QD VISION RESPONSE TO NANOCO'S OEKO INSTITUT SUBMISSION ON ROHS EXEMPTION 39B

This paper responds to aspects of Nanoco Group PLC's response to the questions from OEKO Institut on the public consultation regarding exemption Restriction of Hazardous Substances (RoHS) 39.b. As has been its pattern throughout the analysis of the exemption process, Nanoco's submission combines its unfulfilled promised product launches, and incomplete and/or incorrect statements to paint a picture that Nanoco wishes could be true, but simply is not.

In particular, we focus on the incomplete and/or incorrect statements and other inaccuracies of such response concerning:

1) the proper subject matter of this Oeko Institut inquiry;
2) product availability;
3) the technical criteria for assessing the validity of the exemption;
4) the appropriate colour gamut for measuring colour performance;
5) the proper focus of energy performance and the true energy efficiencies;
6) the relative safety and environmental friendliness of the applied cadmium and indium technologies; and
7) the disqualification of indium phosphide (InP) as a potential alternative for cadmium selenide (CdSe).

1. THE PROPER SUBJECT MATTER OF THIS OEKO INQUIRY

QD Vision and 3M have applied for an exemption for the use of CdSe quantum dots (QDs) in displays including those used in monitors and televisions. Displays for monitors and televisions utilize a collection of numerous, often interdependent technologies, each with its own properties and impact on both colour and energy performance. For example, colour performance can be materially affected by other components, such as colour filters and LEDs, used in a display. Energy consumption can also be dramatically influenced by, for example, the number and efficiency of the LEDs.

Because of this, the subject matter of the inquiry is properly focused on the performance of the QDs currently used in the displays - not the actual finished displays themselves. Such testing can be achieved only by comparing system-level performance of an identical display using QD films with CdSe and InP QDs – keeping all other elements the same.

2. PRODUCT AVAILABILITY

Oeko's decision should take into account the "availability" of substitutes and the socio-economic impact of substitution (article 5 of RoHS) - "availability of a substitute" means: "*the ability of a substitute to be manufactured and delivered within a reasonable period of time as compared with the time required for manufacturing and delivering the substances listed in Annex II"* (article 3 (25) of RoHS).

In its submission, Nanoco states that "the commercial availability of Cd-free QD materials and components is now well established." In fact, the opposite is true.

After years of promises, Nanoco's Cd-free QDs are still not available in the market. The company has yet to deliver a commercially-available Cd-free QD solution for use today in any monitor, television, or other type of display in Europe or anywhere else in the world. For purposes of Article 5 of RoHS, Nanoco's technology is therefore irrelevant because it is not available on the market, and has not been tested for reliability and long-term use.

Samsung does not sell its QDs to other display manufacturers. It simply produces InP QDs for inclusion in its own branded televisions. Samsung is therefore not a supplier of Cd-free QD materials and components *per se* to the market.

As 3M has explained in its recent submission:

> *"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."*

The presence of Samsung TVs that include Cd-free QD materials in the market is not synonymous with - nor evidence of - the availability of Cd-free QD materials and components.

In short, when considering the availability of Cd-free QDs for commercial displays, there are no alternatives. Any effort to eliminate the use of CdSe QDs in displays for all monitor manufacturers and other television manufacturers effectively removes all QDs useful for displays from the market. Such results would undermine EU antitrust law and policy.

Europe is beginning to experience the influx of a range of competitive CdSe QD television brands from Thompson, Hisense, and others, given the widespread availability on the market of CdSe QDs to all manufacturers. Eliminating CdSe QD materials and components from the market in combination with the effective unavailability of Cd-free QDs (since to date they are only available as a bundled component in a Samsung television) raises significant legal, commercial, and policy concerns.

A. Monitors

Monitors are the future of medical diagnostics, e-commerce, gaming, entertainment, and so much more. European competitiveness in these areas is dependent on unconstrained access to the same technologies used in the United States and Asia.

Nanoco's submission does not refer to a single QD-based monitor using anything other than CdSe QDs. This is because none exists. Even Samsung, one of the largest manufacturers of monitors in the world, does not produce a monitor based on InP QDs. This is because

1.) InP QDs have not proven stable enough to be used in close proximity to LEDs in a packaged edge optic, and

2.) the high costs of O_2-barrier film make the cost of film-based solutions non-competitive for use in monitors.

