Response to RoHS Exemption Application Nº 2013-5

Nanoco is a well-established UK-based developer and manufacturer of CFQD™ cadmium-free quantum dots, free of cadmium and other toxic heavy metals, which can be used in many applications including display screens, lighting, solar cells and biological imaging. Dow Electronic Materials, a division of The Dow Chemical Company, is a well-known supplier of specialty chemical products and applications into the electrical and electronic manufacturing industry for over 50 years.

In January 2013, Dow Electronic Materials entered into a global licensing agreement with Nanoco to manufacture, market and sell CFQD™ cadmium-free quantum dots. Small-scale manufacture is currently undertaken in the UK and larger scale manufacture is scheduled to be online by mid-2014. A pilot launch of the first TVs using CFQD™ cadmium-free quantum dots is planned for the first half of 2014, with full commercial production expected within the following 12 months. We would like to jointly submit the following response to the public consultation on this exemption application. Prior to responding in detail to the issued list of questions, we include a summary of our understanding of the application's key issues. We also include an overview of the application of quantum dot technology into liquid crystal displays.

1. Exemption Justification: Key Issues

i. *There is no viable cadmium-free quantum dot alternative available or likely until at least 2021*
We shall show that Nanoco's CFQD™ cadmium-free quantum dots are both available and viable. Their optical emission performance currently meets the requirements for commercial LCD screens, in terms of enhanced screen colour range and lifetime (at least 30,000 hours).
Whilst the applicant has compared their cadmium-based quantum dots to indium phosphide, Nanoco's CFQD™ cadmium-free quantum dots are not made from indium phosphide. Although containing indium, they are made from a unique, alloyed semiconductor matrix with quite different properties.

ii. *OLEDs as an alternative consume too much energy and only small display sizes are currently available*
OLEDs are certainly another viable alternative and TVs expect to capture 17 % of the OLED market by 2014. Energy usage is currently higher than for LCD TVs but likely to reduce dramatically over coming years. Display sizes up to 55" are currently available.

iii. *Quantum dot technology offers improved energy efficiency over conventional TVs*
Any energy savings from use of quantum dots would apply to both cadmium-based and CFQD™ cadmium-free quantum dots. However, we understand that energy savings are associated with improved efficiency of the LED backlights and not the down-converting material; LEDs are more efficient than previously used backlight sources, *e.g.* fluorescent tubes.

iv. *Indium is a scarce material*
We estimate that incorporation of CFQD™ cadmium-free quantum dots into LCDs will increase the total indium content of these devices by just 15 %. Substitution of indium tin oxide (the major use of indium in an LCD) with indium-free materials is being investigated. Recovery and

recycling of indium has already been developed and a leading indium supplier predicts supplies are sufficient to last another 50 to 100 years, as recycled indium already accounts for around 65 % of global supply.

v. *Environmental and safety impact is small*

Since cadmium in Electrical and Electronic Equipment is controlled 10-fold more than the other "RoHS" substances, its impact cannot be considered small. With a toxicity (LD_{50}) of 100 – 300 mg/kg (rats and mice, oral)[i] cadmium's use and pathways into the environment will always be significant.

An independent report suggests that cadmium can be released from cadmium-based quantum dot components certainly under acidic conditions making the risk not insignificant to both health and environment.

The link between the claimed energy saving and reduced emissions of cadmium from coal burning for power generation raises some questions. Firstly, the energy mix in Europe is different from the USA and the data presented may not be applicable. Secondly, emissions from power generation are already being reduced through various policies and regulations in Europe. Finally, the principle of justifying the use of cadmium in consumer products through off-setting against power generation emissions in this way may create a precedent for a greatly increased number of exemption requests in the future.

2. Overview of Quantum Dot Applications

Liquid Crystal Display Backlight Unit (LCD BLU) Technology

Quantum dots can be used in different ways in electronic displays. It is perhaps worthwhile giving a high level overview of how LCD BLU technology works, and how quantum dots may be integrated into the LCD BLU.

