Consultation Questionnaire for the Joint Evaluation of Three Requests for Exemptions, Dealing with Cadmium Quantum Dot Applications

1. Each of the applicants has provided proposals for exemptions covering certain Cd QD applications. LE and OSRAM further provided a proposal for a formulation that could cover all three application areas, assuming they are all justified. The various formulations can be viewed in the table below.

Applicant	Initial requested exemption formulation	Proposed joint exemption formulation
Najing	Cadmium selenide in downshifting cadmium-based semiconductor nanocrystal quantum dots for use in display lighting applications (<0.1 µg per mm^2 of display screen area).	
OSRAM	Cadmium in downshifting semiconductor nanocrystal quantum dots directly deposited on LED chips for use in display and projection applications (< 5 µg Cd per mm^2 of light emitting LED chip surface).	Cadmium in downshifting semiconductor nanocrystal quantum dots - directly deposited on LED semiconductor chips for use in display and projection applications (< 5 µg Cd per mm^2 of light emitting LED chip surface) - directly deposited on LED semiconductor chips for use in lighting applications of at least CRI 80 (< 1.000 ppm in the luminescent material) - not directly deposited on LED semiconductor chips for use in display and projection applications (< 0.2 µg Cd per mm^2 of display screen area)
LE	Cadmium (<1000 ppm) in luminescent material for on-chip application on LED semiconductor chips for use in lighting applications of at least CRI 80.	

Please explain if you support that there is a need for an exemption for Cd QD applications.

We do not support that there is any need for an exemption for Cd QD applications.

Indeed, we believe that the applications should not be considered at all, because they do not meet the requirements laid out in RoHS under Article 5(1)(a) and Annex V. Further details on the legal arguments to support this position are included in our letter to the Commission which forms part of this consultation response (copy provided).

a. If not, please explain why?

   We believe that an exemption is not justified because elimination or substitution is possible *via* both design and materials changes that do not require any of the materials or substances listed in Annex II (see Question 3). Since our response to Question 3 outlines a number of alternative materials and technologies to Cd-based QDs, and given that these are already available in the amounts required to meet the forecast demand, we believe that the reliability of these substitutes is ensured. Further, we believe that, owing to the significant toxicity of cadmium, the negative impact of substitution to the environment, health and consumer safety does not outweigh the claimed benefits, which we also dispute.

The energy efficiency data provided by Najingtech to support their application is outdated and inaccurate, so should not be admitted as evidence for the consultation – see our analysis in **Annex 1**.

In addition, by extending the scope of the exemption to include lighting, the EU would be creating a market for cadmium in on-chip display and lighting applications where no market previously existed. This is contrary to our understanding of the purpose of RoHS exemptions, which we understand to be to allow companies time to develop restricted substance-free alternatives to existing products – not to continue to develop new and improved products reliant on highly toxic cadmium and present no evidence that they are developing cadmium-free alternatives instead.

b. If yes, please detail which of the proposed formulations you support or provide an alternative proposal, also explaining why you support an exemption and the specific formulation alternative.

n/a

In both cases, please provide detailed technical argumentation/evidence in line with the criteria in Art. 5(1)(a) to support your statement.

2. From the information provided by the applicants it can be understood that Cd QDs have various application areas of relevance to the RoHS Directive (displays and lighting) and may be applied in such applications in different configurations (on-edge, on-surface, on-chip within the LED package and on-chip within a thin layer on top of the chip). As regards the scope of a possible exemption, please provide information to clarify:

a. Which of the above application areas should be covered by a future exemption;

b. For each application area, which configurations should be included in the scope of a future exemption and with which Cd threshold; and

c. For how long would an exemption be needed in your opinion in each of these cases (i.e. proposed duration).

	DISPLAYS			LIGHTING		
	ON-CHIP	ON-EDGE	ON-SURFACE	ON-CHIP	ON-EDGE	ON-SURFACE
EXEMPTION JUSTIFIED	No	No	No	No	No	No
EXEMPTION DURATION	n/a	n/a	n/a	n/a	n/a	n/a

In relation to the application to extend Cd QD exemption into lighting, we would like to point out that the main reason that this was removed from the scope of Exemption 39 at the last review was the global lack of any commercial products after many years of development. This continues to be the same today, so there is no justification to reverse this decision.