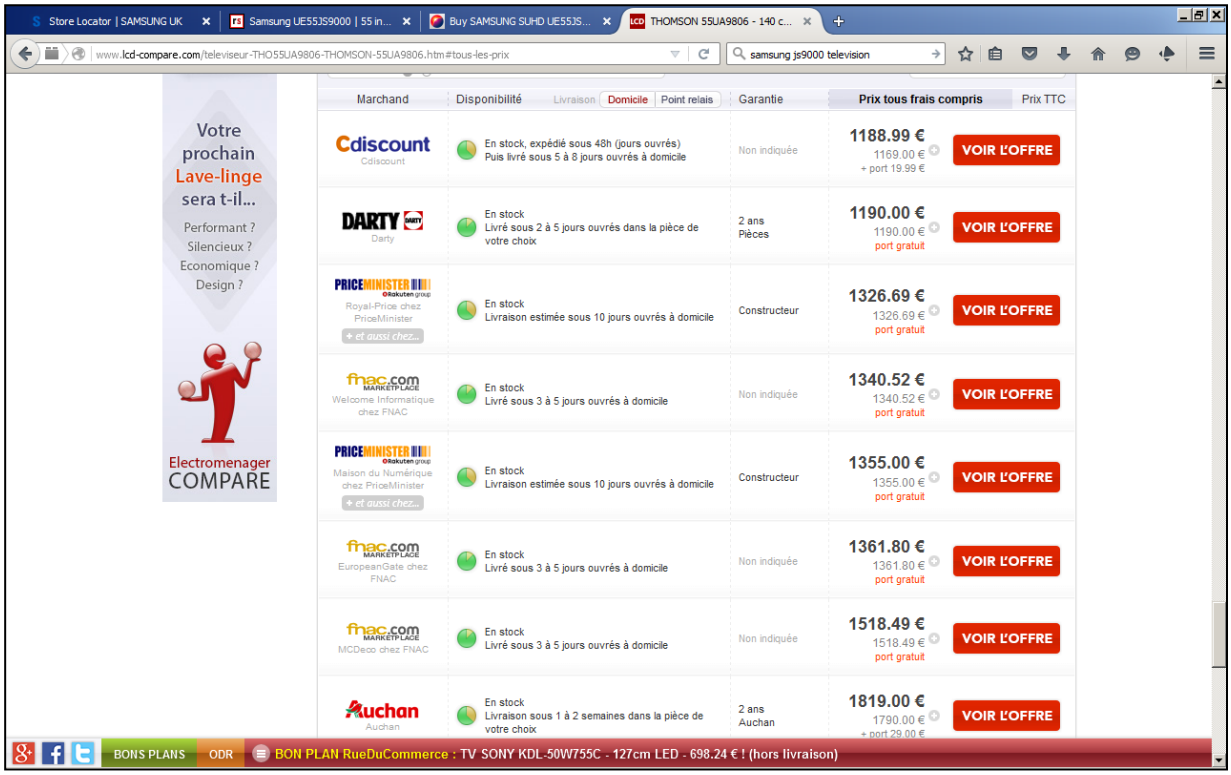
The only commercial QD-based monitors produced today use CdSe QDs. There is no alternative at this time. This fact alone should be sufficient to end the inquiry and sustain a CdSe QD exemption.

B. Televisions

As detailed above, Nanoco places wrongful reliance and wrongly makes claims regarding the availability of Samsung TVs. Nanoco also downplays the availability of the Philips TV and ignores the availability of the Thomson television based on QD Vision's CdSe QDs. This incorrect assessment is likely the result of overly simplistic research – perhaps as simple as conducting a basic Google search from a computer based in the UK. Google search algorithm is location-sensitive and often limits its results to the country from which the search is originated. As a counter-example, a similar search for Samsung's SUHD televisions in Croatia reveals no online or retail availability.

On the other hand, a recent online search (see below) performed in Brussels for the Thomson 55UA9806 (Color IQ™ QD-based) 55" television showed availability at a number of online retailers at prices ranging from €1200-1800.

QD Vision's Brussels-based consultant, EPPA SA, independently ordered a Thomson 55UA9806 which was delivered on 21st of November. EPPA also ordered three Philips monitors and, while the retailer confirmed that Philips will deliver them as soon as possible, they are out of stock due to sales success. The order was accepted and delivery will occur in January 2016.



SCREENSHOT FROM LCD COMPARE WEBSITE; 10 NOVEMBER 2015 10:34AM CET

An important dimension of availability is price; moreover, the cost of substitution also determines the "socioeconomic impacts" of substitution.[1] Just because a product is physically in the market does not necessarily mean it is truly "available" to most consumers. Because InP QDs have been deployed only in a more expensive O_2 barrier film solution, current end products based on them cost far more at retail.