In an LCD BLU (**Figure 1**), the backlight comprises a white light source. Each pixel is controlled by an array of backlit thin film transistors (TFTs). The TFTs individually control each liquid crystal to determine whether light from the backlight is transmitted or blocked. The rear and front polarisers are aligned at 90° to one another. When a pixel transistor is turned off, the liquid crystal molecules rotate the polarised light through 90°, such that light passes through the colour filters and the front polariser to the screen. When a pixel transistor is turned on, the liquid crystal molecules align such that the light passes through the layer without being rotated, thus it is blocked by the front polariser.

To produce white light, the backlight can comprise blue LEDs in combination with a down-converting material to absorb a proportion of the blue light, which is subsequently re-emitted at longer wavelengths. In conventional LCD BLUs, the down-converting material is a rare-earth phosphor such as cerium-doped yttrium aluminium garnet (Ce:YAG), which is integrated directly onto the LED chips. An alternative down-converting material comprises a combination of red and green quantum dots (QDs).

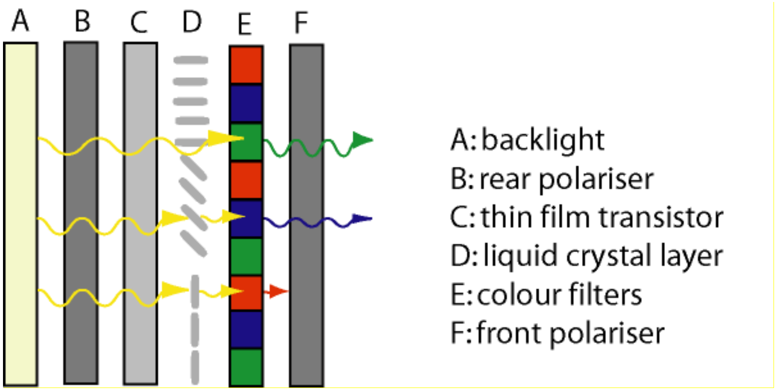

Figure 1: Schematic diagram of an LCD BLU.

There are three potential strategies to integrate quantum dots into conventional LCD BLUs: "on-chip", "on-edge" and "on-surface", as defined by Coe-Sullivan *et al.* (**Figure 2**).[ii]

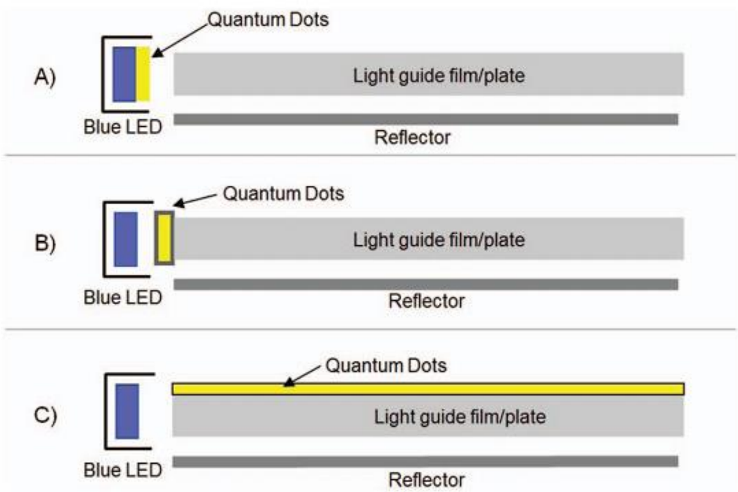

Figure 2: Integration strategies for QD-BLUs for LCD TV: A) on-chip, B) on-edge, and C) on-surface.

With on-chip geometry, the QDs are deposited directly onto the LED surface and are encapsulated within the LED package. The on-edge configuration has the QDs incorporated into a remote component, such as a capillary, that is situated in close proximity to the LED chips. Finally, on-surface configuration incorporates QDs into a remote film that covers the entire screen area. The on-chip design uses the least amount of QD material but is difficult to achieve in practice due to the thermal degradation of the quantum dots that are in direct contact with the LED source. In contrast, the on-surface design would have the highest quantum dot usage but would operate near to room temperature. The on-edge design is a compromise between temperature (on-chip) and quantity (on-surface) conformations.

