Cleeve Road, Leatherhead
Surrey, KT22 7SA, UK
T: +44 (0) 1372 367221

Report Title:	**Socio-economic assessment for Cd QD displays**
Author(s):	Dr. Paul Goodman
Client:	3M Display Materials & Systems Division
Client Reference:	
Report Number:	2015-0001
Project Number:	REG0273001
Report Version:	Final Report
Document Control:	For publication

Report Checked by:

Dr. Alex Martin
Senior Regulatory Consultant

Report approved by:

Dr. Chris Robertson
Head of Regulatory Compliance

January 2016

Ref. REG0273001 3M socio economic report

ERA Technology Limited
Cleeve Road
Leatherhead
Surrey KT22 7SA, England
Tel : +44 (0) 1372 367350
Fax: +44 (0) 1372 367359

Read more about Edif ERA on our Internet page at: www.edifgroup.com

1. Introduction

3M uses cadmium selenide based quantum dots (Cd QD) to manufacture display films that are used in televisions, smart phones and other display devices. These have the technical advantage of a wider colour gamut than available alternative technologies. There are many types of display on the market, but each has different performance image quality and reliability. Cd QD not only has a technical advantage in colour gamut, but 3M has also shown that the display results in a smaller energy consumption than standard LED-LCD displays and a recently introduced TV that uses a display using indium phosphide (InP) quantum dots. A detailed LCA has been generated that compares the overall health and environmental impacts and this socio-economic analysis compares the impacts of these technologies on human health, the environment, industry and consumers. This is based on guidance published by the European Chemicals Agency (ECHA) on socio-economic assessments for REACH restrictions[1].

2. Health and environmental impacts

2.1 Manufacture phase

Exposure / pollution potentially could occur during manufacture of QD material and QD film. However, the operation entails small/medium -scale wet chemical processes and no dust or air emissions of cadmium occur. A small amount of solid waste is generated that is disposed of by licensed hazardous waste operators so that no adverse health or environmental impact occurs. Manufacture phase impacts are considered in detail in the 3M Life Cycle Assessment (LCA).

2.2 Use phase

Consumer exposure from inhalation, consumption and/or absorption and leaks of cadmium into the environment during the use phase are not possible and do not occur. However, cadmium and other toxic substances that are present in coal and oil are emitted and occur in waste from electricity generation. The use of a Cd QD TV will result in less cadmium in emissions and waste from electricity generation since these have been shown by comparative measurements to be more energy efficient than standard designs of LCDs and also InP QD LCDs used in a television.

3M have compared a standard television (TV1 from 3M's LCA) with the same television with the display replaced by a 3M Cd QD display (TV2 from the LCA) and these have been tested under a variety of operating conditions. With the same luminance, but wider colour gamut for the Cd QD TV,

[1] http://echa.europa.eu/documents/10162/13641/sea_restrictions_en.pdf

the use phase energy consumption (i.e. electricity) of the Cd QD TV (TV2) was found to depend on TV screen size. A typical value is a saving of **42%**[2] compared to a standard TV (TV1).

When a 3M Cd QD display was compared with commercial InP QD displays installed in two models of TV at constant luminance, but wider colour gamut dor the CD QD version, the Cd QD display TV consumed **14%** and **22%** less electricity. 14% has been used for the calculations below[3]. A third scenario is where the luminance and colour gamut of the two display types are the same. This is not measurable experimentally, but it has been estimated by 3M that the Cd QD TV would consume **22%** less electricity than the InP QD TV.

Environmental and health benefits compared to the current situation with standard LCD TVs would be achieved by a reduction in cadmium emissions to air and in solid waste due to lower electricity consumption, as well as from a reduction in the amounts of the other toxic substances present in coal and oil and greenhouse gas emissions.

Reduction in electricity generation

Source One[4] show that a standard design 55 inch LCD TV consumes 239.83 watts in the operating mode and so this standard LCD TV will consume 350.2 kWh electricity per year assuming 4 hours viewing per day. Therefore the annual electricity saving, assuming 4 hours viewing per year which is the average EU daily viewing time[5] will be:

Savings from Cd QD display in comparison with	Measured energy saving	Electricity saved per year (4 h / day) per TV	EU electricity saving assuming 10% are Cd QD[6]
Standard LCD	42%	147.1 kWh	6,350 million kWh / yr
InP QD display	14%	49 kWh	2,119 million kWh / yr
InP QD same luminance and colour gamut	22%	77 kWh	3,330 million kWh / yr

Note that actual electricity savings are slightly higher as the above figures do not include transmission and distribution losses estimated to be 6.7%.

