parameters mentioned by the three actors as relevant for enabling a comprehensive comparison of performance of the technologies (general performance and environmental performance). Please explain your views and if relevant specify other parameters that should be considered.

Our case is presented in the answers given above.

We would like to add that it is clearly not possible to carry out any comparison of the performance of commercial cadmium QD lighting products with commercial cadmium-free QD lighting products because there are **no cadmium QD lighting products on the EU market**. This is despite the fact that it is now more than 6.5 years after Exemption 39 was enacted, and even longer since it was originally applied for. In contrast, cadmium-free lighting products are now available and are generating a lot of market interest that should see the number of products and volume of sales growing rapidly.

Under these circumstances, it is clear that an extension of Exemption 39 cannot be legally justified for lighting products. It is possible that a new Exemption application could be made in future, by Philips Lumiled or others, when they have completed the development of their products so that they can be properly assessed and compared with RoHS compliant alternatives, which will include both cadmium-free QDs and non-QD phosphor technologies. However, there is every indication that RoHS compliant technologies will be able to offer similar benefits in terms of improved lighting quality and energy efficiency over the same 1-2 year development timescale proposed by Philips Lumiled, given that cadmium-free QDs and some improved phosphor products are already commercially available.

5. The applicants and a manufacturer of a substitute candidate have provided information as to the compounds used in Cd-free and Cd-based technologies relevant to the exemption requests, and as to their potential hazardousness and toxicity. Please state with which of the views presented you agree or disagree and explain why;

APPLICANT'S ARGUMENT	NANOCO COUNTER-ARGUMENT
QD Vision states that alternative QD materials to Cd-based QDs are solely based on InP and, as such, assesses the hazards of InP.	As detailed in section 6. There are a number of alternatives to cadmium QDs that do not use InP. Nanoco CFQD® quantum dots are not made from InP, but from alloys containing indium and other metallic and non-metallic elements. Therefore, the hazards of the material are not the same as for InP. Accredited toxicology testing has shown Nanoco CFQD® quantum dots to be, according to EU GHS – CLP: EC1272/2008, "Not classified" for acute (oral) toxicity, skin and eye irritation, acute fish toxicity and acute daphnia toxicity. Ames and micronucleus testing has not shown any genotoxicity or mutagenicity, which would be the key concerns for any similarity to InP carcinogenicity. The organic content was also shown to be readily biodegradable. Classification of CFQD® quantum dots is limited to Skin Sensitisation (Category 1b) based on a weak positive result for Red CFQD® quantum dots only.
QD Vision expects InP compounds to become progressively less available on the market, due to future inclusion in substance restrictions under RoHS and REACH, and due to difficulty in recycling.	InP is not restricted under RoHS or REACH and it is only a 4th priority substance for possible future review under RoHS. A review has not yet been scheduled and the outcome should not legally be pre-judged. Also, InP is a compound composed of indium and phosphorus. When InP is burned or dissolved, the indium and phosphorus are separated and form different compounds that are not classified as carcinogenic, so the hazard is already neutralised before exposure can occur. With regards to recycling, the main source for cadmium recycling relates to cadmium-nickel batteries. Despite an end-of-life recycling rate for cadmium of 15%,[46] 2016 targets for battery recycling, under the Batteries Directive,[47] are unlikely to be met by most countries in the EU.[48] This clearly shows that despite a great deal of effort and publicity, the recycling of cadmium from an easily identifiable, well labelled and concentrated source (NiCad batteries) is alarmingly low. If we then consider the potential for recycling efficiency from displays, it is likely that it will be much lower than for batteries. The manufacturers do not currently identify that the products contain cadmium, so consumers and recycling companies will not even know it is present. The display would need to be completely dismantled (which is very likely to break the glass capillary used for 'on-edge' designs) and the cadmium containing components correctly identified and segregated for separate and specialised recycling. This will be expensive and potentially hazardous for the operatives, raising the probability that companies and individuals