As an example, the lowest price found in Europe for a Samsung InP QD-based television is 1700 GBP or over €2400. In contrast, the Thomson CdSe QD television is widely available for less than €1200 - roughly half the lowest price for the Samsung. The respective list prices of these televisions are 3000 GBP or €4280 for the Samsung and €1880 EURO for the Thomson. Thus, while a Samsung bundled InP QD-based television might be physically available, because of the higher prices, such products are in reality available only to a fraction of the consuming public and, for that reason, cannot be considered to satisfy the "availability" requirement.

In other markets, comparable CdSe QD-based products from Hisense and Philips are available at even lower prices, because they do not contain the high-end differentiating features (*e.g.*, Harman-Kardon speakers) of the Thomson television. These products are expected to be made available in Europe in early 2016.

[1] The price of a substitution product has been taken into account to assess the socioeconomic impacts of a substitute as part of previous exemption evaluations.

In sum, while Nanoco claims that "Cd-free QD displays have an overwhelming market share compared to Cd-based QD displays," its own submission confirms that CdSe QDs represent 100% of the market for monitors, 100% of the supply of QDs for manufacturers of televisions, and the only truly "available" televisions in the market based on retail price.

3. TECHNICAL CRITERIA FOR ASSESSING THE VALIDITY OF THE EXEMPTION

In its submission, Nanoco incorrectly asserts that the only criterion for assessment should be the relative toxicity of the different compounds. In fact, the directive identifies a number of compounds which should be phased out unless they offer some desirable technical characteristics that cannot otherwise be obtained. This is the case with CdSe QDs. The technical characteristics and corresponding benefits of CdSe QDs that to date have not and cannot be matched by alternative QD materials include:

A. *Colour performance* - Prior to the use of CdSe QDs, most of today's displays only showed about one-third of the colours that the human eye can see. CdSe QD solutions enable almost twice that – enhancing the clarity of medical diagnoses, improving entertainment experience, and reducing the inefficiencies of colour-related returns in e-commerce. This is a measurable technological edge that InP QDs so far cannot match.
B. *Energy-efficiency* – Laboratory tests show that CdSe QD displays are significantly more energy efficient than any other wide colour gamut technology available on LCDs today, while producing the benefit of a much wider colour gamut. These potential energy savings would translate to over €3B in avoided energy costs every year in Europe alone. Because of their limited colour performance, solutions based on InP QDs use significantly more energy than even today's phosphor-based displays.
C. *Safety and environmental friendliness* – This energy savings potential would translate to almost 7 million tonnes of avoided CO_2 production per year. And, because fossil fuel-powered electrical production plants are a leading source of elemental (or "free") cadmium in the atmosphere, CdSe QD displays result in a net reduction in free cadmium in the environment. In fact, 1.5 mg of CdSe in a typical 55" television would result in a net 40 mg reduction in free cadmium in the environment over the average life of the TV. Said another way, InP QD displays result in the release of more free cadmium into the environment than those using CdSe QDs.

These are measurable, tangible benefits that also fit within the letter and spirit of European policies to improve energy efficiency and reduce wasteful uses.

Still, reducing the amount of elemental cadmium and indium in the environment is an important goal, and QD Vision is working to develop both QDs based on other compounds and products with cadmium levels below the 0.01%[2] threshold. But, for today, having tested both cadmium and indium based QD products, QD Vision has found that only CdSe offers the full benefits of colour performance, energy, safety, and environmental friendliness.

4. APPROPRIATE COLOUR GAMUT FOR MEASURING COLOUR PERFORMANCE

A widely recognized reason for using QD technology in display products is to provide improved colour gamut. The importance of improved colour gamut is confirmed by the growing list of global technology leaders that have made significant commitments to supporting wide colour gamut standards in the near future. Examples of these commitments include:

- BBC has disclosed plans to broadcast 4K TV programs and channels in 2016 – including a wider colour gamut
- Japan's NHK will broadcast the 2020 Summer Olympics using the Rec. 2020 specification

- Rec. 2020 is the basis for the new Ultra UHD Blu-Ray spec and the CEA's new "HDR Compatible" specification
- Others committed to Rec. 2020 include Intel, Netflix, Sharp, 3M, Google, Sony, and Canon

Given the amount of industry support for Rec. 2020, benchmarking colour performance to historical standards such as sRGB and NTSC - which correlate to only one-third of the colours of the human visible spectrum – and DCI-P3, which is only slightly larger than sRGB and NTSC, ignores the current gamut coverage requirements of today's commercial market and would be a mistake. With the advent and adoption of new technologies that far exceed these historical standards, they are rapidly losing market relevance.