The existing RoHS Exemption 39 is intended to cover the use of cadmium-based quantum dots in the on-chip design, whereas the requested exemption is to cover the on-edge and on-surface designs.

Questionnaire: Exemption Request N^{o} 2013-5

Exemption for "Cadmium in LCD Quantum Dot Light Control Films and Components"

1. The wording suggested by the applicant for this new exemption would be "Cadmium in LCD Quantum Dot Light Control Films and Components".
    a. Do you agree with the scope of the exemption as proposed by the applicant? Please suggest an alternative wording and explain your proposal, if you do not agree with the proposed exemption wording.

We consider the suggested wording of the proposed exemption extension vague and open to use throughout display applications with no effective limitation on the amount of cadmium that could be used in a device.

Fundamentally, however, we do not see a need for this exemption since a cadmium-free alternative (Nanoco's CFQD™ cadmium-free quantum dots) is available.

The proposed exemption wording is ambiguous by the term "light control … components"; it provides no limitation to the amount of cadmium that can be contained in a device and raises the opportunity to be exploited for many other cadmium-containing applications. To illustrate the significance of this issue, we refer to the existing RoHS Exemption 39;

> "*cadmium in colour converting II-VI LEDs (< 10 µg Cd per mm^2 of light-emitting area) for use in solid state illumination or display systems*"

for which ambiguity in the term "light-emitting area" has been similarly exploited. Exemption 39 has been applied to a commercially available cadmium quantum dot LED TV, which became available on the EU market in June 2013. Comparing the term "light-emitting area" in the three possible architectures or uses of quantum dots as light down-converters (**Figure 2**), the amount of cadmium quantum dots required is much greater the further away from the LED chips. The original RoHS Exemption 39 request related to the use of cadmium as a colour-converting material in an on-chip configuration. In this context, the "light-emitting area" was in relation to the surface area of each LED chip (the light emitter), not to the total backlight area or the surface area of the filters or the area of the display screen, each of which might be interpreted as a light-emitting area. The proposed wording of the exemption could, therefore, be used to define the whole screen surface area to allow much higher quantities of cadmium per unit than the original Exemption 39 area of each LED chip in the backlight. This is illustrated in **Table 1**, which compares the light-emitting area for three different QD BLU designs with a 40" screen and a 16:9 aspect ratio. All calculations are based on a specific commercially available cadmium quantum dot LED TV, which utilises cadmium-based QD down-converting technology and has been available on the EU market since June 2013. The TV screen is double-edge-lit, comprising two full-length QD-containing capillaries, each illuminated by a row of blue twin-chip solid-state LEDs. Calculations of the sum of the LED areas within each chip, the approximate surface area of each glass capillary (which acts as the colour-converting component), and the screen area have been used. The corresponding maximum "allowed" cadmium content per device, according to the 10 µg per mm^2 light-emitting area limit of Exemption 39, is tabulated.

Table 1: Estimated light-emitting area and the corresponding maximum "allowed" cadmium concentration (according to the existing RoHS Exemption 39) for on-chip, on-edge and on-surface QD BLU designs, for a 40" screen.

BLU DESIGN	ESTIMATED LIGHT-EMITTING AREA, mm^2	MAXIMUM Cd CONTENT "ALLOWED" (EX. 39)
On-chip	48 (light-emitting area, based on the LED area within each chip,[1] of the two LED light bars)	480 µg
On-edge	1×10^4 (surface area[2] of two glass capillaries)	100 mg
On-surface	4×10^5 (display area[3] of a 16:9, 40" screen)	4 g

