Quantum Dot Enhancement Film
Cadmium Emissions Analysis
European Energy Mix

PREPARED FOR:

nanosys™

PREPARED BY:

SourceOne, Inc.
53 State St, FL 12
Boston, MA 02109
Phone: (617-399-6100
www.sourceone-energy.com

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Introduction

SourceOne was tasked with determining the level of cadmium emissions associated with energy generation that is avoided through the use of Nanosys Quantum Dot Enhancement Film (QDEF) in televisions. Cadmium emissions are avoided through power conservation due to the higher efficiency of the cadmium-containing QDEF device as compared with comparable television display technologies that do not contain cadmium such as QLED. The display itself contains approximately 23.74 mg of cadmium per m2 of screen display. Cadmium is utilized within the displays as a component of the nanocrystals distributed throughout the film. The cadmium within QDEF televisions is directly responsible for the power savings over existing display technology as it allows high brightness at lower power levels. As such, while the quantity of cadmium in QDEF has declined sharply in recent years, its inclusion in the manufactured product is also essential. SourceOne is an energy consulting firm. While the bulk of our analysis was focused on the EU grid emissions from the electrical generation sector, we also provide some context and assessment of the cumulative impact assessment based on factory test calculations and projections provided by Nanosys.

Background

Cadmium is a toxic metal most commonly used in consumer rechargeable batteries. According to the US Environmental Protection Agency (EPA), "the acute effects of cadmium in humans through inhalation exposure consist mainly of effects on the lung. Chronic inhalation or oral exposure leads to a build-up of cadmium in the kidneys that can cause kidney disease."[a] Cadmium is not produced through a direct mining effort, but is typically recovered and refined as a byproduct of Zinc mining. Quantum Dot Enhancement Film is compliant under the European Union directive on the Restriction of the use of certain Hazardous Substances in electrical and electronic equipment 2011/65/EU (RoHS). These exemptions were extended in early 2019. Nanosys is not considered a producer of electronic equipment, but its customers (and customers' customers) fall under this designation.

Cadmium from Power Plant Emissions

Cadmium in the atmosphere is mainly caused by the burning of fossil fuels; specifically coal and to a lesser extent fuel oil. Solid fuel represents 21% of the Electricity Mix in the European Union (EU 28), fuel oil about 2%. The remaining 77% are generated without cadmium emission with nuclear (26%), gas (20%), renewable energy sources (29%) and other sources (2%).

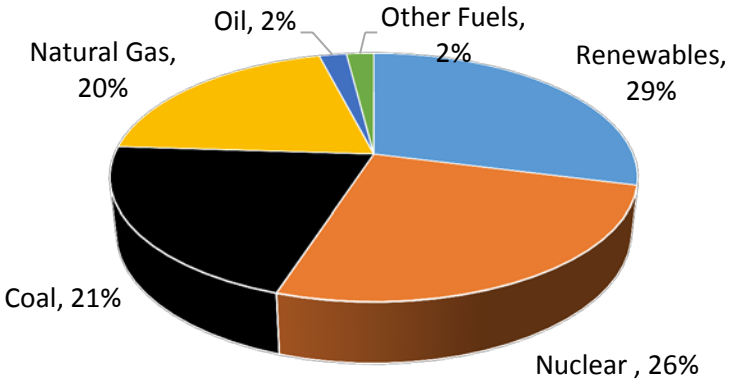


Figure 1- EU-28 Electricity Generation by Source

The cadmium content in solid fuels is highly variable based on the mining location and the type of solid fuel burnt. The European Environmental Agency provides data regarding the cadmium emitted by different

[a] EPA, TTN Air Toxics: Cadmium Compounds

industries. In year 2016 the total cadmium emission from public electricity generation in EU-28 was 9.14 tonnes[b]. The European Energy Commission provides yearly data for electricity generation and usage for the different countries of EU-28. For year 2016 the total electricity generated in the EU-28 was 3,255 TWh[c]. Based on these two numbers we can derive the average cadmium grid emission of 2.81 µg/kWh.

