3M Display Materials & Systems Division

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Ms. Yifaat Baron
RoHS exemptions evaluation
Oeko-Institut
Institute for Applied Ecology
P.O. Box 1771
79017 Freiburg, Germany
http://www.oeko.de

Re: 1st Questionnaire Regarding CdQD Exemptions:

Dear Ms. Baron,

This letter is a response to the Oeko-Institut October 13, 2015 1st Questionnaire Regarding CdQD Exemptions:

- Ex. Re. No. 2013-2 for "Cd in color 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 "Cd in light control materials used for display devices"

3M is a leading manufacturer of backlight enhancement films in the LC Display industry. We are consumers of Quantum Dot (QD) materials; not a manufacturer of QD materials. At this point we are utilizing Cadmium Selenide (CdSe) containing QDs as they provide the most energy efficient solution to achieve current and future color standards. We are committed to utlize non-Cd based alternatives if and when they can meet customer requirements. To date no commercially viable non-Cd QD substitutes are available on the market and there are no non-Cd QD for purchase on the market. Due to repeated delays of QD manufacturers to bring a non-Cd solution to the market, we are requesting a favorable recommendation of this reassessment. The original exemption request was shortened from the standard 5 year period to 4 years based on representations and assertions that substitutes would become available early 2014. It is now more than a year after the date the non-Cd solutions were initially promised to be available for purchase on the market, and there continue to be no sources of non-Cd QDs available for purchase. Accordingly, we respectively request the full 5 years for the exemption from the day of the forthcoming reassessment report.

Oeko-Institut Question 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:

3M DMSD Response to the overall summary of the market situation posed in question 1:-

3M is a leading manufacturer of backlight enhancement films in the LC Display industry. We are consumers of QD materials for use in films. Again, to date no commercially viable non-Cd substitutes are available for purchase on the market. Although one manufacturer (Samsung) has put one line of TVs on the market containing a non-Cd (indium phosphide) QD material, this is a captive supply used in only one line of TV. For clarity, the Samsung non-Cd QD material is not available for purchase by others. Aside from the single line of Samsung televisions, there are no other electronic displays, in any application, using non-Cd QD solutions, and there are absolutely

no non-Cd Qd materials available for purchase in production quantities from third parties due to repeated delays by QD manufacturers to bring a non-Cd solution to the market for general purchase.

Accordingly, the conditions for granting the RoHS exemption request have not materially changed since the April 22, 2014 date of the Oeko-Institut and Fraunhofer-Institut IZM report "Assistance to the Commission on Technological Socio-Economic and Cost-Benefit Assessment Related to Exemptions from the Substance Restrictions in Electrical and Electronic Equipment (RoHS Directive) Final Report – Pack 4: Report for the European Commission DG Environment under Framework Contract No ENV.C.2/FRA/2011/0020". All three criteria for granting the RoHS exemption still hold true for the case of exemption 39 (b). 3M's exemption case 2013-5 meets each of the criteria specified in Article 5(1) (a) of Directive 2011/65/EU. This is summarized in Table 1, and further described in our response to the Oeko-Institut's question 1e in this response.

The following is more detail on the market situation since the first assessment was issued on April 22, 2014.

1. **Non-Cd QDs are not available on the market to purchase.**
    a. Samsung, a TV manufacturer, placed a non-Cd/indium phosphide-containing television line on the market. This TV manufacturer is limiting use of its non-Cd QDs to its own devices. The non-Cd QDs are not available to anyone else for purchase and use for commercialization. Samsung's use of non-Cd QDs is limited to one line of TVs, and the non-Cd QDs are not used, or proven to meet requirements, in other display applications (tablets, mobile devices, other types of displays).
    b. Manufacturers developing non-Cd technology have all repeatedly delayed commercialization and manufacturing scale up of non-Cd QDs. To date, no manufacturer (including the one commercialized non-Cd TV film) has demonstrated a comparable color gamut and energy performance to Cadmium Selenide(CdSe) based QDs.
    c. Reliability of supply is still a factor in the market today. 3M, as one of the world's leading manufacturers of display film, has an open invitation to all QD manufacturers to purchase a non-Cd solution. To date, no substitutes that deliver color and energy performance required by electronic customers have been made available on the market.

    Article 5(I)(a)(2) of Directive 2011/65/EU provides that one basis for granting an exemption is when *the reliability of substitutes is not ensured*. This criterion is met, because there is no available substitute on the market today for CdSe based QDs.