For this specific cadmium quantum dot LED TV, the volume of resin within each capillary was estimated to be approximately 1 cm^3. Independent analysis of the resin by inductively coupled plasma mass spectrometry ICP-MS measured the cadmium concentration to be 1,060 ppm (see **Table 2**). Thus, assuming the density of the cured resin to be in the region of 1.2 g cm^{-3}, at a concentration of 1,060 ppm the amount of cadmium would fall in the region of 2.5 mg per TV (two capillaries), *i.e.* around five times the maximum cadmium concentration that would be permitted under the existing RoHS Exemption 39 if light-emitting area is understood to be that of the LED chips. Though the applicant's current request is not for an extension to Exemption 39, we understand that it would be acceptable to the applicant, with a change of wording.[iii] Therefore, we feel that clarification as to the component(s) to which the exemption could be applied is necessary. If the light-emitting area is taken to refer to the area of a colour-converting film, then up to 4 g of very toxic cadmium[iv] would be permitted per TV, almost a 10,000-fold increase compared to the area of the LED chips. This clearly illustrates that the proposed wording could lead to no effective control of the amount of cadmium that could be used in each TV or similar device.

Table 2: Independent ICP-MS analysis on the resin from a commercially available quantum dot LED TV.

ANALYSIS	RESULTS	UNITS
Concentration of Cadmium	1060	mg/kg
Concentration of Chromium	<0.3	mg/kg
Concentration of Lead	<0.2	mg/kg
Concentration of Mercury	<0.02	mg/kg

It would seem more logical and in keeping with the intention of RoHS regulations that the total amount of cadmium allowed per TV should be limited. If this exemption is approved we would recommend that the amount of cadmium be limited in relation to the BLU LED chip surface area, as per the original intent of Exemption 39.

[1] Based on the LED chip size, the light-emitting area of each LED light bar, comprising 48 twin-chip LED chip packages, each consisting of two 0.5 mm x 0.5 mm LED chips, is 48 x 2 x 0.5 mm x 0.5 mm = 24 mm^2.
[2] The surface area of each oval shaped capillary with dimensions of 2 mm x 4 mm x 510 mm was estimated to be [(2 mm x π) + 4 mm] x 510 mm = 5244 mm^2.
[3] The screen dimensions for a 40", 16:9 display are 34.86" x 19.61"; 34.86" x 19.61" x $(25.4 \text{ mm/"})^2 = 4.4 \times 10^5$ mm^2.

However, we would like to repeat our comment that whilst cadmium-free quantum dots are available as a viable and safer alternative, this exemption request is no longer justified.

b. Please state whether you either support the applicant's request or whether you would like to provide argumentation against the applicant's request. In both cases provide detailed technical argumentation/evidence in line with the criteria in Art. 5 (1) (a) to support your statement.

Nanoco Technologies Limited (Nanoco) is a UK-based company that has developed and manufactures CFQD™ cadmium-free quantum dots. In January 2013, Nanoco and Dow Electronic Materials entered into a global licensing agreement for the manufacture, marketing and sale of Nanoco's CFQD™ cadmium-free quantum dots in electronic displays. Large-scale manufacture is planned for mid-2014.

Noting Article 5(1)(a) of the 2011 RoHS Directive, granting this exemption to use cadmium would weaken the environmental and health protection in the community when CFQD™ cadmium-free quantum dots are an available, better alternative to the environment and health. Nanoco's CFQD™ quantum dots are nanocrystals with an alloyed matrix composed of a complex semiconductor material, free of any RoHS regulated heavy metal. As with cadmium-based QDs, Nanoco's CFQD™ cadmium-free quantum dots can down-convert blue LED light (re-emitting across the visible spectrum); fine tuning of the particle size determines the quantum dot emission wavelength. CFQD™ quantum dots are synthesised by Nanoco's unique, patented "molecular seeding" method, enabling the production of particles with a narrow size distribution.[v]

Nanoco's CFQD™ cadmium-free quantum dots are an effective, efficient and reliable down-converting material. Herein, we will provide supporting data for LCD applications (see Question 2). We envisage that CFQD™ display technology will be commercially available within the next 12 months, well within the minimum five year period requested for this exemption, making it, in our opinion, unjustified.

2. The application mentions that possible substitutes are OLEDs, traditional LED LCDs with more absorptive colour filters, RGB LEDs, Hybrid LEDs, wide colour gamut white LEDs, plasma displays and cadmium free Quantum Dots.
    a. Please provide information concerning these possible substitutes or developments that may enable substitution or elimination at present or in the future. If possible please provide data to establish reliability of possible substitutes.