Even if this application were to be considered at all, its scope would have to be strictly limited to specific lighting applications where it could be demonstrated that LEDs with rapidly improving high performance phosphor technology were not able to provide similar performance acceptable to meet market needs. This would be best achieved by monitoring the adoption of possible new Cd QD based 'on chip' lighting products in other markets and their actual performance in use. An adequate amount of data would be required to support any future application, which could reasonably be expected to require at least 3 years to collect given that no commercial products have yet been launched.

Given that recent data from Osram suggests that their own newly developed high performance phosphors can already achieve equivalent levels of energy efficiency and colour performance compared to Cd QD technology (see section 3 ii), it is clear that allowing the introduction of toxic Cd QD into on-chip LEDs would act against the principles of RoHS by discouraging the development of cadmium-free technologies and encouraging the development of new cadmium-based products.

Please consider providing information in a tabular format to clarify your views for each case and provide information to support your views.

3. Please provide information concerning available alternatives or developments that may enable reduction, substitution or elimination, at present or in the future, of Cd QDs in the various application areas and configurations mentioned in question 2.

    a. In this regard, please provide information as to

        i. Technological improvements which allow reducing the amount of Cd in a specific EEE;

        In its response to Clarification Question 5a, OSRAM states "OSRAM Opto Semiconductors is currently planning to release 90 CRI OSCONIQ products in May 2019, which utilize Cd-based QD material at a level below 100 ppm Cd and are definitely compliant with the current ROHS regulations." Nanoco does not have detail of the technological improvements that have facilitated the amount of Cd to be reduced, but the data suggest that RoHS compliant products (< 100 ppm Cd) can be achieved with a 7 % improvement in luminous efficacy and 7 % reduction in energy consumption compared to phosphor-only LEDs.

        In their current website section on their commercial products, Nanosys Inc. (who were an applicant in previous applications to extend Exemption 39), provide a table to compare their Cd QD, low Cd QD (Hyperion) and Cd-free QD products (https://www.nanosysinc.com/products):

Type of QD	TRADITIONAL		HYPERION		HEAVY METAL FREE	
Color Standard	Color Gamut	Relative Brightness	Color Gamut	Relative Brightness	Color Gamut	Relative Brightness
DCI-P3	>99%	100%	>99%	100%	>99%	100%
AdobeRGB	>99%	100%	>99%	100%	>99%	90%
NTSC	>100%	100%	>100%	100%	>100%	95%
BT2020	>90%	100%	>90%	100%	>85%	95%

Note: 1. Above performance has been verified using Nanosys Quantum Dot products with appropriate color filters. 2. Similar performance may not be achievable with non-Nanosys Quantum Dots. 3. Relative brightness is meaningful only within the same color gamut, not across different color gamut standards.

*DCI-P3/BT2020 uses coverage in CIE 1976; Adobe RGB uses coverage in CIE 1931; NTSC uses area in CIE 1931

Their 'Hyperion' product has been developed with reduced cadmium content to allow QD films which comply with RoHS without the need for Exemption 38:

HYPERION™

Hyperion Quantum Dots match the color performance of our industry-leading Quantum Dot materials with over 90% BT.2020 color gamut coverage. However, unlike traditional Cadmium-based materials, Hyperion Quantum Dot films do not require an exemption to the European Union's Restriction on Hazardous Substances (RoHS) Directive. This is because Hyperion Quantum Dots are made using a novel manufacturing technique that combines a Cadmium-free red emitter with an ultra-low Cadmium green emitter.

The result: no-compromise performance with no need for a RoHS exemption.

