Nanoco Response to 1st Questionnaire Regarding CdQD Exemptions:

Ex. Re. No. 2013-2 for "Cadmium in colour converting II-VI LEDs (< 10 µg Cd per mm2 of light-emitting area) for use in solid state illumination or display systems" (Request for renewal of Exemption 39 of Annex III of Directive 2011/65/EU)
Ex. Re. No. 2013-5 for "Cadmium in light control materials used for display devices"

Abbreviations and Definitions

Cd	Cadmium
QD	Quantum dots

Questions + *Answers*

1. 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. Please provide information:
    a. Regarding the availability of Cd-based and Cd-free products for display applications using these technologies that have become available on the market since the review was finalised in 2014, please specify what products have become available (display type, dimensions and other characteristic aspects for clarifying the performance class).

Answer:
Cadmium-free QD Displays available in EU as of October 2015 include:

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

Further Samsung models using Cd-free QD technology are also available.

The commercial availability of Cd-free QD materials and components is now well established:

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

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.

Other cadmium-free display technologies (non-QD) include:

i) 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.

ii) Colour filter technology is improving, which enables LED/phosphor technology to achieve higher colour standards.

iii) 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.

iv) Other technologies continue to emerge. For example the IPS Quantum display technology used on the LG G4 mobile phone.

Cadmium-based QD Displays available in EU from 2014 to October 2015:

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

Announcements have been made about one or two other Cd-based QD display products being launched soon in the EU, such as a Philips 27" computer monitor. However, we were not able to find these on sale in the EU at the time of this letter.

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, the Asus laptop computer has been available only in small numbers through a few specialist outlets. Similarly, the Thomson TV has only been available in limited numbers through a few retailers in a few EU states.

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We believe that Cd-free QD displays have an overwhelming market share compared to Cd-based QD displays.

b. For products mentioned in a, please clarify if products are still on the market or please explain why distribution was discontinued;

Answer:
All the cadmium-free QD displays listed are still widely available across all EU states and are being sold in large numbers.

The Sony KDL-55X9000A and the Kindle Fire HDX were discontinued in 2014. We are not able to say for sure why, but we believe that the Sony replacement used cadmium-free rare earth doped phosphors instead of cadmium QDs.

The Asus Zenbook NX500 laptop and Thomson UA9806 TV are currently available in very limited quantities in only a few EU states. It is not clear why supplies are so limited, whether by technical or commercial factors.

c. 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;

Answer:
The main reason for using QD technology in display products is to provide improved colour gamut. However, the required colour gamut is determined by the colour standards used by the display and media industries, as extra colour capability can only be used when there is content available that has been encoded with the appropriate colour data. Also, it is necessary to differentiate between area and coverage. The colour triangle area of a display could be 110% of the area of the NTSC colour standard triangle, but only cover 85% of the position of the standard triangle. In this case the display would only be able to show 85% of the NTSC standard colours, so the 85% coverage is the relevant performance measure.

The 3 relevant colour standards for displays are:
i) DCI (P3)
The standard most widely referred to by leading TV manufacturers is DCI P3, which has been developed for digital cinema. This represents the highest quality media generally available.

ii) sRGB (Rec. 709)
The standard most widely referred to by computer monitor manufacturers is sRGB, which has the same colour space as Rec. 709 that is also used for TVs.

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iii) NTSC

Generally regarded as a secondary standard, but is more commonly used in certain markets.

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 standard 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 standard to make it more achievable.

In terms of the environmental performance of Cd and Cd free products, the primary consideration should be annex II (RoHS) listed substances. The hazards, long term health and environmental impacts of cadmium salts is well documented and detailed in CLP Regulations (EC/1272/2008 Annex VI). These were the basis for inclusion in the original RoHS (2002) and for a 10 fold lower threshold (0.01%w) than for any other listed substance. The use of Cadmium presents serious risks right through the life cycle of display and lighting products including manufacturing, distribution, consumer use and waste disposal/recycling:

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.

d. For the products mentioned in a), please provide detailed information as to the parameters specified in c), including for example performance related to energy consumption, light and colour output parameters, comparison of hazardous material aspects; etc.

Answer:

Manufacturers do not publicly provide this level of detail. However, the table below provides a comparison of energy efficiency using published data:

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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
Panasonic Viera TX-55AX630B	Non-QD	55”	160	115	A	http://www.currys.co.uk

Higher colour range displays inherently use more energy than standard displays, because the relative sensitivity of the human eye to purer green and red light is lower. The greater light efficiency of a display using cadmium-free QDs allows for high colour range displays to be produced with a similar or overall lower power consumption compared to standard colour, conventional UHD televisions. This has now been commercially demonstrated by the Samsung range of SUHD TVs using Cd-free QD technology, which achieve an ‘A’ rating for energy efficiency. In fact the energy consumption of the Samsung JS9000 is lower than some comparable TVs with lower colour gamut using standard LED/phosphor technology, such as the Panasonic TV included in the table for reference.