[46] UNEP: Recycling Rates of Metals, 2011, p. 38
[47] 2006/66/EC
[48] http://www.euractiv.com/general/eu-set-battery-directive-targets-news-508303 (accessed 09/12/15)

	will not see it as in their interests to carry it out. It is therefore most likely that cadmium QD displays will either be incorrectly disposed of or, if they are recycled, that the cadmium components will not be segregated and recycled – but instead will contaminate the recycling route for other electronic materials. Some of the same recycling identification challenges will apply to cadmium-free QD components, but these do not carry the serious, persistent and bio-accumulative hazards of cadmium. Indeed, the risk is that cadmium QD components will be incorrectly identified and processed with cadmium-free QD components, contaminating the recycled material. Similar concerns apply to lighting products. The EEB support a move from mercury containing fluorescent lights to LEDs that do not contain RoHS restricted materials[49]. Only 45% of lights are recycled and even these create exposure hazards. One of the key environmental advantages of LED lighting will be lost if they contain cadmium, which RoHS recognises to be a more serious risk than mercury.
Table 3 of QD Vision's Supplemental Statement on Life Cycle Analysis compares the amount of cadmium in an on-edge component to InP in an on-surface component, claiming 40 times more Cd-free material is required. It is later claimed that InP QDs can only be used in on-surface films due to limits on their operating lifetime under heat and flux.	Table 3 does not show a like-for-like comparison, since it compares the amount of elemental cadmium, a constituent of the compound CdSe, to the amount of the compound InP. Further, the data imply that all Cd-based displays use the 'on-edge' configuration, whereas several Cd-based displays have used an 'on-surface' film, as promoted by the Applicants 3M. They already presented evidence in 2013 that the film design would be the preferred option for many manufacturers and applications using cadmium QDs. We disagree that InP (or Cd-free QDs in general) cannot be used on-edge. Nanoco's decision to develop on-surface films is based on customer preference rather than technical limitations. The film design is much more robust than the glass capillary and requires much less redesigning of the display. It also allows the display to use an array of LEDs for back-lighting. This allows for local area dimming, to improve the contrast ratio and provide high dynamic range (HDR). It also allows for greater energy saving by dimming the LEDs in darker areas of the picture.
3M states that it believes it is difficult to determine if a CdSe core QD is more toxic, less toxic, or equally toxic to an indium phosphide core QD, since both cadmium and indium phosphide have significant human health hazard classifications.	A study comparing the toxicity of CdSe/ZnS QDs and InP/ZnS QDs *in vitro* and *in vivo* concluded that almost identical amounts of Cd^{2+} and In^{3+} leached from the QD cores, and that In^{3+} had a "much lower intrinsic toxicity compared to Cd^{2+}".[50] *In vitro* toxicity testing performed by University College London, comparing Nanoco's CFQD® quantum dots to commercially available CdSe/ZnS QDs, showed a 70 % reduction in the viability of mouse cells after 24 and 48 hours of incubation at a QD concentration of 40 nM, *i.e.* only 0.007 wt. %. For CFQD® quantum dots, no reduction in cell viability was observed over 48 hours at concentrations up to 40 nM (see Fig.2 below).

[49] http://www.eeb.org/index.cfm/library/environmental-ngos-response-to-stakeholder-consultation-2015-2-on-mercury-containing-lamps/

[50] V. Brunetti, H. Chibli, R. Fiammengo, A Galione, M.A. Malvindi, G. Vecchio, R. Cingolani, J.L. Nadeau and P.P. Pompa, *Nanoscale*, 2013, **5**, 307