This provides further updated evidence that even leading Cd QD producers accept that these alternative technologies can already achieve equivalent performance for both energy efficiency and colour gamut.

ii. Substance alternatives;

DISPLAYS	LIGHTING
InP QDs InP QD displays are widely available on the EU consumer electronics market, from Samsung (see table below). Samsung states that QYs > 95 can be achieved for its InP-based QDs.[1] We have measured a previous generation of Samsung QD TVs (model QE55Q9FN), which displayed a red FWHM of 41 nm and a green FWHM of 38 nm in the film, providing	

98.5 % DCI-P3 coverage (106.5 % area) in CIE 1976 colour space. Many newer models are now available.[2] Comparing like-for-like (*i.e.* 4K TVs), we would expect these newer models to perform at least as well, if not better, in terms of colour quality and efficiency. The energy efficiency rating for these models is as high as A+ for 65" and A for 55".	
CFQD® quantum dots CFQD® quantum dots from Nanoco comprise an alloy material based on indium. For research materials, green FWHM of 33.5 nm can be achieved. Green QDs with a FWHM of 35 nm are commercially available. Red FWHM of 38 nm can be achieved in the lab. Red QDs with 43 nm FWHM are commercially available. A QY of 85 % can be achieved in the lab for both red and green QDs.	
Conventional phosphors Cd-based QDs can be replaced with conventional phosphors in displays. Data[3] from Lumenari suggest its Emerald-525 green phosphor can be incorporated into displays achieving 94.0 % BT.2020 in CIE 1976 colour space. Data[4] from GE suggest its TriGain™ phosphor has been used in conjunction with $AlON:Mn^{2+}$ phosphor to produce displays demonstrating 111 % NTSC area in 1976 colour space.	**Conventional phosphors** Cd-based QDs can be replaced with conventional phosphors in lighting. As stated by LightingEurope in the exemption request, a narrow red FWHM at the right wavelength is required to achieve both high CRI and high luminous efficacy. Some narrowband phosphors are already commercially available. Data[4] from GE for its commercially available TriGain™ phosphor ($K_2SiF_6:Mn^{4+}$) suggest that it can be used to produce lighting with a CRI of 90 and R9 > 90. The material exhibits 5 emission peaks between 609 – 648 nm, each having a narrow FWHM < 2 nm. The material shows no thermal quenching up to 150°C, making it suitable for on-chip applications. Data from Osram[5] suggests that it has developed new Brilliant Green phosphor using $A_4(Li_3SiO_4)_4:Eu^{2+}$ (A= alkali metal) and new Brilliant Red phosphor using $SrLi_2Al_2O_2N_2:Eu^{2+}$. These can be combined to make an

	LED with CRI > 90 %, CCT 3,000 K and luminous efficiency **19 % better than the current 'state of art' for mid- to high power LEDs.** This should be compared to the 20 % increase in luminous efficiency claimed by Osram for the use of Cd QDs in section 5(b) of their application to extend Exemption 39. **From this is clear that new high performance phosphors can provide equivalent levels of energy efficiency compared the Cd QD technology.**

Samsung commercially available InP-based QD displays:

MODEL	PRODUCT TYPE & SIZE
Samsung Q950R	TV: 65", 75", 82"
Samsung Q90R	TV: 55", 65", 75"
Samsung Q85R	TV: 55", 65", 75"
Samsung Q80R	TV: 55", 65"
Samsung Q70R	TV: 43", 49", 55", 65", 75", 82"
Samsung Q60/Q60R QLED	TV: 43", 49", 55", 65", 75", 82"
Samsung Q9FN/Q9/Q9F QLED 2018	TV: 65", 75"
Samsung Q8FN/Q8/Q8F QLED 2018	TV: 55", 65", 75", 82"
Samsung Q7FN/Q7/Q7F QLED 2018	TV: 55", 65", 75"
Samsung Q7CN/Q7C QLED 2018	TV: 55", 65"
Samsung Q6FN/Q6/Q6F QLED 2018	TV: 49", 55", 65", 75", 82"
Samsung Q9F/Q9 QLED 2017	TV: 65", 75"
Samsung Q7F/Q7 QLED 2017	TV: 55", 65", 75"
Samsung LU	Monitor: 28", 32"
Samsung LC	Monitor: 27", 32", 34" ultra-wide

iii. Technology alternatives.