The Rec. 2020 specification was approved in October 2015[2] and is now an industry standard. It is true that meeting it is challenging. But the whole point of new standards is to set a bar that companies must aim for, but cannot fully meet at adoption. Otherwise, the standard would be meaningless. In truth, while it is generally understood in the industry that CdSe QDs show the promise of achieving Rec. 2020 colour gamut targets, there is currently no known technical path to Rec. 2020 for InP QDs.

Nanoco also alleges that QD Vision has asked for a change to the Rec 2020 standard, and implies that this somehow disqualifies the standard. Once again, the truth is far different. QD Vision has fully supported the Rec. 2020 standard and has simply proposed a small change to the green primary colour point. The fact is that a number of companies, including 3M, Nanosys, and QD Vision, are proposing a minor shift in the primary wavelength for the green primary colour point that will make the specification more commercially achievable – benefitting both manufacturers, including Nanoco, and consumers worldwide.

The suggested change was made ultimately for the benefit of the consumers so that reasonably priced Rec. 2020 finished products could be produced. Nanoco's objection unnecessarily casts a doubt on a reasonable technical request by QD Vision in the process of assisting in the drafting of the new standard.

Having first tried improperly to discredit the most meaningful standard in the industry today, Nanoco then tries to confuse the evaluation of the comparative colour performance by including a TV based on Samsung's bundled and not commercially-available InP QDs as well as a hypothetical solution based on Nanoco's "product" which has yet to be introduced to the market. Nanoco also asserts the colour gamut performance of its limited list of solutions without offering any clear standards or independent testing methodologies to justify its claims. In contrast, in our opening filing, QD Vision submitted clear performance scores based on accepted methodologies. These conclusions were independently confirmed in the submission prepared by 3M. Since then QD Vision retained Gamma Scientific to independently verify the results under strict IEC and ISO protocols. The results are totally coherent with QD Vision's earlier claims and show the vast superiority of CdSe QDs over InP QDs – the latter performing no better than classic phosphor technologies. Given the vague and lightweight nature of the claims made by Nanoco, they fall far short of contradicting the solidly supported conclusions reached by 3M and QD Vision, conclusions that can be verified independently according to the published methodologies for verification by independent and accredited authorities.

5. PROPER FOCUS OF ENERGY PERFORMANCE AND TRUE ENERGY EFFICIENCIES

Nanoco argues first that energy efficiency is a secondary factor. In fact, the importance of energy efficiency in widely adopted consumer products is universally recognized and rewarded. The recent, landmark commitment by 195 nations to reduce greenhouse gases reflects an unprecedented global alignment to be more responsible for managing our impact on the environment. NGOs and governments alike have insisted energy efficiency

[2] http://www.itu.int/rec/R-REC-BT.2020/en

should be designed into new electronic equipment from the very start. Viewed in this light, energy consumption is becoming one of the most important commonalities in evaluating the overall impact of new technologies.

The dramatic energy efficiency of CdSe QDs was a major factor in granting the original exemption, as confirmed by Oeko Institut, the European Commission, the European Parliament, and the country representatives. Therefore, describing energy efficiency as a "secondary factor" reflects a lack of understanding of this important variable and an attempt to downplay a competitive performance deficiency.

Turning to relative energy efficiency, Nanoco distorts the results by failing to use equivalent environments. Unlike Nanoco, in its pending applications, QD Vision and 3M focus on QD performance and its specific relationship to energy consumption in otherwise equivalent displays, in summary:

- To deliver the wider colour gamut of CdSe QD displays, InP QD displays would require thicker, less energy-efficient color filters, resulting in higher energy use and cost. In this configuration, the InP solution would consume +40% more electricity than the CdSe solution.

- When benchmarked to the limited colour gamut performance (*i.e.,* a comparison based on the maximum performance of Samsung's InP QDs on the market today), simulations of CdSe QD-based displays suggest a +30% energy efficiency advantage over InP QD-based displays.

- In a related test conducted by 3M, using the same Samsung televisions while maintaining equivalent luminance levels and exchanging only the QD film, "the two TVs with Cd-based QDs consumed 15% and 29% less power than the TVs with InP QDs while still providing 12% and 13% higher color."

These more rigorous comparisons are completely counter to the remarks in Nanoco's submission, which were based on marketing claims and product packaging rather than laboratory testing. In addition, independent lab results[3] confirm the opportunity for substantial energy savings associated with the use of CdSe-based QDs – while highlighting the significant increase in energy consumed by televisions configured with InP QDs. In a world growing increasingly sensitive to the penalties of an expanding carbon footprint, the case for InP QDs as a legitimate alternative is wrong and arguably environmentally irresponsible.