	A study into the median lethal concentration (LC_{50}) of In^{3+} and Cd^{2+} ions in *Macrobrachium Nipponense* (freshwater shrimps) found that the LC_{50} of In^{3+} was almost 130 times higher (i.e. less toxic) than that of Cd^{2+} after 96 hours.[51] Soenen *et al.* studied the cytotoxicity of InP/ZnS QDs,[52] using the Alamer Blue assay. No increase in cytotoxicity was observed up to at least 7 days, suggesting the high chemical stability of Cd-free QDs. This was contrasted to Cd-based QDs, which have previously been reported to degrade under endosomal pH conditions, suggesting that the differences between the crystal structures of Cd-free and Cd-based QDs may influence their cytotoxicity, with some Cd-free QDs being very robust against environmental factors such as oxidation.
QD Vision and 3M both argue that there is no risk to workers/the consumer of exposure to CdSe from their products under normal use. They also argue that CdSe is much safer than other cadmium compounds due to low solubility.	There is still a risk to the worker/consumer/environment if the device becomes damaged, *e.g.* (for QD Vision TVs) if the fragile glass capillary component breaks, in a house fire, or in landfill. Data from QD Vision's Quantum Light™ optic, comprising CdSe/ZnS QDs embedded in acrylate polymer and encapsulated between borosilicate glass showed that exposure to 1 M nitric and gastric acids may destroy the ZnS shell, facilitating the acid etching of the CdSe core to liberate Cd.[53] A Cd release of 1.10 – 1.20 mg/g polymer was observed. It is envisaged that similar conditions could be encountered in a landfill environment. See also the evidence that exposure to cadmium occurs in waste recycling facilities (see e.g. paper from German Federal Agency for Workers Protection 2011[54] stating that concentration in the air of cadmium from electronics recycling is above the acceptable risk level). It should be noted that inhalation of cadmium oxide from burning cadmium compounds, as could occur in a house fire or in poorly controlled waste disposal/recycling operations, is rapidly fatal at a dose of only 20 mg for an adult.[55] This is only $1/10^{th}$ of the 200 mg limit that proposed Ex.39(b) allowed for in a large ($1m^2$) TV, so there could be enough cadmium in a TV to kill 10 people. A recent study has compared the toxicity of CdSe QDs with highly soluble cadmium chloride ($CdCl_2$)[56]. QDs were administered orally and it was concluded that the transit through the gastrointestinal tract, with its low pH conditions, could contribute to the QD degradation process to generate cadmium ions. Though the harmful effects of CdSe QDs were observed at higher levels than those of $CdCl_2$, CdSe QDs nevertheless induced toxic and genotoxic

[51] J.-L. Yang, *Biol. Res.*, 2014, **47**, 13

[52] S.J. Soenen, B.B. Manshian, T. Aubert, U. Himmelreich, J. Demeester, S.C. De Smedt, Z. Hens and K. Braeckmans, *Chem. Res. Toxicol.*, 2014, **27**, 1050

[53] J. Liu, J. Katahara, G. Li, S. Coe-Sullivan and R.H. Hunt, *Environ. Sci. Technol.*, 2012, **46**, 3220

[54] https://www.baua.de/de/Themen-von-A-Z/Gefahrstoffe/Arbeiten-mit-Gefahrstoffen/pdf/Elektronikschrottrecycling.pdf?__blob=publicationFile&v=2

[55] Derived from NIOSH fatal dose data: http://www.cdc.gov/niosh/idlh/7440439.html and adult respiration rate data from Californian EPA : http://www.arb.ca.gov/research/resnotes/notes/94-11.htm

[56] M. Alaraby, E. Demir, A. Hernández, R. Marcos, Assessing potential harmful effects of CdSe quantum dots by using Drosophila melanogaster as in vivo model, Science of the Total Environment 530–531 (2015) 66–75

	effects, along with changes to the level of oxidative stress and in the expression of different genes involved in stress response. They concluded that: "Cd, regardless of form, induces significant disturbances to cells that can be detected at molecular level." And "Cd based QDs are toxic, and induce oxidative stress and deregulation of gene expression as well as damage to DNA … The increased use of [Cd-based] QDs may affect human health after short- and long-term exposures."