DISPLAYS	LIGHTING
OLED Organic light-emitting diode (OLED) displays are widely available on the market in a range of sizes, from mobile devices to TVs up to 77". OLED is a complementary technology to QD displays, with each offering a number of advantages and disadvantages. In terms of energy efficiency, OLED displays can perform very well. For example:	**"Remote" QD film** (similar to on-surface configuration) The thermal stability issues associated with Cd-free QDs in an on-chip configuration can be mitigated using a remote film. In the past, Nanoco has developed such lighting fixtures. For example, lamps were prepared with a CCT of 6,500 K, CRI of 95.3 and R9 of 91.6. The luminous efficacy at source was 102.3 lm/W, however, it should be

65”: LG OLED65C9PLA achieves A rating with annual consumption of 190 kW/h per annum.[6] 55”: LG OLED55E9PLA achieves A rating with annual consumption of 154 kW/h per annum.[7] **These energy efficiencies are equivalent or better than commercially available Cd QD TVs.** See table in **Annex 2**.	noted that these lamps were prepared some years ago, using red QDs with FWHM > 60 nm and QY of 72 %. Using CFQD® quantum dots available today, having superior optical properties, this luminous efficacy could be significantly improved.
Laser TVs Hisense’s “Laser TV” technology is commercially available and can reportedly achieve 97 % of the Rec. 2020 colour space.[8] The technology uses an ultra-short laser light projector to project an image on a screen, to resemble a TV screen.	

b. Please provide quantitative data as to the application specifications to support your views.

See above.

4. 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 QDs in various application areas and configurations mentioned in question 2.

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).

TECHNOLOGY	APPLICATION
Native colour microLED	**Displays** A microLED is generally considered to be an LED with a chip size ≤ 100 µm. Native colour microLED technology utilises red, green and blue microLEDs as individual sub-pixels on a screen. With FWHM values ≤ 24 nm, colour gamuts in the mid-90s of the BT.2020 standard can be achieved, with high dynamic range and good viewing angles.
Halide perovskite QDs	**Displays and lighting** Halide perovskite QDs of the form ABX_3, (A = CH_3NH_3, CH_5N_2, Cs; B = Pb, Sn; X = I, Br, Cl) have tuneable emission across the visible spectrum, narrow FWHMs (12 – 40 nm) and near-unity QYs. They are currently being researched

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	as alternatives to Cd-based QDs for both displays and lighting.[9,10]
Other QDs (*e.g.* silicon and graphene)	**Displays and lighting** Other QD materials, such as those based on silicon and graphene, have been proposed for display and lighting applications, owing to their tuneable emission across the visible spectrum.
Narrowband phosphors	**Displays and lighting** At the 2019 Phosphor Global Summit,[11] OSRAM proposed its newly developed "Brilliant Blue", "Brilliant Cyan", "Brilliant Green" and "Brilliant Red" narrowband phosphors for both general lighting and displays.

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.

TECHNOLOGY	ROADMAP
Native colour microLED	Large demonstrators have already been showcased at several tradeshows. Examples include the Sony Crystal LED[12] and the Samsung's The Wall,[13] with both companies claiming that their products are already available for business-to-business purchasing. Based on a presentation from market analysts Yole Développement[14], we envisage that the technology may be commercially available by 2021.
Halide perovskite QDs	A number of issues need to be addressed before halide perovskite QDs can be incorporated into EEE. These include their poor stability (*e.g.* to light, oxygen, moisture and heat), their toxicity, and their undergoing rapid ion exchange when combined. Thermal and aqueous stability of perovskite QDs are being addressed, for example, using a protective shell and compact polymer layer.[15] Halide perovskite QDs undergo rapid anion exchange when combined, which would pose an issue when combining red- and green-emitting QDs in displays. One method to address this is to separately encapsulate the red- and green-emitting QDs in a polymer, prior to combining them.[16] Another proposed solution is to shell the QDs.[17] Research is ongoing to try to substitute lead for a non-toxic alternative such as tin.[18]
Other QDs (*e.g.* silicon and graphene)	There are a number of technical challenges to overcome before these materials could be used for display and lighting applications. For example, silicon QDs display a

	broad FWHM, while the QY for graphene QDs is typically < 30 %. Research into these materials for display and lighting applications is in its infancy, so we expect it would be five years or more before commercial products become available.
Narrowband phosphors	Lumenari is targeting FWHM = 33 – 35 nm and QY = 85 % in its next generation of phosphors.[3] Osram[10] have already developed new phosphors Brilliant Green with FWHM < 0.2 eV and Brilliant Red with FWHM of < 0.18 eV and QY > 90 %. Thus, we expect this technology to be available on the consumer market in the next 1-3 years.