[2] Data from 3M LCA – TV1 use phase = 2.73 x 10^4 MJ and TV2 use phase = 1.57 x 10^4 MJ. The savings as TV screen size dependent, figure 2 of the 3M LCA shows that electricity savings (TV2 over TV1) are 41% for 48 inch and 45% for 65 inch TVs. Therefore, a saving of 42% has been used for this assessment.
[3] Data from table 5 of 3M submission to stakeholder consultation (answers to Q2b), January 2016
[4] SourceOne Inc, "Quantum Dot Enhancement Film Cadmium Emissions Analysis European Energy Mix", report prepared for Nanosys, November 2013.
[5] JRC report on ecolabel for televisions
[6] Recent research shows that there are two TVs per EU household, there are 216 million households

The saving in electricity generation is equivalent to reduced cadmium emissions to air, reduced solid waste that contains cadmium and reduced CO_2 emissions.

Cadmium in solid waste: Electricity generation from coal globally requires about 1kg for 2kWh[7]. The cadmium content of coal and oil are very variable.

Coal is a naturally occurring mineral and so the concentration of impurities inevitably is very variable, even within one mine. It is therefore not possible to find a published average value of cadmium content and it is more realistic to consider the range of values that occurs in most coal used in the EU to generate electricity. A publication by Swaine[8] has collated data from previous publications with coal cadmium content data. The data for European coal sources are summarised below:

Source	Cadmium content in ppm (mg /kg)
France (two areas)	<0.1 and 0.03
Germany - Ruhr	0.5 to 10
Germany - various	0.02 to 21
Poland – Belchatow mine	Two ranges given: 3.2 to 7.9 and 0 to 4
Poland – coal used for power generation	<0.03
Poland – 7 mines	1.9 to 4.9
UK – South Yorkshire	0.03 to 0.1
UK – 20 areas	0.02 to 5
UK – 23 coal mines	<0.03 to 3.4
Bulgaria	1.9

Clearly, a complex mix of sources is used in the EU to generate electricity, and coal, with a very low concentration of cadmium, cannot always be used. The most common range overall appears from

[7] http://www.euractiv.com/energy/analysis-efficiency-coal-fired-power-stations-evolution-prospects/article-154672

[8] D. J. Swaine, Trace Elements in Coal", Butterworths, 1990

the table above to be in the range 0.02 to 5 ppm of cadmium and so an average of 2 ppm or 2 mg / kg is used here.

Crude oil does however contain cadmium in similar concentrations as in coal. This is not surprising as both coal and crude oil are derived from the same material, i.e. pre-historic vegetable matter. Published examples include[9]:

Source	Cadmium content in ppm
Arabian Light	2.1
Iranian Heavy	1.44
Arabian Heavy	0.54
Iranian Light	0.76
Kuwait	<0.4
Statfjord	2.4
Oseburg	2.1
Ural	0.69

The Best Available Techniques (BAT) Reference Document for the Refining of Mineral Oil and Gas gives a global range of cadmium in crude oil of 0.10 – 29.1 mg/kg[10].

Electricity is generated from refined fuel oil which may not itself contain cadmium as it is removed by the oil refining process and so it either occurs in solid wastes or in heavy fractions such as bitumen. Oil is refined both inside the EU and outside the EU, but cadmium will occur in waste wherever this is carried out. Oil accounts for only 3% of the EU's electricity generation currently. If the average cadmium content of crude oil is assumed to be 1ppm (1mgCd/kg of crude oil), then assuming that 1kg oil generates 2kWh electricity is shown below:

[9] Oil and Gas Journal, from a Dutch study. 1999.
[10] http://eippcb.jrc.ec.europa.eu/reference/BREF/REF_BREF_2015.pdf

The estimated amount of cadmium in solid waste electricity generation from coal and oil avoided by using Cd QD displays in TVs would be:

Energy source	Coal	Oil
µg Cd in waste / kg fuel	2	1
% of EU electricity from fuel	30%	3%
Comparison of Cd QD with standard LCD	147.1 kWh saved per TV per year	
Savings due to coal / oil	44.1 kWh	4.4 kWh
Kg fuel saved (2kW/kg fuel)	22 kg	2.2 kg
Cd in solid waste saved / TV / year	44mg	2.2mg
Cd in solid waste saved / TV / 10 year lifetime[11]	440 mg	22 mg
Cd in solid waste saved / year if 10% of EU TVs used Cd QD	1.9 tonnes / year	95 kg / year
Comparison of Cd QD with InP QD	49 kWh / year saved	
Savings from fuel	14.7 kWh	1.5 kWh
Kg fuel saved (2kW/kg fuel)	7.4 kg	0.7 kg
Cd in solid waste saved / TV / year	14.7 mg	0.7mg
Cd in solid waste saved / TV / 10 year lifetime	147 mg	7.4 mg
Cd in solid waste saved / year if 10% of EU TVs used Cd QD	637 kg / year	32 kg / year
Comparison of Cd QD with InP QD with the same luminance and colour gamut	77 kWh / year saved	
Savings from fuel	11.6 kWh	1.1 kW
Kg fuel saved (2kW/kg fuel)	5.8 kg	0.5 kg
Cd in solid waste saved / TV / year	23.1 mg	1.1 mg
Cd in solid waste saved / TV / 10 year lifetime	231 mg	11 mg
Cd in solid waste saved / year if 10% of EU TVs used Cd QD	1,001 kg / year	50 kg / year

One 55 inch Cd QD TV contains **39.7 mg Cd**, whereas the lifetime saving of cadmium in solid waste is as follows:

[11] http://www.eupnetwork.de/fileadmin/user_upload/Produktgruppen/Lots/Final_Documents/Lot_5_Final_Report_1-8.pdf

10 year lifetime	Coal saving	Oil saving	Total	Total saving including transmission and distribution losses / TV
Compared to standard LCD	440 mg	22 mg	462 mg Cd	493 mg Cd
Compared with InP QD	147 mg	7.4 mg	154.4 mg Cd	165 mg Cd
Comparison of Cd QD with InP QD with the same luminance and colour gamut	231 mg	11 mg	242 mg Cd	259 mg Cd

Air emissions: Source One[4] finds that 3.46 µg Cd is emitted per kWh generated.

10 year lifetime emissions of cadmium to air avoided would be:

10 year lifetime	Electricity saved kWh	µg Cd emitted	Total including transmission and distribution losses / TV
Compared to standard LCD	1471	5.09 mg	5.43 mg
Compared with InP QD	490	1.72 mg	1.81 mg Cd
Comparison of Cd QD with InP QD with the same luminance and colour gamut	770	2.66 mg	2.84 mg Cd

Reduction in greenhouse gas emissions as tonnes equivalent CO2

Method 1: Source One[4] estimate that each 55 inch Cd QD TV avoids emission of 2,438 kg of CO2 equivalent greenhouse gas emissions when compared to a traditional TV over 50,000 hours of usage.

Recent research shows that there are on average two TVs per EU household, there are 216 million households, and TVs are typically watched for 4 hours per day, so for 1,460 hours per year. Therefore, the saving would be 30 billion tonnes equivalent of CO2 if all TVs were Cd QD types and 3 billion tonnes if only 10% use this technology.

Method 2: Using the above calculations of electricity savings and IEA data which shows for OECD countries in Europe, that greenhouse gas emissions from electricity generation is 0.4517

kgCO2e/kWh.[12] The annual EU energy savings (assuming 2 x 216 million TVs) would avoid emissions of:

Comparison	Electricity saved kWh / TV / yr	Total saving assuming 10% are Cd QD	Annual tonnes CO2e saving (10% of TVs are Cd QD)
Compared to standard LCD	147.1	6,355 million kWh / y	2,870,000 tonnes
Compared with InP QD	49	2,117 million kWh / y	956,000 tonnes
Comparison of Cd QD with InP QD with the same luminance and colour gamut	77	3,327 million kWh / y	1,502,300 tonnes

Monetary value of reduced electricity consumption due to cadmium in solid waste

There are potential health benefits from avoiding landfill of cadmium and other toxic substances in electricity generation waste.

The calculations above show the quantity of cadmium in solid waste avoided for two scenarios. The quantity of cadmium in solid waste avoided is:

Scenario	Cd in solid waste / TV / year	Including transmission and distribution losses	Amount of Cd in waste per year for 10% of EU TVs are Cd QD
Compared to standard LCD	46.2 mg	49.3 mg	2,129 kg
Compared with InP QD	15.4 mg	16.5 mg	714 kg
Comparison of Cd QD with InP QD with the same luminance and colour gamut	24.2 mg	25.9 mg	1,121 kg

A study by COWI[13] has attempted to monetise the health and other benefits from avoiding cadmium in solid waste and gives a value of £1.28 million per tonne of cadmium in solid waste and so monetary benefit from 10% of TVs using Cd QD technology (£/€ exchange rate used = 1.4).