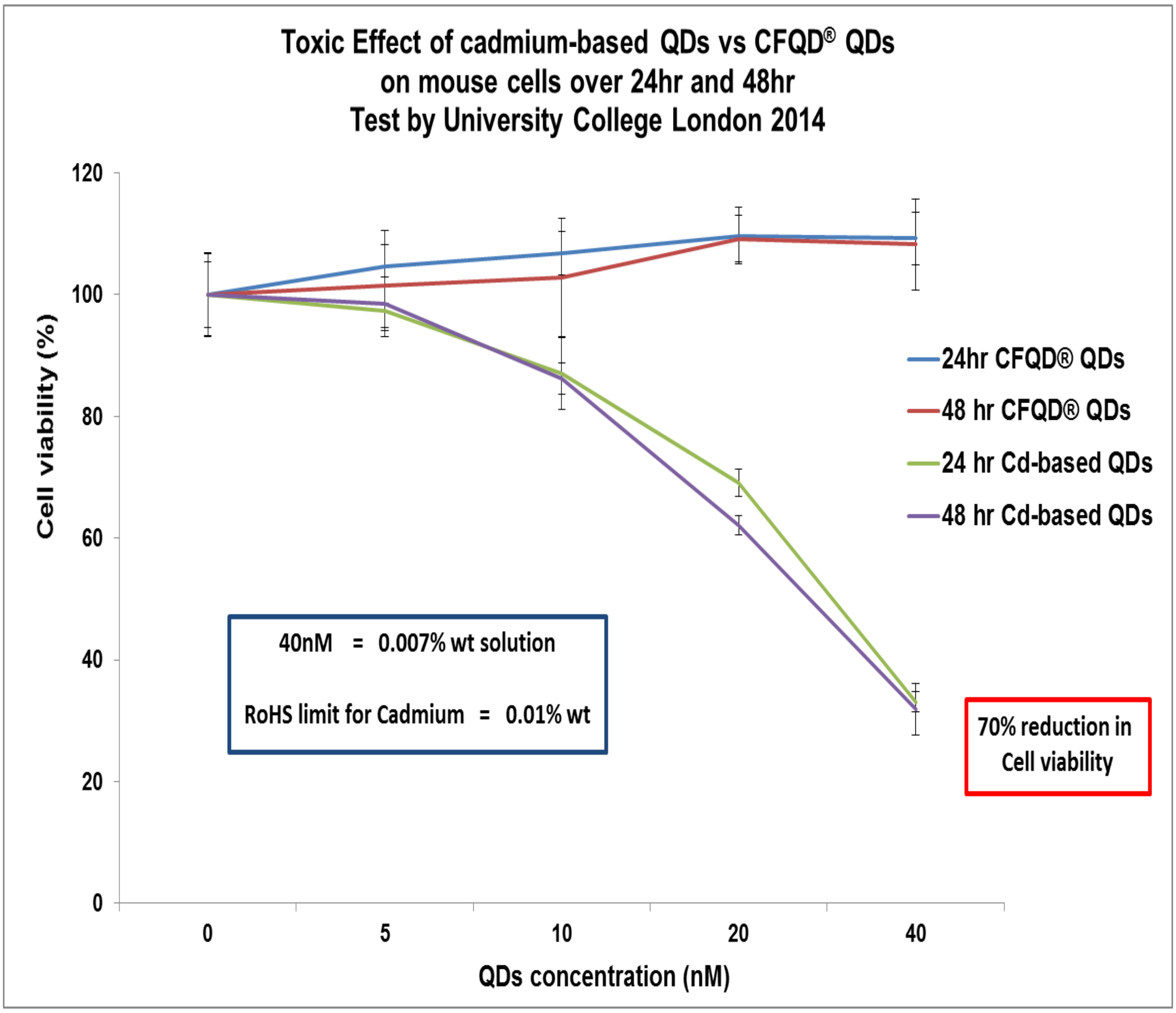


Figure 2: In vitro cell viability versus QD concentration, for CdSe/ZnS QDs and CFQD® quantum dots.

6. Please provide information as to research initiatives which are currently looking into the development of possible alternatives for some or all of the application range of Cd in the scope of the requested exemptions (and among others in the scope of Ex. 39);

a. Please explain what part of the application range is of relevance for such initiatives (in what applications substitution may be possible in the future).