2. **The use of Cd QD Technology is growing. More products are on the market now than when the exemption request 2013-5 was initially made.**
    a. Please refer to Table 2 for a summary of devices that are currently on the market.
    b. There is also strong interest from display makers for medical devices to incorporate the QD technology. The enhanced color image is an invaluable asset in that market segment, as it allows for better discrimination in and enhanced ability to read diagnostic images.
    c. The automobile industry is also eager to use these higher performing displays in their applications as they provide better daylight readability.
3. **Cd QD technology remains the only viable way to achieve color and energy efficiency**.
    a. At the QD Forum held March 18, 2015 in San Francisco, the performance and suitability of both non-Cd and Cd-based QD Materials were discussed by the leading producers in the industry. It was clearly outlined that, based on the current demonstrated state of technology, commercialized non-Cd materials have not demonstrated the ability to fully meet current

color standards (DCI-P3) nor are they able to meet pending color standards in an energy-efficient way. See Tables 3 -5.

b. Recent video on the state of QD technology from Nanosys, a market supplier developing non-Cd QDs, shows that Cd based QDs have better performance. This video includes recent measurements Nanosys took at Consumer Electronics Show in January 2015: https://www.youtube.com/watch?v=Zjwoy9n2_48

4. **New Color Standard**.

a. Since submission of the original application 2013-5, a new color standard, International Telecommunication Union (ITU-R Rec. 2020), has been published which requires extremely large colour gamuts. It is intended that upcoming ultra high definition (UHD) television broadcasting will use this standard. Additionally, it is anticipated the first UHD BluRay™ players supporting this standard will be introduced to the market in early 2016. This color performance cannot be met by non-Cd technology at this time.

Therefore, although there have been changes in the market place, these changes have not negated the need for granting the exemption. In fact, the market situation describe above reinforces the need for the exemption. New color standards are requiring better color performance from display devices,

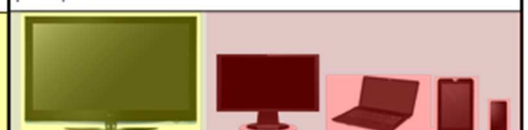
Originally the Oeko-Institut and Fraunhofer-Institut IZM recommended a time period of 3 years for the exemption, less than the allowable 5 years. This shorter time line may have been based on claims by Nanoco-Dow to Oeko Institut referenced in the Oeko-Institut and Fraunhofer-Institut recommendation report of April 22, 2014:

> ***"As for product availability on the market, Nanoco-Dow[98] explains that:***
> ***"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 envisage that CFQD™ quantum dot-containing colour-converted LED lighting (SSL) will be available by the end of 2015."***[1]
>
> ***"Nanoco-Dow have provided information as to a promising Cd-free QD material that is scheduled to come on to the market shortly, however as long as products are not commercially available, such alternatives could not yet be regarded as an available substitute, nor could the comparable properties and reliability be confirmed. "*** [2]

The suggestion was that non-Cd material would be available in 2014. This has not yet come to fruition. It is now near the end of 2015 and Nanoco-Dow's non-Cd dots are not available on the market as a raw material. Once the non-Cd QDs are available, it will still take up to 5 years or more to develop consumer electronic products incorporating those dots to meet the new color standards. The lack of non-Cd QDs available for purchase on the market illustrates that non-Cd technology is harder to scale up than expected. Moreover, even the small prototype R&D quantities of non-Cd QDs that were made available to 3M from non-Cd QD makers have not been able to succeed in producing a non-Cd solution that demonstrates the performance properties that match the CdSe solution. 3M strongly believes the original positive recommendation for granting the exemption from the Oeko-Institut and Fraunhofer-Institut on April 22, 2014 still stands. 3M requests the full five years for the exemption so the non-Cd technology can continue to be developed.

[1] Oeko-Institut and Fraunhofer-Institut IZM, Assistance to the Commission on Technological Socio-Economic and Cost-Benefit Assessment Related to Exemptions from the Substance Restrictions in Electrical and Electronic Equipment (RoHS Directive) Final Report – Pack 4 Report for the European Commission DG Environment under Framework Contract No NV.C.2/FRA/2011/0020 April 22, 2014 ("Pack 4 Final Report"), page 65
[2] Pack 4 Final Report, page 73

Table 1 – Summary of the current market condition and RoHS Exemption Article 5(1)a criteria.