5. For the various application areas and configurations mentioned in question 2, please provide data as to actual product currently on the market and how this is to develop within the next five years. Please refer in your answer to:

    a. Types of products (lighting products for various purposes, displays of various size and type), also specifying the applied Cd QD configuration;

    b. The amount of Cd contained within the product;

    c. Alternative products of the same type that are Cd free and that provide similar performance in terms of colour output (CRI, colour gamut, etc. as relevant to the application area) energy efficiency.

	DISPLAYS			LIGHTING		
	ON-CHIP	ON-EDGE	ON-SURFACE	ON-CHIP	ON-EDGE	ON-SURFACE
CD PRODUCTS ON MARKET?	No	No	Yes†	No	No	No
AMOUNT OF CD	n/a	n/a	0.05 µg/mm^2 display area[*]	n/a	n/a	n/a
ALTERNATIVES	Conventional phosphors	Cd-free QDs	Cd-free QDs	Conventional phosphors		Cd-free QDs

† Commercially available TVs and gaming monitors that, to the best of our knowledge, contain Cd-based QDs are currently available from the following suppliers. Note, we have checked availability on the UK market, which we believe to be representative of

[*] This concentration is stated by Najing in its exemption request, and is in good agreement with our own measurements on the Kindle Fire HDX tablet (now discontinued), for which we measured a cadmium concentration of ~ 0.04 µg/mm^2 display area.

the EU market. Where unavailable in the UK, we understand that the products may be available in other countries.

MODEL	PRODUCT TYPE & SIZE	AVAILABILITY IN UK
Vizio P Series Quantum	TV: 65”	Not available
Hisense U9	TV: 65”, 75”	Limited availability
Hisense NU9700	TV: 70”	Not available
TCL X10	TV: 75”	Not available
Cello C66QLED	TV: 55”	Available
Vizio Elite UHD	TV: 49”, 55”, 65”, 75”	Not available
Asus ROG Swift PG27UQ	Monitor: 27”	Available
Acer Predator X27	Monitor: 27”	Available

As can be seen from comparing the above data with the data provided for Samsung Cd-free QD TVs in Question 3 a ii, Cd-free QD displays are more widely available, and in a greater range of display sizes, than Cd-based QD displays.

6. For the various application areas and configurations mentioned in question 2, please provide information to allow a comparison of technologies (within the Cd QD portfolio and beyond) in relation to the performance they provide so as to support the views expressed in earlier answers (support of the exemption and its various scope options or objections to an exemption).

   a. Please refer in your answers to the parameters of relevance for this comparison (include as a minimum colour output parameters, energy consumption and energy efficiency parameters) and provide quantitative data to allow a comparison of relevant products.

   b. Please specify the relevant standards or methods that are considered as acceptable for measuring and comparing the various parameters mentioned in a.

   The relevant colour standards to compare display technologies (both Cd-based and Cd-free) 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[19] and widely adopted. This represents the highest quality media generally available. Samsung, the market leader in QD TVs, has optimised its SUHD range using the DCI standard. Hence DCI should be regarded as the market standard for high colour gamut displays today.

   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 for printing design applications than for TVs.

iv. **NTSC (1953)**

This is an outdated standard that was replaced Rec. 709 for television media many years ago.[20] It is still referred to by some manufacturers, but media content is not recorded using this standard.

Note that displays are usually designed to optimise performance against one of these standards. Because the red, green and blue 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 BT.2020 (also known as Rec. 2020). However, this is a future standard that has not yet been adopted by the industry, and the colour standard for BT.2020 is still under development. Indeed, even cadmium QD manufacturers have been calling for changes to this colour standard to make it more achievable.[21] There are no commercially available cadmium QD TVs that achieve > 90 % of BT.2020, though it has been reported that 55” displays achieving 95 % of the BT.2020 colour gamut have been demonstrated using Cd-free QDs.[22]

These colour standards are typically measured in either CIE 1931 or CIE 1976 colour space. CIE 1931 colour space provides a view of all colours that are visible, but the variance in perceived colour is non-linear from colour to colour. This results in issues when trying to make uniform measurements. CIE 1976 colour space was later developed to minimise the variations in perceived colour. Thus, colour comparisons in CIE 1976 colour space are more meaningful.