Alternatives to Cd-based QD colour-converting materials include 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.[57] 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[58,59].

OLED

- OLED technology can be integrated into displays and lighting.
- The technology is complementary to colour-converted QD technology.
- OLED display and lighting products are already available on the EU market.
- 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[60].

IPS Quantum Display

- IPS Quantum Display technology, developed by LG, uses potassium- and nitrogen-based compounds in combination with a blue LED.[61]
- The technology can be used to achieve 98% of the DCI colour standard, and is currently available in LG G4 smartphones.

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:

---

[57] http://www.qled-info.com/introduction/ (accessed 09/12/15)
[58] C. Ippen, T. Greco and A. Wedel, *J. Info. Display*, 2012, **13**, 91
[59] B. Chen, H. Zhong, W. Zhang, Z. Tan, Y. Li, C. Yu, T. Zhai, Y. Bando, S. Yang and B. Zou, *Adv. Funct. Mater.*, 2012, **22**, 2081
[60] http://www.flatpanelshd.com/news.php?subaction=showfull&id=1448894534
[61] http://www.pocket-lint.com/news/133728-lg-g4-ips-quantum-display-explained-how-is-it-different-to-a-normal-lcd (accessed 10/12/15)

- Apple have 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[62].
- TriGain™ Phosphor from GE[63]. GE claims a 32% improvement in luminous efficiency at CCT of 4000K compared to a conventional high CRI LED. This is $K_2SiF_6:Mn^{4+}$ 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[64].
- Sharp produce 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[65].
- Dexerials have 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[66].
- $Sr[LiAl_3N_4]:Eu^{2+}$ phosphor[67]. This paper demonstrates a 14 % increase in luminous efficacy compared with a commercially available high CRI LED.

Considering the different types of cadmium-free QD technology:

Cd-FREE NANOPARTICLES	POTENTIAL APPLICATIONS	ADVANTAGES
CFQD® quantum dots	Colour-converted displays and lighting; QLED	• Tuneable emission across visible spectrum • Relatively narrow FWHM
InP-based QDs	Colour-converted displays and lighting; QLED	• Tuneable emission across visible spectrum • Relatively narrow FWHM
I-III-VI-based nanoparticles, *e.g.* $CuInS_2$; $AgInS_2$	Colour-converted lighting; QLED	• Heat stable • Large absorption coefficients • Long photoluminescence lifetimes • Versatile band gap tuning by manipulation of particle size, elemental compositions and alloying with different semiconductors • Reduced reabsorption due to larger Stokes shifts • Tuneable emission across visible spectrum
Transition metal doped II-VI	Colour-converted lighting; QLED	• No reabsorption • Heat stable

[62] https://medium.com/backchannel/exclusive-why-apple-is-still-sweating-the-details-on-imac-531a95e50c91#.zadzbp28j
[63] http://www.gelighting.com/LightingWeb/na/images/MISC020-GE-TriGain-Phosphor-for-LED-Screens-Whitepaper_tcm201-100804.pdf
[64] http://techon.nikkeibp.co.jp/english/NEWS_EN/20131217/323134/
[65] 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 © 2015 ITE and SID
[66] Y. Ito et al, A backlight System with a Phosphor Sheet Providing both Wider Color Gamut and Higher Efficiency, SID Digest, 2013, ISSN 0097-966X/13/4402-0816
[67] P. Pust et al, Narrow-band red-emitting Sr[LiAl3N4]:Eu2+ as a next-generation LED-phosphor material, nature materials, June 2014, DOI: 10.1038/NMAT4012

nanoparticles, *e.g.* Zn(S,Se):(Mn,Cu)		• Higher resistance to photo-oxidation
Group III nitrides, *e.g.* GaN; InGaN; InN; Zn_3N_2	Colour-converted displays and lighting; QLED; QD laser diodes (QLD)	• Tuneable emission across visible spectrum • Chemical stability
Silicon	Colour-converted lighting; QLED	• Abundant element • Tuneable emission across visible spectrum • Good compatibility with the existing large silicon electronics market
Carbon-/2D material-based QDs	Colour-converted displays and lighting; QLED	• Tuneable optoelectronic properties through creation of multilayer structures • Formation of hetero-structures with no lattice parameter constraints • Reduced reabsorption due to larger Stokes shifts

b. Please provide a roadmap of such on-going research (phases that are to be carried out), detailing the current status as well as the estimated time needed for further stages.