	Quantum Dot (QD) Technology: CdSe-Based	Quantum Dot (QD) Technology: non-Cd	RoHS Exemption Art 5(1)(a) Criteria Met
Efficiency	As stated in 2013-5 exemption-related materials provided to the Oeko-Institut, the commercialized efficiency meets expectations and continues to show improvement, supporting conclusion of net positive environmental benefit	**Original Submitted Projection:** 20-40% lower system luminous efficiency (and corresponding lower energy efficiency) presented to the Oeko Institut confirmed based on testing of recently commercialized non-Cd TVs (see Tables 3-4). **New (Post 6/1/13) Market Development:** Even larger color gamuts adopted (ITU-R Rec. 2020) for future UHD broadcast TV and next generation Ultra HD BluRay™. Currently non-Cd cannot achieve the efficiency required to meet these new standards.	Criteria 3 (Net Environmental Impacts) and Criteria 1 (Technically Impracticable)
Color Gamut	As stated in 2013-5 exemption application the commercialized color performance meets expectations, and can practically achieve existing and adopted next-gen standard color gamuts (i.e., ITU-R Rec. 2020)	**Original Submitted Projection:** As predicted by theory, non-Cd QDs have large spectral widths resulting in lower color performance. Testing of recently commercialized TVs (see Tables 3-4) show ~13% lower color gamut. **New (Post 6/1/13) Market Development:** To date unable to achieve large color gamuts. Even larger color gamuts adopted (ITU-R Rec. 2020) for UHD TV Broadcast and next generation Ultra HD BluRay™. Currently non-Cd cannot achieve the color gamuts required to meet these new standards.	Criteria 1 (Technically Impracticable)
Reliability	Thousands of hours of in-device use	No independently verifiable information available for TVs on market; not proven for other applications.	Criteria 2 (Reliability of Substitutes not Ensured)
Application Size	Proven from +85" (TVs) to 7" (Tablets). Feasible for Smartphones, but not yet implemented. 	Introduced by one manufacture for one application (TVs). Not yet implemented in other devices. 	Criteria 1 (Technically Impracticable) and Criteria 2 (Reliability of Substitutes not ensured) and Not Available (captive to one)
Commercialization	Commercialized for TV, monitor, laptop, and tablet devices by multiple brands from multiple QD suppliers. Suitable for smartphone applications, requires a thin film product currently under development.	TV market only, commercialized by <u>one</u> brand with a captive supply of non-Cd dots. Performance suitability for applications other than TVs not proven. Additionally, UHD TV standards cannot currently be met.	Criteria 1 (Technically Impracticable) and Criteria 2 (Reliability of Substitutes not ensured) and Not Available (captive to one)

3M Assessment
- (green) = Acceptable
- (yellow) = Questionable
- (red) = Unacceptable

Oeko-Institut Question 1a:

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).

3M DMSD Response to question 1a:

Table 2. is provided to summarize the type of device on the market, the availability, and the QD chemistry. This information is provided to the best of 3M's knowledge, but is not guaranteed to be complete.

Table 2. Commercial Quantum-Dot Based Displays

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

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

As you can see from the above table, only one product line manufactured by a single manufacturer uses non-Cd based material.

The following press releases anticipate additional implementation of Cd based QD technology.

- AUO (large panel supplier to the industry) announced full line up of QD TV's (scaling production, but end TV brands not disclosed yet) http://www.auo.com/?sn=107&lang=en-US&c=9&n=1775
- Changhong QD TV http://www.changhongglobal.com/egdch/1982_10022.htm
- German article: http://www.areadvd.de/tests/ces-2015-die-tv-neuheiten-von-changhong-uhd-curved-und-quantum-dot-technologie/
- 3M and Nanosys demonstrated displays showing over 90% of the Rec. 2020 gamut at SID (June, 2015)
- At IFA (September, 2015) TCL and QD Vision demonstrated a TCL- branded TV that presented over 90% of the Rec. 2020 color gamut
- Vizio announced commercial availability of first REC 2020 TV (R-series) on October 6, 2015

Oeko-Institut Question 1b:

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

3M DMSD Response to question 1b:

Table 2 summarizes the display devices on the market today that use QDs. Products are typically discontinued due to the nature of the electronics industry. The life cycle of an electronic device is typically 6 to 12 months, and it is customary with these types of electronic devices to replace models on a frequent basis. 3M as a long term film supplier into the market, offering a full range of brightness enhancement films, fully understands that consumers want more energy efficient products with enhanced color displays. These attributes allow for smaller batteries in portable devices and compliance with local energy standards in monitors and TV's. It is the nature of the electronic industry that models will be replaced with the next generation seeking to improve brightness, color and energy efficiency.