6. RELATIVE SAFETY AND ENVIRONMENTAL ASPECTS OF THE APPLIED QD TECHNOLOGIES

Nanoco conveniently confuses CdSe QDs, containing cadmium selenide, with free cadmium.

As QD Vision explained in its initial response, use of CdSe QDs in displays would actually reduce the amount of free cadmium released into the environment in Europe as a result of the superior energy savings. Indeed, given its higher energy consumption and the direct relationship between electricity from carbon and free cadmium, the use of InP QDs actually releases far more free cadmium into the environment than use of CdSe QDs. Moreover, on a life-cycle analysis, the use of CdSe QDs helps to enhance the recycling of recycled cadmium in Europe from various sources, including used NiCd batteries.

In its submission, Nanoco suggests that CdSe QDs would potentially be harmful to the consumer. This suggestion is also misleading. As noted above, only 1.5 mg of CdSe QDs are used in a 55" display, and these QDs are encapsulated in a polymer matrix, so there is virtually no risk of consumer exposure. The only point of possible exposure would be during the recycling process. In our extensive life cycle assessment, we confirmed what Umicore – the world's largest electronic recycler -- had stated: that the added risk of the tiny amount of cadmium has no effect on the total risk for the worker. Further, as noted on page 61 of the Pack 4 report issued by the Oeko Institut on 22 April 2014, an assessment of the hazards of Cd and potential exposures to workers

[3] Annex: Performance Benchmarking of Wide Color Gamut Displays

during the recycling of LCD televisions shows that the risk is controlled and no effect on the health of the workers involved is anticipated. Other aspects of the television recycling process are much more hazardous and require such protective measures that the potential exposure of a worker to the cadmium is either hypothetical or immaterial.

7. DISQUALIFYING INDIUM PHOSPHIDE AS A POTENTIAL ALTERNATIVE FOR CADMIUM SELENIDE

In addition to all of the above arguments demonstrating that InP is not an alternative to CdSe based on lack of availability, failure to deliver comparable colour, energy inefficiency, and lack of comparable environmental safety, InP also is actually disqualified from being considered as an alternative.

According to article 5, paragraph 1a of the RoHS Directive, exemptions should be permitted if the negative environmental, health, and consumer safety impacts caused by substitution are likely to outweigh the environmental, health and consumer safety benefits of the substitution. When viewed from this perspective, InP is not an alternative to CdSe, as its hazardous properties lead to weakening the environmental and health protection. Moreover, InP is prioritised by the EU Commission for a restriction under RoHS.

While CdSe is not classified, InP combines several hazardous characteristics - Carcinogen cat 1B, Reprotoxic Category 2 and STOT RE 1 (Specific Target Organ Toxicity – Repeated Exposure).

In 2014 the EU Commission launched a major work on Methodology for Identification and Assessment of Substances for Inclusion in the List of Restricted Substances under the RoHS2. As a result a methodology manual[4] has been published together with substance inventory. Over 11 000 substances have been assessed according to the prioritisation criteria for health and environment hazard and waste relevance (negative impact during EEE waste management operations). Eighty of these substances have been prioritised in a Priory list[5] for restriction under RoHS. InP is one of them.

InP has been identified in the Group 1 of highest possible concern for Human Health Hazard as it meets several of the hazardous criteria – InP is a carcinogen category 1B, reprotox cat 2 and STOT Re 1. InP has also met the criteria for the highest concern related to the negative impacts in the EEE waste management. As a result, InP has been ranked 18th and included in the Fourth priority group for RoHS restrictions[6].

In March 2015 the European Commission has already restricted[7] the first four substances from this RoHS priority list. InP is now 14th priority for restriction. In addition to the regulatory prioritisation, InP has been short listed by leading NGOs such as ChemSec Substitute It Now (SIN) list[8]. Substituting with InP is therefore not a regulatory option as it is already prioritised for a restriction under RoHS.

For all of the reasons cited here and in QD Vision's and 3M's earlier submission, the CdSe QD exemption should be sustained.

[4] http://www.umweltbundesamt.at/fileadmin/site/umweltthemen/abfall/ROHS/finalresults/Annex1_Manual.pdf
[5] http://www.umweltbundesamt.at/rohs2
[6] http://rohs.exemptions.oeko.info/?id=213
[7] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32015L0863&from=EN
[8] http://sinlist.chemsec.org/keywords/22398-80-7

Abbreviations and Definitions

QD	Quantum dot(s)
CdSe	Cadmium selenide
InP	Indium phosphide (formerly referred to as "cadmium-free" in other documents)
CdSe QDs	QDs including a CdSe core typically surrounded by a semiconductor shell
InP QDs	QDs including an InP core typically surrounded by a semiconductor shell