Organic light-emitting diode (OLED) and plasma displays are complementary technologies to LCD displays. RGB, hybrid and wide colour gamut LEDs utilise different strategies to produce white emission from the LCD backlight, compared to QD colour-converting technology. In the case of traditional LED LCDs with more absorptive colour filters, the technology would employ a white LED backlight. The aforementioned technologies are adequately discussed in the applicant's exemption request. Of the alternative technologies suggested by the applicant, only cadmium-free quantum dots could be used as a direct substitute for cadmium-based II-VI QDs as colour-converting materials. Both employ a blue solid-state LED backlight with red and green QDs to down-convert a proportion of the blue emission. The blue, green and red light combines to produce white light. Nanoco manufactures cadmium-free quantum dots, so our response will focus on the reliability of CFQD™ quantum dots as a possible substitute.

Nanoco devotes its entire research, development and manufacturing capacities to the production of cadmium-free, RoHS compliant quantum dot materials and their associated technological applications. As such, Nanoco is best placed to comment on the performance, efficiency and availability of cadmium-free quantum dots. Nanoco's CFQD™ quantum dot performance far exceeds that suggested in the exemption request; the applicant's own research into indium phosphide quantum dots is somewhat behind the advancements made by Nanoco. Other cadmium-free QD materials with superior performance to indium phosphide are available, one example being Nanoco's CFQD™ cadmium-free quantum dots, nanocrystals with a unique, alloyed semiconductor matrix.

The exemption request suggests that cadmium-free quantum dots suffer from low quantum efficiencies, also referred to as photoluminescence quantum yield (QYs), and broad full-widths at half-maxima (FWHM). FWHM represents the distribution of emission wavelengths within an ensemble of QDs. Nanoco's molecular seeding technology can be used to synthesise CFQD™ cadmium-free quantum dots with optical performance (QY and FWHM) far exceeding that of other cadmium-free quantum dot materials such as indium phosphide. Scientific literature well-documents that indium phosphide quantum dots display broader FWHM values than II-VI QDs such as CdSe. In part this is due to stronger quantum confinement effects of visible-emitting indium phosphide nanoparticles which results in a large emission wavelength change from a small change in particle size.[vi] However, Nanoco's CFQD™ cadmium-free material is not indium phosphide and has superior properties. The alloyed matrix of elements in CFQD™ quantum dots ensures that both the semiconductor band gap and the strength of the bonding interactions within the nanoparticles can be manipulated, reducing the strength of the quantum confinement effects and thus the range of wavelengths (*i.e.* the FWHM) emitted by a given size distribution of QDs. As a result, a given size distribution of CFQD™ quantum dots exhibits a significantly narrower wavelength distribution than that exhibited by the same size distribution of indium phosphide QDs. The QY and FWHM values of Nanoco's CFQD™ material are sufficient to produce highly energy-efficient devices with a broad colour gamut.

Nanoco's molecular seeding method of synthesis is scalable. Plans to scale up production are already underway and are expected to be achieved by mid-2014. CFQD™ cadmium-free quantum dot LCD displays are expected to be launched within the next 12 months.

CFQD™ BLU Performance

The **Overview of Quantum Dot Applications** summarises the mechanism of operation of an LCD backlight unit (BLU), and the strategies that can be employed to integrate QD colour-converting materials into the BLU: "on-chip", "on-edge" and "on-surface" (**Figure 2**). CFQD™ BLUs for LCD displays have been compared using the on-chip and on-surface geometries, with colour gamuts significantly greater than those suggested for cadmium-free quantum dots displays in the applicant's exemption request.