Before considering the roadmap for cadmium-free solutions, it must be noted that for lighting there are <u>no</u> commercial cadmium QD products available – even though it is now 18 months past the scheduled end of Ex.39. Clearly a roadmap is also required for the development of cadmium QD technology in lighting, with the earliest date for products being 2016 (according to Philips Lumiled submission). However, extending an Exemption to promote innovation using cadmium is clearly the opposite of the intended purpose of the RoHS Directive, which is to phase out the use of cadmium and other listed materials as soon as practical.

Cadmium-Free Nanoparticles

Cd-FREE NANOPARTICLES	STATUS
CFQD® quantum dots	Lighting products already available on the EU market, e.g. Marl's Orion QD and Budmaster Cropmaster QD. Display materials commercially available from Nanoco (UK) and Dow (Korea). Display products expected on the EU market in 2016.
InP-based QDs	Display products are already on the EU market, *e.g.* Samsung's SUHD TVs. Integration into lighting products is feasible now.
I-III-VI-based nanoparticles, *e.g.* $CuInS_2$; $AgInS_2$	Available to purchase in small quantities from several manufacturers.[68,69] Prototype QD-LEDs have already been reported[70,71]

[68] http://www.ubiqd.com/page2.html (accessed 09/12/15)
[69] http://www.nn-labs.com/product-catalog/cis/ (accessed 09/12/15)
[70] J Zhang, R Xie, W Yang, A Simple Route for Highly Luminescent Quaternary Cu-Zn-In-S Nanocrystal Emitters, Chemistry of Materials, April 1, 2011
[71] WS Song, H Yang, Fabrication of white light-emitting diodes based on solvothermally synthesized copper

	Integration into lighting products expected within 2-3 years.
Transition metal doped II-VI nanoparticles, *e.g.* Zn(S,Se):(Mn,Cu)	Available to purchase in small quantities from at least one manufacturer.[72] Integration into lighting products expected within 2-3 years.
Group III nitrides, *e.g.* GaN; InGaN; InN; Zn_3N_2	Scale-up of synthesis may need to be addressed. Integration into lighting products expected within 5 years.
Silicon	Early stage of development. Method of reproducible synthesis and mass-manufacture needs to be developed. Expect to appear in lighting products in the longer-term, *e.g.* 5 years +.
Semiconductor/2D material-based QDs	Early stage of development. Method of reproducible synthesis and mass-manufacture needs to be developed. Expect to appear in display and lighting products in the longer-term, *e.g.* 5 years +.

QLED

- Improvements in optical performance (luminance and efficiency) required.
- Envisage 3 – 5 year development for commercial QLED products.

OLED

- Small and larger area OLED devices are already available on the EU market, *e.g.* Samsung Galaxy S6 Edge+ smartphone and LG Smart 3D Ultra HD Curved OLED TV, both available from major retailers across all EU Member States.
- OLED lighting products are already available on the EU market, *e.g.* LG Chem OLED lights available from Plus Opto.[73]

IPS Quantum Display

- Small area devices are already commercially available, *e.g.* LG G4 smartphone, available from major retailers across all EU Member States.
- LG have not yet released information as to the scalability of the technology and whether it is likely to be integrated into larger area devices and/or lighting products.

indium sulfide quantum dots as color converters, Applied Physics Letters 100, 183104 (2012)
[72] http://www.nn-labs.com/product-catalog/d-dots/ (accessed 09/12/15)
[73] http://www.plusopto.co.uk/led-lighting/oled-lighting.aspx (accessed 10/12/15)