Oeko-Institut Question 1c:

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;

3M DMSD Response to question 1c:

The relative parameters for enabling a comprehensive comparison of performance are:

A. color gamut – the ablility to meet current and future color standards
B. luminance and power -- energy-efficiency
C. net positive environmental impact
D. relability

It is important to note that devices containing displays (such as televisions, monitors, notebooks, tablets, phones, etc.) are designed and implemented by different manufacturers to meet a variety of different needs. While it is possible to measure the color, luminance, and power consumption of multiple devices, comparing these data is not a meaningful way to compare the relative performance of specific components within the devices. Too many other attributes vary among different devices since a display is an entire system that combines components, and the combination of the performance characteristcs impacts the overall system performance. For example it is possible that a device could have an extremely efficient color enhancement film, but has overall low energy efficiency because of poor electronics design or the choice of cheaper and lower efficiency LEDs.

In 3M's experience, the only meaningful way to compare the relative performance of different, specific components is to evaluate those components in the same device so that you are isolating the performance of the particular component and eliminating the other factors introduced by testing differing systems. This requires modification of the device using the two technologies that are to be compared. 3M has conducted such testing in commercially available SUHD TVs which contain non-Cd QDs from the factory. 3M has replaced the commercial non-Cd QD film with a commercial Cd-based QD film made by 3M. This kind of comparative testing ensures that the only differences in performance are those that result from the QD technologies.

Oeko-Institut Question 1d:

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.

3M DMSD Response to question 1d:

Per the comments with regard to comparative testing in the response to question 1c above, 3M DMSD has evaluated one sample each of two commercial InP-based TV models and modified them with 3M Cd-based film. **At equivalent luminance, the two TVs with Cd-based QDs consumed 15% and 29% less power than the TVs with InP-based QDs while still providing 12% and 13% higher color (see Table 4)**. The measurement data and steps to determine power at equivalent luminance and color are described below.

First, Table 3 contains luminance, power, and color data in the two TVs with different QD dot chemistries. In this case, the power of the TVs were held constant. The only difference between the as-received and modified TV is the quantum dot film.

Table 3. Measured performance comparison of TVs at constant power (different luminance and color).

SUHD Model	Quantum Dot Film (Chemistry)	Luminance (cd/m^2)	IEC On-Mode Power (W)	Color Gamut (1931 CIE xy)		
				NTSC Area	DCI-P3 Overlap	Rec2020 Overlap
UN48JS9000F	As-Received (InP)	420.2	193.5	88.4%	90.0%	65.9%
UN48JS9000F	3M Modified (CdSe)	537.6	193.5	99.9%	91.6%	74.6%
UN65JS9500FXZA	As-Received (InP)	427.7	339.7	89.3%	90.4%	66.6%
UN65JS9500FXZA	3M Modified (CdSe)	596.6	339.7	99.7%	91.1%	74.5%

A. color gamut – the ablility to meet current and future color standards

- In the two models tested, the Cd-based quantum dot film results in a 12% and13% increase in color gamut area and coverage of the Rec2020 color space compared to the InP-based film.
- With its Cd-based film, 3M has demonstrated prototype LCD monitors that achieve even larger (>90%) coverage of the Rec2020 color standard.
- Recent video on the state of QD technology from Nanosys, a market supplier developing non-Cd quantum dots, shows that Cd based QDs are better in performance, using recent measurements they took at CES.
  https://www.youtube.com/watch?v=Zjwoy9n2_48

B. luminance and power -- energy-efficiency

The comparative data in Table 3 show that, at constant power, the luminance of the system with the Cd-based film is increased by 28% and 39% compared to the commercial system with InP-based film. This luminance increase can be implemented as a power decrease by reducing the luminance of the Cd-based system to the levels of the as-received InP-based system. Table 4 shows the calculated power of the Cd-based systems when operating at the same luminance as their InP-based counterparts.

Table 4. Measured and calculated† performance comparison at constant luminance.

SUHD Model	Quantum Dot Film (Chemistry)	Luminance (cd/m^2)	IEC On-Mode Power (W)	Color Gamut (1931 CIE xy)		
				NTSC Area	DCI-P3 Overlap	Rec2020 Overlap
UN48JS9000F	As-Received (InP)	420.2	193.5	88.4%	90.0%	65.9%
UN48JS9000F	3M Modified (CdSe)	420.2	163.8†	99.9%	91.6%	74.6%
UN65JS9500FXZA	As-Received (InP)	427.7	339.7	89.3%	90.4%	66.6%
UN65JS9500FXZA	3M Modified (CdSe)	427.7	240.3†	99.7%	91.1%	74.5%

As can be seen in Table 4, the power of the Cd-based systems is reduced by 15% and 29% at equivalent luminance, but the color of the Cd-based systems is still improved. Due to fundamental properties of human vision, smaller color gamuts with less saturated colors are more efficient at producting visible light. Therfore, even further power savings could be realized if the color of the Cd-based system is reduced to match that of the InP-based systems and the two display systems are compared on equal terms.