On-Chip

In the on-chip geometry, CFQD™ material has been incorporated into a 22" LCD display. The light bar from a commercially available LCD TV, comprising LEDs with a conventional rare-earth (Ce:YAG) phosphor, was replaced with a light bar consisting of 60 colour-converted CFQD™ cadmium-free quantum dot-LEDs. In doing so, the colour gamut was increased from 67 % to 92 % of the area of the United States National Television Systems Committee (NTSC) 1953 colour triangle, an internationally recognised standard, as shown in **Figure 3**. Quantum dots (both cadmium-containing and cadmium-free) cannot currently withstand the harsh conditions of the on-chip environment to provide the necessary performance lifetimes for display applications. However, the results show that CFQD™ material can be used instead of cadmium QDs to significantly improve the colour gamut with respect to that of a rare-earth phosphor colour-converted TV.

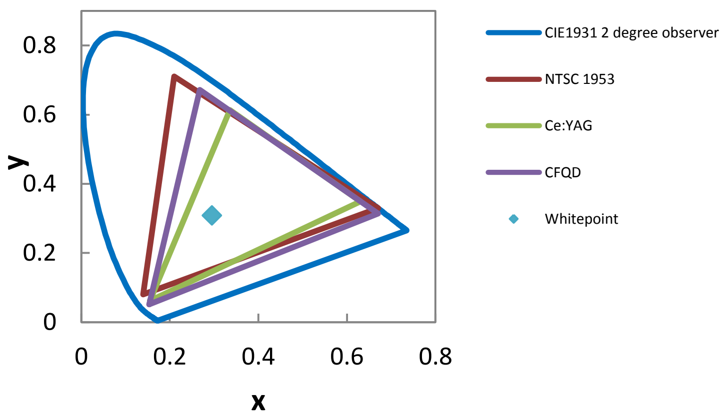

Figure 3: Colour triangle of an on-chip CFQD™ BLU (*purple*) compared to that of a conventional Ce:YAG BLU (*green*) and the NTSC 1953 standard (*red*).

On-Surface

In the on-surface geometry, CFQD™ quantum dots have been incorporated into a film displaying 97 % NTSC 1953 area (89 % NTSC 1953 overlap), as shown in **Figure 4**. The colour gamut is comparable to that displayed by the commercially available cadmium quantum dot LED TV; though the colour gamut of this TV is reported as 100 % of the NTSC 1953 standard, our internal measurements found that the maximum overlap with the NTSC 1953 colour triangle was just 91 %, as shown in **Table 3**. The results contradict the applicant's claim that CFQD™ films are less efficient than cadmium-containing QD films by approximately 37 % for a 100 % NTSC target.

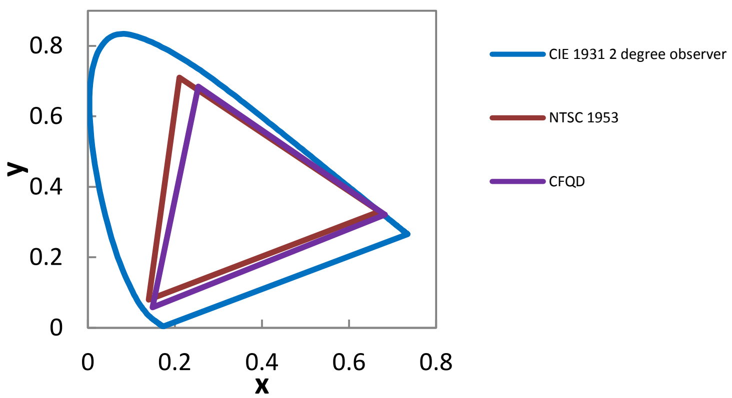

Figure 4: Colour triangle of an on-surface CFQD™ BLU (*purple*) compared to that of the NTSC 1953 standard (*red*).

Table 3: Summary of the display settings of a commercially available cadmium quantum dot LED TV and the corresponding optical performance compared to the NTSC 1953 standard.