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 2,400 K. 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 in percentage 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.
iii. **Luminous efficacy at source (LES)** is the amount of light flux produced for the electrical power consumed, measured in lumens per Watt (lm/W).
iv. **The R9 value** 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.

As examples of values that can be achieved for conventional white LED lighting today, the Soraa VIVID A60 lamp, with a CCT or 2,700 K, displays a CRI of 95, LES of 73 lm/W and R9 of 95,[23] while the Philips Master LEDspot ExpertColor MV with the same CCT displays a CRI of 97 and LES of 67.95 lm/W.[24]

7. As part of the evaluation, socio-economic impacts shall also be compiled and evaluated. The applicants have provided various data and information in this respect. If possible, please provide additional information where more detailed quantification is possible concerning:

   a. The volume of EEE concerned;

DISPLAYS	LIGHTING
We cannot provide data beyond that which has been supplied by the applicants.	We cannot provide data beyond that which has been supplied by the applicants.

   b. Amount of Cd to be avoided should the exemption not be granted;

DISPLAYS	LIGHTING
According to one report, 2.0 million QD displays are forecast to be sold in 2020, increasing to 2.3 million in 2021.[25] Assuming Europe has a 30 % worldwide market share, an average display screen size of 65", and a Cd concentration of 0.05 µg/mm^2 display screen area, this would equate to 35 kg Cd per annum that could be avoided in 2020.	Since on-chip lighting products are not currently on the market, we do not have any data to contribute here.

   c. Estimations as to possible additional waste to be generated through a forced phase-out (if relevant);

DISPLAYS	LIGHTING
For high-end electronics products such as QD displays, the product's market lifecycle (the time a particular product line remains on the shelves) would correspond approximately with the timescale of a forced phase-out. Thus, we would expect no additional waste to be generated from a forced phase-out.	n/a – Products are not currently on the market

d. Estimation of impacts on employment in total, in the EU and outside the EU, should the exemption not be granted. Please detail the main sectors in which possible impacts are expected – manufacturers, supply chain, retail, etc.

DISPLAYS	LIGHTING
Other than Cello Electronics, which we understand has a manufacturing site in the UK where its TVs are assembled, to the best of our knowledge Cd-based QD TVs are manufactured outside Europe. Therefore, we would expect employment in manufacturing in the EU to be little affected if an exemption were not to be granted. Further, due to the availability of Cd-free QDs, manufacturers and retailers would have the option to switch to Cd-free QD displays. Thus, we expect total employment across all sectors to be little affected, both within the EU and outside the EU, were the exemption not to be granted.	n/a – Products are not currently on the market

e. Please estimate additional costs associated with a forced substitution should the exemption not be granted, and how this is divided between various sectors (e.g. private, public, industry; manufacturers, suppliers, retailers).

DISPLAYS	LIGHTING
Display manufacturers may argue that there is an increased cost to them in developing alternative Cd-free displays. However, since manufacturers are aware of the RoHS Directive and many claim to already be working on alternatives, they should be little affected. Equivalent quality Cd-free QD displays are available on the EU market at a similar cost to Cd QD displays, so the consumer should not be affected.	n/a – Products are not currently on the market

Yours sincerely,

Andrew Gooda
Supply Chain & Compliance Director
Nanoco Technologies Ltd

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Annex 1

ROHS Cd Exemption Technical Data Reply

In the Najingtech Application document comparison data of commercial screens is presented as follows:

(B) Elimination/substitution:

1. Can the substance named under 0(A)1 be eliminated?
No. Justification:

Test was conducted to detect the performance difference between Cadmium based QD film and Cadmium free QD film. From energy saving perspective, Cadmium based QD film has saved 16% energy compared with Cadmium free QD film. Energy saving is the most attractive strength for mobile society and severe energy shortage human confronts.