C. **Net positive environmental impact.** 3M in our original exemption dossier[3] provided evidence that concludes the CdSe based QDs used in the Quantum Dot Enhancement Film (QDEF) provide a net positive environmental impact.
   - Reduces the energy usage of TVs
   - This reduced demand for energy ultimately reduces emissions of pollutants such as Cd, other heavy metals, and greenhouse gases during the electricity production process at power plants
   - Provides an economic savings to consumers because the device is more energy efficient
   - The CdSe is bound within a solid matrix with no exposure to consumers
   - The majority of display devices in the EU are recycled or reused
   - Recycling activities are unlikely to result in any human or environmental exposure to these substances. 3M has conducted a wipe study[4] and TCLP[5] test to demonstrate that Cd is not leached from the product.

   3M is conducting an additional Life Cycle Assessment to reconfirm the original analysis.

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

[3] 3M(2013) Application for RoHS Exemption: Cadmium in LCD Quantum Dot Light Control Films and Components. Availabe at http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_IX/Request_2013-5/3M_QDEF_Exemption_Dossier.pdf

[4] NIOSH 9100 Wipe Tests for Cadmium in 3M QDEF Films for Optical Systems Division, Laboratory Request Number: E13-0646, SGS US-Testing Labs, November 25, 2013

[5] E12-00117 QDEF, Pace Analytical Services, Inc 3/01/2012 Available at http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_IX/Request_2013-5/E12-117_Final_Report_QDEF_Film_2__Public.pdf

Oeko-Institut Question 1e:

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.

3M DMSD Response to question 1e:

3M DMSD lists the justifications for Directive 2011/65/EU Article 5(I) (a) 1, 2, 3

Directive 2011/65/EU Article 5(I) (a)

1. their elimination or substitution via design changes or materials and components which do not require any of the materials or substances referred to in Article 4(1) is scientifically or technically impracticable;

There is no substitute for CdSe QDs that meet the color quality or energy consumption performance metrics required by 3M's customers in the electronics market. 3M, as a world's leading manufacturer of display film, has an open invitation to all QD manufacturers to purchase a non-Cd solution. Unfortunately, to date no substitutes that deliver color and energy performance required by our customers have been made available on the market. Therefore, the substitution of CdSe QDs is technically impracticable. The following assessment from Oeko-Institut/Fraunhofer-Institut's report is still valid.

> "*... However, most of these alternatives are said not to provide comparable colour gamut performance as is possible with Cd QD products, or otherwise to result in significantly higher energy consumption. Though the colour aspect could be seen as an aesthetic aspect, the applicants have provided quantifications of this quality that allow it to be addressed on a comparative and thus technical basis. In this sense, if the colour gamut aspect is to be understood to suffice, alternatives could be understood to provide performance inferior to that of the Cd QD applications****, thus meaning that elimination is not possible on the grounds that substitutes are not practical as the colour gamut provided would be significantly inferior to that of the discussed applications.*[6] "

2. the reliability of substitutes is not ensured;

There is no freely available substitute non-Cd QD solution on the market that can provide comparable color and energy properties to CdSe QDs. Tables 3 & 4 above demonstrate that the performance is not equivalent from a reliability performance point of view. Again, while a single manufacturer has made a single line of devices (TVs) available on the market using non-Cd based QDs, the material itself is not available for purchase by third parties and the performance of the Cd free material is not on par with that of CdSe QDs. **This situation illustrates that the reliability of substitutes is not ensured**. It is important to remember once the non-Cd QDs are available, it will still take up to 5 years or more to develop consumer electronic products incorporating those dots to meet the new color standards.

3. the total negative environmental, health and consumer safety impacts caused by substitution are likely to outweigh the total environmental, health and consumer safety benefits thereof;

The lower energy consumption of CdSe QDs containing display devices reduces the environmental pollutants during the electrical energy production process. There is also an economic benefit for consumers. Devices that use less energy are more efficient and cheaper to run. This translates into economic savings for the consumers.

[6] Pack 4 Report, page 87

This energy savings is achieved while providing a display device that does not result in any exposure of cadmium to the consumer since the CdSe QDs are bound in a film. Please refer to the answer to 4c below for additional information. The following statement from the Oeko-Institut/Fraunhofer-Institut report is still valid.