Cd-based QD technology should, in theory, be able to provide similar energy performance, but claims that it can save 20-30% more energy than Cd-free QDs in displays have not been proven in commercial products in the EU. In fact, the Sony Cd-based QD TV used 41% more energy than the equivalent Samsung TV and was only ‘B’ rated. The Thomson Cd-Based QD TV, although also ‘A’ rated, uses 7% more power per year than the Samsung Cd-free QD model and 2.5% more than the Panasonic ‘standard LED’ model.

Colour performance is harder to assess from public information and testing is not as well standardised as for energy efficiency, so Nanoco has carried out internal testing to provide a consistent comparison:

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

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Using the current industry standard DCI-P3 colour measure (developed for digital feature films) and CIE 1976 colour space, the Sony Cd-based QD TV scored 95%, but the Samsung Cd-free QD TV was even better at 97%. This clearly shows that Cd-free QD technology is fully capable of delivering high colour performance as well as, or better than, cadmium. This is also supported by internal test data produced by Nanoco on display films using CFQD® QDs, which has shown figures up to 99% of DCI-P3.

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

e. If possible, please provide a comparison of similar products of the two technologies to support your views as to if the exemption requests mentioned above are justified according to the Article 5(1)(a) criteria.

Answer:
The data presented above demonstrates that Cd-free QD technology is able to provide the high levels of colour performance that the market is looking for, as measured by the leading colour standard DCI-P3. While Cd-based QD technology is also able to meet the required colour standard, it does not have any unique performance that would justify an Exemption.

Similarly, Cd-free QD technology as demonstrated in commercial TV products has shown that it can provide high colour and high energy efficiency, equalling or exceeding comparable TVs using conventional LED/phosphor technology. In contrast, Cd-based QD products have shown lower energy efficiency than either Cd-free QD or conventional LED/phosphor models. This is despite claims in the last RoHS review that they would save 20-30% of the energy used. Again, this shows that there is no justification for an Exemption.

2. 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 lighter or darker hues; etc.) or darker

Answer:
Comparison of power consumption should be made using regulated and/or industry standard test methods. However, it should be noted that luminance can be effected by the colour temperature of the white image. Also, the luminance is affected by the purer green and red colours used in high colour gamut displays. Because the human eye is less sensitive to the

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wavelengths of light, the luminance appears less even when the same number of photons of light are being emitted.

The Energy Labelling Directive 2010/30/EU provides the standard for energy efficiency testing and labelling for many consumer products in the EU. Commission Delegated Regulation (EU) No. 1062/2010 specifies the requirements for televisions.

The Eco-design Directive 2009/125/EC established a framework for the setting of eco-design requirements for energy-related products. Commission Regulation (EC) No 642/2009 specifies the eco-design requirements for televisions.

The EU Energy Star system is a voluntary energy labelling scheme for office equipment. With the ENERGY STAR logo, consumers can easily identify energy efficient products. It covers office computers displays screens. ENERGY STAR was first started by the US Environment Protection Agency in 1992. The EU agreed to take part in 2001 to include office equipment not carrying an EU energy efficiency label.

LED Lighting is covered by Commission Regulation (EU) 2015/1428 with regard to eco-design requirements for non-directional household lamps and Commission Regulation (EC) No 1194/2012 is the implementation of Directive 2009/125/EC with regard to eco-design requirements for directional lamps, for light emitting diode lamps and related equipment.

3. 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 use in the future in solid-state illumination applications. Please provide information:
    a. Please clarify if lighting products (*solid state illumination)* have become available and if relevant provide detail for such products related to the aspects raised in the following questions.

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

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

The Nexus Par 30 LED was discontinued in 2013.

The Zylight F8-D LED Fresnel is the only Cd-based lighting product we have found available in the EU. However, this is a very expensive (>€2000ea) specialist theatrical spotlight for professional use only.

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At the Lux Live exhibition this year, Nanoco will be demonstrating 4 product ranges. A panel lamp, a strip light and a spot light for domestic and commercial use will be shown, each of which will be available in 3 colour temperatures. A horticultural lamp will also be shown in a strip light version and a panel lamp version is also being developed.

b. For products mentioned in a, please clarify if products are still on the market or please explain why distribution was discontinued;

Answer:
The reason for Nexus to discontinue their Par 30 LED lamp was not disclosed.
The Orion light from Marl is currently available, with new models being launched this year.

c. 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;

Answer:
The main measures for comparison of LED lighting products are:

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

d. For the products mentioned in a), please provide detailed information as to the parameters specified in c), including for example performance related to energy consumption, light and colour output parameters, comparison of hazardous material aspects; etc.

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Answer:
Further performance details will be provided during the public consultation period.

The environmental and material hazard comparisons for lighting are essentially the same as for Cd-free vs Cd-based QDs in displays.

e. If possible, please provide a comparison of similar products of the two technologies to support your views as to if the exemption requests mentioned above are justified according to the Article 5(1)(a) criteria.