TV	QD Film	Luminance(nit)	Power (W)	Luminance Efficiency (nits/W)	Energy saving	NTSC Area (1931)
TCL X3	CdSe-based	484.5	170	2.85	116%	110.32%
Samsung Q7C	InP-based	686	280	2.45	100%	99%

We believe this to be an unfair comparison for the following reasons:

1. TCL X3 power consumption quoted is the same as stated on the TCL website (source: https://www.tcl.com/content/tcl-site/en/products/x3/x3-65.html). However the max power consumption stated for the equivalent screen size Samsung Q7C on the Samsung website appears to be significantly lower than quoted in the table at 225W (source: https://www.samsung.com/uk/tvs/qled-q7c/QE65Q7CAMTXXU/). Calculating the luminance efficiency using the Samsung stated power consumption value and the luminance quoted in the table gives us a value of 3.05, or 7 % better energy efficiency than the equivalent TCL X3 model.

2. Power values stated fail to take into account the underlying power consumption of other systems in the TV, implying that 100 % of the power is used in illuminating the screen. This is a particular issue for modern TVs due to additional features (such as smart capability and high end speakers) which will contribute to power consumption. A fair evaluation of screen efficiency could be produced by plotting a power v screen brightness curve and extrapolating the power consumption when the screen brightness is zero. This would give the background power consumption of the unit allowing for a calculation of the efficiency of the backlight unit (BLU) light output only.

3. TVs should be set to the same brightness output before comparing relative power consumption. Higher brightness values are generated by pumping the backlight LEDs with more power which lead to higher heat generation. Elevated temperature reduces the efficiency of both the LEDs themselves and the colour converting medium (in this case QDs). Therefore TVs set to a lower brightness value should naturally appear more efficient.

4. Table implies that the BLU system in both TVs are the same and the only difference in efficiency would be caused by the comparative QD films. Other factors which may affect the BLU efficiency include: efficiency of the LEDs used, efficiency of the light guide plate, combination of optical films used.

We also question the QD film comparison data provided by Najingtech in their clarification documentation presented as follows.

TV product NO.	Hisense XT910	TCL55 X2			Samsung 55KS7300		
QD film's in-formation	3M (CdSe)	Najing (CdSe)			Samsung(Cd-free)		
Test fixture	TCL 55 X2	TCL 55 X2			TCL 55 X2		
Quantum effi-ciency (QE)	92.81%	89.56%			67.69%		
Relative QE ratio	100%	96.50%			72.93%		
NTSC(1931)		105.48%			89.01%		
DCI-P3		95.59%			91.43%		
		Luminance(nit)	x	y	L(nit)	x	y
White		432	0.2839	0.2966	324	0.2840	0.2964
R		92	0.6871	0.3004	64.97	0.6825	0.3093
G		293.33	0.2156	0.7146	227.55	0.2779	0.6547
B		45.16	0.1535	0.0613	32.7	0.1492	0.0685

Data presented in the table is from display technology that is 3 years old and fails to take into account the relative gains made in InP QD technology, in terms of both colour gamut and brightness. This is because CdSe QD technology is relatively mature and is no longer making significant improvements every year, while cadmium-free QD technology is newer and still improving rapidly

Brightness of the Samsung series of films has also seen to increase over subsequent years. Table below shows data of QD films from different Samsung device models after the release of the KS7300 device. All films were measured on the same BLU set up using the same instrument to allow direct comparison.

Model	Year	x	y	L, nits
SUHD KS8000F	2016	0.2812	0.2558	3729
C32HG70	Early 2017	0.2853	0.2535	4050
QN55Q7F	2017	0.2600	0.2446	4196