"The consultants conclude that the use of Cd in QD films used for solid state lighting and display lighting applications, would thus not weaken the environmental and health protection afforded by the REACH Regulation[7]"

Oeko-Institut Question 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

3M DMSD Response to question 2:

International Electrotechnical Commission has established IEC 62087 as the method of choice for evaluating television power consumption in the active use mode. A 10 minute video test clip is run and energy use is integrated to determine the power consumption in a real-world setting. Televisions can be put through this test in a variety of situations (dark room, bright room, different picture settings, etc.).

Oeko-Institut Question 3:

At the time of the first review, it was understood from various stakeholders that the Cd-based and Cd-free QD technologies were also being developed for possible use in the future in solid-state illumination applications. Please provide information: **3a:** 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. **3b:** For products mentioned in a, please clarify if products are still on the market or please explain why distribution was discontinued; **3c:** 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; **3d:** 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. **3e:** 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.

3M DMSD Response to question 3-3a to 3e:

3M is not currently developing QD solid state illumination products and cannot speak to these applications and questions posed in 3a to 3e.

Oeko-Institut Question 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:

[7] Pack 4 Report, page 71

Oeko-Institut Question 4a:

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;

3M DMSD Response to question 4a:

The QDs used in 3M DMSD's light control films are nanocrystals (~3-7µm in size) of a core/shell architecture. Cd selenide (CdSe) is the core material and Zinc sulphide (ZnS) is the shell material (see Figure 1). The exact substance is defined as "Siloxanes and Silicones, 3-[(2-aminoethyl) amino] propyl ME, di-Me, reaction products with Cd zinc selenide sulfide, lauric acid and oleylamine (CAS#1623456-05-2)".

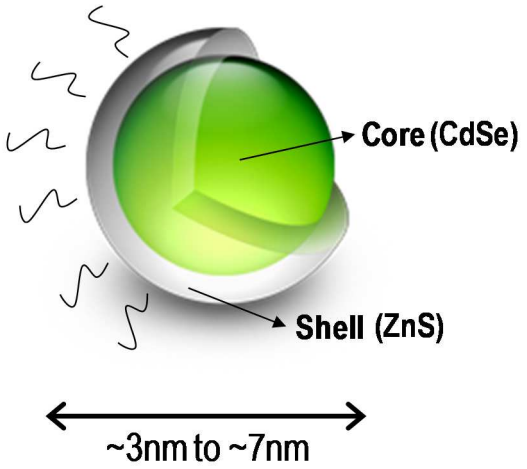


Figure 1. Diagram of a QD showing the core/shell architecture.

The CdSe QDs are the only available dots on the market. So long as market conditions remain favorable to this technology, 3M intends to keep CdSe QDs solution on the market until a viable alternative is available.

3M and 3M's technical partners are actively researching/developing a non-Cd based solution(s) that can meet requirements for future UHD broadcast TV and BluRay™ (Rec 2020) standards in conjunction with meeting energy efficiency targets. 3M is not a supplier of QDs and eagerly awaits a viable non-Cd based solution. When a viable non-Cd QD is available, 3M DMSD would convert to a non-Cd solution. Based on our extensive experience in manufacturing and commercializing display enhancement films, a very aggressive time estimate for the conversion to non-Cd technology would be a minimum of 5 years. Significant scientific and engineering work will be needed to successfully commercialize a film product. This includes new resin designs, coating scale-up, and sufficient time to test industry desired product life times of 30,000 hours. After the Cd free QD film is fully qualified, additional time is needed to design, specify, and qualify non-Cd film into a device and yet more time is need before the devices would appear on store shelves.

3M requests the full five years for the exemption beginning at the conclusion of this reassessment so the non-Cd technology can continue to be developed, commercialized and introduced into the market.

Oeko-Institut Question 4b:

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);

3M DMSD Response to question 4b:

CdSe QDs are the only solution on the market today and are the only solution expected to be on the market by the end of 2015. Again, while Samsung has introduced a TV line that utilizes a non-Cd solution, the use of that technology is limited and Samsung is not making the material available for third party purchases.

Oeko-Institut Question 4c:

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

3M DMSD Response to question 4c:

No toxicology data was identified for CAS 1623456-05-2, the specific cadmium selenide core QD used by 3M. Therefore, there are no hazard classifications or REACH restrictions assigned specifically to CAS 1623456-05-2. As described previously, the cadmium in the core of QD CAS 1623456-05-2 is cadmium selenide (CAS 1306-24-7). There was no toxicology data found specific to cadmium selenide. Instead, the classification of cadmium selenide as listed in Table 5 is based on the harmonized generic classifications of cadmium compounds and selenium compounds. At this point in time, it is unknown if the hazards associated with cadmium or cadmium selenide are appropriately applied to CAS 1623456-05-2, the specific cadmium selenide core QD used by 3M. 3M will continue to investigate the human health hazard potential for QD CAS 132645-05-2 and will inform the Oeko-Institut when a conclusion is reached.