Condition	Picture Setting	Colour Setting	Colour Space	Format	Area NTSC, %	Overlap NTSC, %
A	photo-vivid	default	sRGB	ITU601	61	60
B	photo-vivid	max	sRGB	ITU601	46	46
C	photo-vivid	max	Adobe RGB	ITU601	91	89
D	photo-vivid	max (red also set to max)	Adobe RGB	ITU601	100	91
E	photo-vivid	max	Adobe RGB	ITU601	66	58
F	photo-vivid	max	Adobe RGB	ITU709	85	84
G	photo-original	max	Adobe RGB	ITU709	80	78

The conditions to which QDs are exposed in the on-surface geometry are much milder than those of the on-chip geometry. To assess the performance lifetime, a CFQD™ film was prepared and irradiated at 2.5 mW cm^{-2} to simulate the conditions of an on-surface environment. The photoluminescence intensity remained stable during 3,000 hours of testing. Extrapolating the data using a logarithmic curve suggests a lifetime of at least 30,000 hours,[4] contradicting the applicant's argument that cadmium-free quantum dot display lifetimes are well-short of 20,000 hours.

Overall, CFQD™ cadmium-free quantum dots can be used to achieve similarly performing display devices to cadmium QD-containing TVs already available on the EU market, in terms of both optical performance and lifetime.

b. According to the applicant OLED are the only possible substitute relevant for the near future that can be used in similar cadmium QD-based LCD applications. Please explain in detail, the status quo of using OLED in comparison to applications using cadmium in LCD Quantum Dot Light Control Films and Components.

[4] Note, when quoting extrapolated lifetimes, current protocols state that LEDs must be tested for at least 10 % of the time quoted.

OLEDs emit, rather than down-convert light, and as such cannot directly substitute II-VI semiconductor down-conversion materials. OLEDs operate without a backlight or colour filters. Currently, OLEDs are commonly found in small- to medium-sized displays, such as smartphones and tablets. An online source[vii] summarises the status of OLED technology for display applications; 55" OLED TVs are currently on sale in the Korea, the UK and the US, while prototypes of a 56" OLED display have been unveiled at the Consumer Electronics Show. A leading OLED manufacturer plans to commercialise a 60" flexible, ultrahigh definition TV by 2017.

For in-depth analysis of the status of OLED technology, Öko-Institut and Fraunhofer IZM may wish to consult the market researcher Displaybank, which has published a number of reports on the subject.[viii]

c. Do you agree with the applicant's statement that OLED technology consumes three times more energy in the use phase than cadmium QD applications?

It is our understanding that the relative energy consumption of OLEDs compared to cadmium-based QD LCD will depend on the colour of the image being produced. For a white background, the energy consumption of an OLED display might be as high as three times that of a cadmium-based QD LCD, but for a predominantly black image an OLED display will consume very little energy, since no light is produced to display a black pixel. Overall, current power consumption of OLED TVs is higher as it is not yet fully optimised. As the technology stabilises for mass production, power consumption is expected to improve dramatically, towards that of an LCD.

d. Please explain further, what display sizes cannot yet be manufactured with OLEDs? Is it possible to use OLEDs and applications using CdSe QD in the same application (can they replace one another), for instance in the small sized displays?

Currently, OLED displays up to 55" are available on the Korean, UK and US markets. According to DisplaySearch,[ix] TVs are expected to account for 17 % of the OLED display market by 2014, with rapid OLED display area growth predicted during 2017.

For smaller displays, OLED technology is already commercially available in products including mobile phones, digital cameras, and monitors,[vii] for which equivalent II-VI semiconductor down-converted displays are not yet marketed. OLEDs and QD down-conversion materials will both be suitable for applications requiring smaller displays.

3. The applicant estimates that quantities of 147 kg of cadmium may be placed on the EU market annually through LCD Quantum Dot Light Control applications (TV, monitor, Notebook, tablets and smart phones), see also following table. As demonstrated in this table, it would be useful to receive information as to what % of LCD area in the EU uses OLED technology and what area this represents (see relevant columns). Please quantify for

the EU, if possible. Estimation is fine in case you do not have exact data. Please elaborate as to assumptions and calculations.