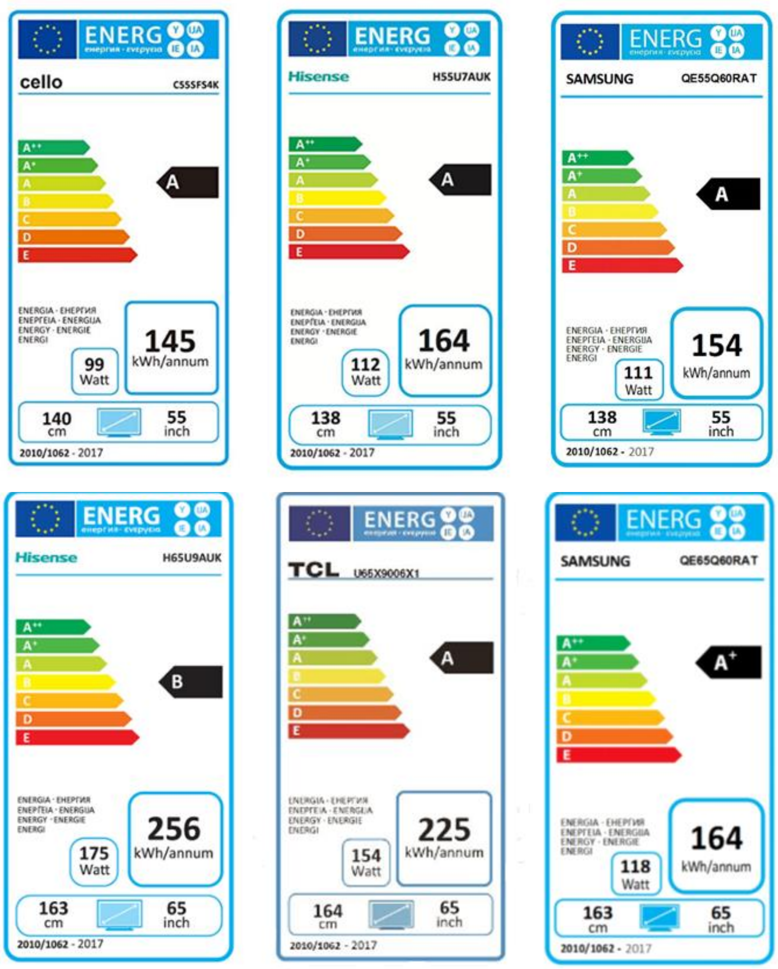
Gains of > 10 % in brightness were seen in the space of 1 year on the technology with subsequent films expected to be brighter due to the enhanced performance and FWHM of emission of the dots. Since then the Samsung film technology has been improved further in 2018 and again in 2019, as their latest models have recently been launched on the EU market. These improvements will have further reduced or eliminated the claimed energy efficiency advantage for cadmium-based QD film.

Independently assessed gamut results from the Samsung TV range show that their 2018 model was capable of producing a DCI-P3 colour gamut of 99.57 in the 1976 colour space (https://www.rtings.com/tv/reviews/samsung/q7fn-q7-q7f-qled-2018).

Annex 2

Energy Efficiency Comparison of EU Available QD TVs

Size	Tech	Brand	Model	Efficiency Class	Annual Power kWh	Link
55 inch	Cd QD	Cello	C55SFS4K QLED	A	145	https://www.amazon.co.uk/Cello-QLED-Superfast-4K-Freeview/dp/B07GT24LXG
55 inch	Cd QD	Hisense	55U7A	A	164	https://www.johnlewis.com/hisense-55u7a-uled-hdr-4k-ultra-hd-smart-tv-55-inch-with-freeview-play-ultra-hd-certified-black-silver/p3518053
55 inch	Cd-free QD	Samsung	QE55Q60RATXXU	A	154	https://www.johnlewis.com/samsung-qe55q60r-2019-qled-hdr-4k-ultra-hd-smart-tv-55-inch-with-tvplus-freesat-hd-charcoal-black/p4043592
65 inch	Cd QD	Hisense	65U9A	B	256	https://www.johnlewis.com/hisense-65u9a-uled-hdr-4k-ultra-hd-smart-tv-65-with-freeview-play-ultra-hd-premium-certified-black-silver/p3519088
65 inch	Cd QD	TCL	U65X9006X1	A	225	https://www.amazon.de/TCL-U65X9006-Fernseher-Triple-Tuner/dp/B077H5YZ51
65 inch	Cd-free QD	Samsung	QE65Q60RATXXU	A+	164	https://www.johnlewis.com/samsung-qe65q60r-2019-qled-hdr-4k-ultra-hd-smart-tv-65-inch-with-tvplus-freesat-hd-charcoal-black/p4045795



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