In the absence of conclusive information on what human health hazards are appropriately applied to QD CAS 132645-05-2, 3M would take a very conservative approach and classify the dot with the most severe classifications applied to cadmium and cadmium selenide as shown in Table 5. Based on the human health hazard classifications only, 3M believes it is difficult to determine if a cadmium selenide core QD is more toxic, less toxic, or of equal toxicity to an indium phosphide core quantum dot, since both cadmium and indium phosphide have significant human health hazard classifications.

3M is aware that another producer has a QD based on a non-specified indium compound as opposed to cadmium selenide or indium phosphide based dots. Unfortunately, without access to the identity of the specific compound used in these quantum dots, a review of toxicology data is not possible; therefore, one cannot determine the potential health hazards of the compound. However, it is important to recognize that the absence of toxicology data and human health classifications for a particular compound does not indicate there are no hazards associated with that compound; it simply means the hazards are unknown. While it may seem preferable to replace a compound containing cadmium with an unidentified compound without known human health hazards, it is possible that there is no hazard reduction from replacing the cadmium containing compound, and that the replacement may be a regrettable substitution.

The presence of a hazardous material such as cadmium in 3M LCD Quantum Dot Enhancement Films does not mean that the 3M films incorporating the cadmium selenide core quantum dots pose a health risk. The human health hazards of quantum dots are inherent to the material itself, and both cadmium and indium phosphide share the inherent hazards of carcinogenesis, reproductive toxicity, and specific target organ toxicity. The actual health *risks* of cancer or reproductive toxicity, for example, are completely dependent upon exposure to the quantum dot. In the case of 3M LCD Quantum Dot Enhancement Films, there is no potential for exposure to the QD in consumer applications, and without exposure, there is no health risk.

3M previously outlined the potential QD exposure scenarios as documented in 3M Optical Systems Division (OSD) – Clarification Response for Exemption Request No. 2013-5 for Oeko-Institut.[8] For the consumer who purchases an electronic device containing a 3M LCD Quantum Dot Enhancement Film, there is no exposure to the quantum dot. In the quantum dot the core is made out of CdSe encapsulated within a shell of ZnS. The quantum dot is contained within a polymer matrix, the polymer matrix is bonded on each side by a barrier film, and the final product is enclosed within the electronic device. As mentioned above, without exposure to the quantum dot, there is no health risk.

In addition, to further ensure that workers handling 3M LCD Quantum Dot Enhancement Films would not be exposed to cadmium; 3M conducted wipe tests[4] of the product surface. Briefly, cloth pads were wetted with artificial perspiration, wiped repeatedly over the surface of the film, and then analyzed for the presence of cadmium. No cadmium was detected in these wipe tests, demonstrating that cadmium is bound within the film product and does not leach from the material.

In summary, cadmium and indium phosphide share significant human health hazards, such as carcinogenesis, reproductive toxicity, and specific target organ toxicity. However, given that there is no consumer exposure to the 3M LCD Quantum Dot Enhancement Film or the QD itself, neither the dot nor the film pose a health risk.

Please reference the Table 5 for a summary of EU Harmonized Human Health Classifications.

Table 5: EU Harmonized Human Health Classifications

Hazard class	Hazard statement
CdSe Core Quantum Dot (CAS: 1623456-05-2)	
No EU Harmonized or known industry classification	
Other relevant compound classifications	
Cadmium (EC: 231-152-8; CAS: 7440-43-9)	
Acute Toxicity 2	H330: Fatal if Inhaled.
Mutagenicity 2	H341: Suspected of causing genetic defects.
Carcinogenicity 1B	H350: May cause cancer.
Reproductive Toxicity 2	H361fd: Suspected of damaging fertility. Suspected of damaging the unborn child.
Specific Target Organ Toxicity - Repeat Exposure 1	H372: Causes damage to organs through prolonged or repeated exposure.