Application	Global Annual LCD Area (1) (m2)	EU Share of LCD Area (2) (m2)	% Using QD Film(3)	LCD Area Using QD Film in EU (m2)	% Using OLED	LCD Area Using OLED in EU (m2)
TV	157,333,925	26%	2%	818,136	2013: 0.04 % 2017: 3.3 %	2013: 16,362 2017: 1,349,925
Monitor	29,365,561	26%	3%	190,876		
Notebook/Ultrabook	22,819,763	26%	7%	415,32		
Tablets	12,174,293	26%	60%	1,899,190		
Small displays (phones, etc.)	12,000,660	26%	20%	624,034		

The data for the EU market share using OLED have been estimated using global market predictions for OLED TVs published by Displaybank,[x] assuming direct proportionality between the EU and global markets.

4. Please indicate if the negative environmental, health and/or consumer safety impacts caused by substitution are likely to outweigh the environmental, health and/or consumer safety benefits. If existing, please refer to relevant studies on negative impacts caused by substitution.

Since its original drafting, the RoHS Directive has always recognised the human toxicity and environmental impact of cadmium in the community and sought to restrict its release through environmental pathways. Indeed it is controlled to a level much higher than the other "RoHS" substances with a 10 times lower threshold permitted in Electrical and Electronic Equipment.

The only direct substitute to provide a positive health and environmental impact benefit over the use of cadmium-containing quantum dots is a quantum dot not containing a toxic material. Nanoco's CFQD™ cadmium-free quantum dots are free from heavy metals, RoHS compliant and do not present the toxicity risks associated with cadmium-containing II-VI QDs. The applicant argues that the cadmium within a QD film is encapsulated and not accessible to the consumer. However, it does not consider the risk of exposure to workers during the supply and manufacturing chain.

With regards to the disposal of cadmium-based QD-containing colour-converting components and devices, an investigation into the degradation of an encapsulated cadmium QD-containing lighting product, QD Vision's "Quantum Light Optics", showed small releases of cadmium ions (< 0.10 mg/g polymer) in a range of stimulants, but significantly higher release of cadmium ions (1.10 – 1.20 mg/g polymer) in low pH fluids (1 M nitric and gastric acid).[xi] The study results suggest a risk of cadmium leaching from cadmium-based QD-containing colour-converting components and devices when exposed to low pH conditions that may be encountered in a landfill environment.

The improved energy efficiency associated with cadmium-containing LED down-conversion technology compared to rare-earth LED down-converters (conventional LCD TVs), as reported by the applicant, would be likely to apply to CFQD™ cadmium-free quantum dot down-converted LEDs. However, our understanding of the energy savings associated with LED down-conversion technology is that it originates from the LED backlight rather than the QD colour converters; LEDs are more efficient than previously used backlight sources such as fluorescent tubes. As such, there should be little difference in energy consumption between QD-LED-LCD displays and standard LED-LCD displays.

Nanoco's CFQD™ materials contain indium which, as highlighted in the exemption request, is considered a critical material. Information received from a leading indium supplier projects that current indium supplies should last another 50 – 100 years, allowing sufficient time to develop alternative technologies to those that are heavily reliant on indium (predominantly flat panel display and photovoltaic applications).[xii] Indium is three times more abundant than silver and is extracted as a by-product of mining and refining zinc, tin, copper, lead and iron. Extraction of the indium requires investment and this is currently increasing for new and existing refineries. Potential supplies are well-distributed globally, but China is currently the largest single producer. At present, indium supply and demand are well-matched. Indium production is forecast to meet rising demand, with much of the new capacity coming from outside China, reducing the influence of China on global supply balance and pricing. The small consumption of indium that will ensue from the introduction of CFQD™ display products onto market is likely to have a relatively insignificant impact on global indium consumption. We estimate that for a CFQD™ quantum dot LCD with an on-surface configuration, the total indium content will only increase by approximately 15 % compared to that of a standard LCD. In the future, this small increase in indium consumption from the CFQD™ quantum dots could be offset by strategies to replace indium tin oxide in flat panel displays with indium-free transparent conducting oxides such as antimony tin oxide. Further, schemes to recycle indium are already in place,[xiii] with around 65 % of annual indium supply being generated by recycling,[xii] and include provisions to recycle indium from LCDs.[xiv] Thus it is reasonable to assume that strategies to recover indium from CFQD™ quantum dot LCDs could be developed.

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