Compared to standard LCD (TV1)	€3.8 million per year

[12] http://ecometrica.com/assets/Electricity-specific-emission-factors-for-grid-electricity.pdf

[13] Included in a report for Defra available from http://webarchive.nationalarchives.gov.uk/20130123162956/http:/www.defra.gov.uk/environment/waste/research/health/pdf/costbenefit-valuation.pdf

Compared with InP QD	€1.28 million per year
Comparison of Cd QD with InP QD with the same luminance and colour gamut	€2.01 million per year

The true benefit will, however, be higher as this technology is also used in other types of display devices. Other toxic substances including mercury, lead and arsenic are also present in coal and oil and so these are also avoided and so provide additional benefits.

2.3 End of life phase

The end of life phase is considered by 3M's LCA and shows negative values for all impacts. Recycling processes in the EU are regulated by the Industrial Emissions Directive and this restricts emissions of all hazardous substances including cadmium. Therefore it is necessary for waste electrical equipment recyclers to recover cadmium in order to prevent pollution. The IED is enforced in the EU to ensure that cadmium emissions do not exceed safe limits and so there is a mechanism already in place to ensure that safe recovery does occur. Furthermore, 3M's LCA includes the impacts at end of life and the University of Antwerp LCA assumes a worst case scenario where uncontrolled open air incineration is carried out, although this is very uncommon in the EU. Despite this, most of the overall impacts from Cd QD displays are less negative than with the alternative standard LED-LCD and InP QD displays.

3. Employment – in the EU and elsewhere

The situation with regards employment is as follows:

- EU employment: There are very few EU manufacturers of QD materials suitable for displays. Display technology is also mostly manufactured in Asia, not in the EU.
- Non-EU employment: Most Cd-based QD material manufacturers are located outside of the EU (many are in the USA) and most of these companies are SMEs. These supply larger companies that produce films which are used in display and lighting products.

Without exemption 39, the businesses that produce Cd QD materials could not exist and are likely to cease trading. The film and display device manufacturers could continue to operate only if a suitable alternative was freely available in sufficient quantities. Currently, 3M has been unable to source alternatives to Cd QD that give similar performance and reliability and it is likely that inferior performance products could not complete as effectively with traditional technologies.

3.1 Consumer electricity saving

The above calculations show the potential electricity saving from Cd QD displays in comparison with standard LCDs and with InP QD displays. The average EU28 consumer electricity price is €0.208 / kWh[14] and so the annual saving will be:

Scenario	Annual electricity saving (kWh)	Annual EU electricity saving assuming 10% are Cd QD	Annual consumer electricity saving (10% of TVs are Cd QD)
Compared to standard LCD	147.1 kWh	6.35 billion kWh	€1,230 million
Compared with InP QD	52.5 kWh	2.27 billion kWh	€470 million
Comparison of Cd QD with InP QD with the same luminance and colour gamut	82.5 kWh	3.57 billion kWh	€739 million

There will in addition be significant consumer electricity savings from QD monitors, computers, tablets and smartphones.

3.2 Impact on consumers due to product price, product reliability, image quality

Recent history suggests that consumers are seeking to enhance their television viewing through progressively better quality images. The superior colour gamut of Cd QD TVs satisfies this demand and so is likely to be popular as long as prices are not significantly higher and reliability is not inferior. As the change from phosphor film to QD film is relatively straightforward and Cd QD reliability has been shown to be as good as traditional technology, consumers are likely to experience only minimal price differences due to cost of materials and no decrease in reliability as Cd QD TV availability increases. Moreover, many Cd QD display products are already on the market and are no more expensive than other products that give high performance images.

3.3 Impact on competitiveness

There are many manufacturers of Cd QD materials and anyone can use these to make films and display products, as long as they have the necessary expertise. Only one manufacturer claims to have a Cd-free QD material, although 3M has been unable to source this so it is not freely available. Removal of exemption 39 would therefore have a significant negative impact on competitiveness.

[14] http://ec.europa.eu/eurostat/statistics-explained/index.php/File:Half-yearly_electricity_and_gas_prices,_second_half_of_year,_2012%E2%80%9314_(EUR_per_kWh)_YB15.png

3.4 Impact on SMEs

Most Cd QD material manufacturers are SMEs and without exemption 39 would be forced to cease trading.

3.5 Impact on innovation

3M has shown that Cd QD provides the best performance and energy efficiency and this material can be used in all types of display technology as well as in lighting. Removal of exemption 39 would stop further innovation in this area so that future designs of display and lighting would consume more energy and provide inferior performance. This is because there are no suitable substitutes to Cd QD materials commercially available that give equivalent performance.