[8] This is the clarification response from 3M Optical Systems Division (OSD) for Exemption Request No. 2013-5. Exemption for "Cadmium in LCD Quantum Dot Light Control Films and Components" available at http://rohs.exemptions.oeko.info/fileadmin/user_upload/RoHS_IX/Request_2013-5/20130813_3M_OSD_Response_for_Exemption_Request_No._2013-5.pdf

Table 5: EU Harmonized Human Health Classifications	
Hazard class	**Hazard statement**
Cadmium selenide (EC: 215-148-3; CAS: 1306-24-7) – Classification based on generic classifications of selenium compounds and cadmium compounds	
Acute Toxicity 3	H301: Toxic if swallowed.
Acute Toxicity 4	H312: Harmful in contact with skin.
Acute Toxicity 3	H331: Toxic if inhaled.
Specific Target Organ Toxicity - Repeat Exposure 2	H373: May cause damage to organs through prolonged or repeated exposure.
Indium (EC :231-180-0; CAS: 7440-74-6)	
No EU Harmonized or known industry classification	
Indium phosphide (EC: 244-959-5; CAS: 22398-80-7)	
Carcinogenicity 1B	H350: May cause cancer.
Reproductive Toxicity 2	H361f: Suspected of damaging fertility.
Specific Target Organ Toxicity - Repeat Exposure 1	H372 (lungs): Causes damage to organs through prolonged or repeated exposure.

Refer to Table 6 for REACH Classifications.

Substance	REACH SVHC	Annex XVII:
CdSe	To date, Cd selenide (CdSe) has not yet been REACH registered in EU. Therefore, ECHA cannot fall back on the content of the REACH dossier for identification of this substance for SVHC. CdSe is not currently in scope to be added to the candidate list of SVHC for Authorization.	CdSe is not restricted per Annex XVII of REACH, for use in articles (complex articles). Potentially classified under cadmium compounds. Cd is included in Annex XVII REACH under entry 23, which is not relevant for the applications or technology concerned by this exemption extension requests 2013-5. The Cd QD is first incorporated into an amino silicone polymeric material. This amino silicone polymeric material is not a listed polymer type in Annex XVII item 23, so this REACH restriction is not applicable. For more details see separate dossier.[3]
Cd	Cd is on the candidate list of SHCH (Cd (CAS#7440-43-9) ED/69/2013). Please note that within the QDEF product the Cd is < 1000 PPM. Therefore, the Cd concentration meets the SVHC limits.	Cd is included in Annex XVII REACH under entry 23, which is not relevant for the applications or technology concerned by this exemption extension requests 2013-5. The Cd QD is first incorporated into an amino silicone polymeric material. This amino silicone polymeric material is not a listed polymer type in Annex XVII item 23, so this REACH restriction is not applicable. For more details see separate dossier.[3]
InP	To date, Indium phosphide (InP) has not yet been REACH registered in EU. Therefore, ECHA cannot fall back on the content of the REACH dossier for identification of these substances for SVHC. InP is not currently in scope to be added to the candidate list of SVHC for Authorization.	InP is not restricted per Annex XVII of REACH, for use in articles (complex articles).

Oeko-Institut Question 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:

Oeko-Institut Question 5a:

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;

3M DMSD Response to question 5a:

Non-Cd QDs have not been available to purchase. Although one manufacturer (Samsung) has put one line of TVs on the market containing a non-Cd (indium phosphide- InP) QD material, this is a captive supply used in only one line of TV, and the material is not made available for purchase by others. Tables 3 & 4 illustrate that InP QDs performance is inferior to CdSe based solutions. Therefore, even if InP QDs were available today the reliability of supply would not be ensured.

Oeko-Institut Question 5b:

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);

3M DMSD Response to question 5b:

Non-Cd QDs have not been available to purchase YTD. InP QD material is a captive supply and the material is not made available for purchase by others. Tables 3 & 4 illustrate that InP QDs performance is inferior to CdSe based solutions. While Nanoco-Dow has claimed to have developed a non-Cd QD that is not InP, their non-Cd QD is not available on the market and a comparison cannot be made.

Oeko-Institut Question 5c:

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.

3M DMSD Response to question 5c:

Please refer to tables 5&6 above and the answer to question 4c.

3M has demonstrated that each of the criteria of *Article 5(l) (a) have been met even in light of recent market changes, therefore, the original recommendation by the EU Commission to grant the exemption is still valid. With the introduction of new color standards and repeated delay of non-Cd based alternatives by leading QD manufacturers the original exemption expiration date of June 30, 2018 is too short to ensure reliable substitution in the market. 3M therefore respectfully requests a positive recommendation from the forthcoming reassessment granting an exemption for 5 years from the time of completion of the reassessment.*

Please contact me at (651) 736-2768 if there are any additional questions.

Sincerely,

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