Answer:
As for displays, Cd-based QDs in lighting products do not show any unique advantages over Cd-free QDs in lighting technical performance or energy efficiency. Hence, there is no basis for an Exemption under RoHS.

It is worth noting that more than 6 years after Exemption 39 was enacted, there is only one highly specialised and highly expensive Cd-based QD lighting product available in the EU market.

4. Regarding Cd-based QD materials that have been developed for use in articles relevant to the exemption requests above, please provide the following information:
   a. Please state what substances are used in Cd-based QD applications of relevance and clarify if such substances are currently in use in products that are available on the market in general and in particular that are expected to remain available on the market in the coming years;

   Answer:
   We believe that commercially available cadmium-based QD products use cadmium selenide cores with cadmium sulphide and/or zinc sulphide outer shells.

   We believe that cadmium telluride may be used as an alternative to cadmium selenide.

   b. If more than one type of Cd-based material is used in QDs in relevant applications, please provide information and data to allow a comparison of the performance of all alternatives (or at least of alternatives understood to be on the market or market ready by the end of 2015);

   Answer:
   We do not currently have this information. Manufacturers of Cd-based QDs should supply this information.

   c. Please provide information regarding hazardous properties related to substances used, particularly in relation to classifications, Annex XIV and Annex XVII entries relevant to the REACH regulation.

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Answer:
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 severe hazards posed by cadmium, in all its forms, are of course recognised in the RoHS Directive itself, in which the allowed level of cadmium is restricted to a level 10 times lower than other toxic heavy metals, such as lead and mercury.

5. Regarding Cd-free QD materials that have been developed for use in articles relevant to the exemption requests above, please provide the following information:
    a. Please state what substances are used to substitute Cd in QD applications of relevance and clarify if such substances are currently in use in products that are available on the market in general and in particular that are expected to remain available on the market in the coming years;

Answer:
Various semiconductor materials can be used to make QD that will absorb UV/blue light and emit light in the visible range; blue to red. These include:

- *i) CFQD® quantum dots are an inorganic semiconductor alloy based on Indium and including other metallic and non-metallic elements. The process of manufacture is based upon the Nanoco patented "molecular seeding" process for epitaxial growth of the inorganic core.*
- *ii) QDs with a core of indium phosphide and a shell made from zinc sulphide (InP/ZnS) are widely reported in the literature and are available from several manufacturers.*
- *iii) Alloys of copper, indium, gallium, sulphur and selenium (CIS, CIGS) are also reported in the literature to be used for QDs*
- *iv) Graphene has also been reported in the literature to be used for QDs*

In the short term we expect that CFQD® quantum dot materials and InP/ZnS based technology will dominate the cadmium-free quantum dot market, as they are currently the most advanced. However, in the medium to long term, we expect that a wider range of materials will be developed to meet commercial standards of performance in Cd-free QDs.

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b. If more than one type of Cd-free material is used in QDs in relevant applications, please provide information and data to allow a comparison of the performance of all alternatives (or at least of alternatives understood to be on the market or market ready by the end of 2015);

Answer:
Commercial examples of Samsung's Nano Crystal technology in SUHD optical film can be seen in their range of JS8500/9000/9500 televisions. Samsung SUHD displays have received widespread critical acclaim for offering outstanding colour performance, greatly exceeding standard LED technology and similar to OLED technology. These displays also achieve high levels of energy efficiency. For example, the 55" JS9000 model has an 'A' rating and on-mode power consumption of only 110W.

Nanoco and Dow have produced 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 very soon. 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 SUHD film.

At the CES show in January this 2015, Nanosys (one of the applicants for the Exemption) demonstrated their own cadmium-free QD technology in high colour gamut TVs. However, these have not yet been made commercially available so we have not been able to assess their performance.

c. Please provide information regarding hazardous properties related to substances used, particularly in relation to classifications, Annex XIV and Annex XVII entries relevant to the REACH regulation.

Answer:
Nanoco's CFQD® quantum dots are made semiconductor alloys containing indium. CFQD® Quantum dots have undergone some accredited toxicology testing and found to be (according to EU GHS – CLP: EC1272/2008) "Not classified" for acute (oral) toxicity, skin and eye irritation, Acute Fish Toxicity, Acute Daphnia Toxicity. Ames and micronucleus testing has not shown any genotoxicity or mutagenicity. The organic content is shown to be readily biodegradable.

Some other Cd-free QDs do reportedly use indium phosphide (InP). This substance has recently been classified as a carcinogen in Annex VI of CLP (EC/1272/2008). This substance is not an SVHC or on the candidate list for SVHC classification, nor is it restricted under Annex XVII of REACH. InP is not restricted under the RoHS Directive and is only a 4th priority substance for a possible future review under RoHS. A review

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has not yet even been scheduled and the outcome should not legally be pre-judged. There are no restrictions on the use of InP in lighting and display products.

InP is a compound of the 2 elements indium and phosphorus. When InP based QDs are burned or dissolved the indium and phosphorus are separated and form different compounds that are not classified as carcinogenic, so the hazard is neutralised.

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