Table 1– European Electricity Grid Cadmium Emissions

Total Electrical Generation (TWh-E28-2016)	**Total Cd** (tonnes-EU28-2016)	**Grid Cd Emissions** (µg/kWh)
3255.10	9.14	2.81

For context, the EU emission rate of 2.81 µg/kWh can be compared to the emissions rate in the United States, which was 17.46 µg/kWh in 2017. Both numbers have declined rapidly in recent years but the difference can be attributed to two major factors:

- The coal usage in Europe represents only 21% of the electricity Mix compared to 30% in the U.S
- The cadmium content in European coal appears to be much lower in comparison with American coal:

Environmental Impact—Base Case and BT2020 Future Case

Nanosys has determined that in 2018, standard QDEF televisions with its cadmium quantum dots had a 7% efficiency advantage over comparable QLED technologies containing no cadmium. However, the HDTV market is in the midst of rapid transformation related to the adoption of ultra-high-definition television (UHDTV) standards, which necessitate substantially greater power requirements and therefore, a larger efficiency advantage for cadmium technology. Ultra-high-definition television includes 4K UHD and 8K UHD digital formats, which allows the future use of the Rec. 2020 (aka BT2020) color gamut standard. Industry analysts have forecasted that UHDTV screens will make up over 70% of total market in Europe in 2020.[d] The cadmium efficiency advantage in the BT2020 scenario is approximately 25%.

We've conducted our emissions analysis across two scenarios. In the 2018 base case, we used efficiency savings of 12.38 watts per m2, which is based on a factory test by Nanosys whereby the internal power consumption of a 65" 2018 Quantum Dot TV was evaluated both with cadmium Quantum Dots and with cadmium-free Quantum Dots—the next most efficient technology. For the forward looking BT2020 case, no cadmium-free televisions that can meet the BT2020 standard are sold on the market today—the only commercially available units contain cadmium. To establish the BT2020 future case baseline, Nanosys used the most efficient non-cadmium technology available and simulated a cadmium-free Quantum Dot television that targets 90% coverage of the BT2020 standard. The differential in internal power consumption between this and the cadmium-containing unit was 64.70 watts per m2 of screen area. By depicting these two scenarios, we approximate both the impact of the technology as it has been deployed in recent years and how it will likely be deployed in future years.

Quantum Dot Enhancement Film Energy & Environmental Benefits

Nanosys calculations and measurements demonstrate that its cadmium Quantum Dot technology saves 12.38 watts per m2 over current QLED models and 64.70 watts per m2 over models that achieve >90% of the BT2020 standard. This is based on power consumption of 172.21 watts and 193.95 watts per m2 respectively. An estimated display lifetime of 50,000 operating hours and a sales projection of 50,000,000 screens was used for cumulative energy calculations. A summary of the two cases is outlined below.

[b] EEA, National emissions reported to the Convention on Long Range Transboundary Air Pollution, 2018
[c] EEA, Overview of electricity production and use in Europe
[d] GfK Global, https://www.eutelsat.com/en/news.html#/pressreleases/eutelsat-reveals-new-consumer-research-on-ultra-hd-and-data-on-skyrocketing-screen-sales-in-key-tv-markets-1216550

Table 2 – Cadmium Quantum Dot Television Specifications and Energy Savings

	Avoided Watts per m2	TV Lifespan (Hrs)	TV Lifetime Energy Savings (kWh per m2)	Electric T&D Losses	Lifetme Electricity Generation Savings (kWh per m2)	Projected TV Units Sold 2020-2025	Lifetime Energy Savings per Annualized Sales (TWh)	Lifetime Energy Savings Attributed to 2020-2025 Sales (TWh)
2018 Base Case	12.38	50,000	619	6.44%	659	50,000,000	3.63	21.81
BT2020 Future Case	64.70	50,000	3,235	6.44%	3,443	50,000,000	19.00	113.97

Power losses occur between the televisions low voltage source and the power plant itself. These losses can be attributed to transformers and power lines. Based on data from the International Energy Agency, electric transmission and distribution losses in 2014 were estimated at 6.44%.[e] Using Nanosys projections of 50,000,000 TV units sold between 2020-2025, we are able to project the cumulative lifetime avoided energy consumption that can be attributed to the technology, approximately 21.81 TWh in the base case and 113.97 TWh in the BT2020 case.

We can also determine the net impact on cadmium emissions by comparing the cadmium content of the televisions with their associated cadmium avoidance due to grid energy savings and reduced coal consumption. The European grid average cadmium emissions factor was 2.81 µg per kWh. As a result, the net cadmium impact is 21.89 mg per m2 under the base case and 14.07 mg per m2 of QDEF screen area under the BT2020 case, if the television is not disposed of properly and the cadmium is not recycled.

Table 3 – Quantum Dot Enhancement Film Cadmium Data

	Total Cd per m2 TV (mg)	Cd Emissions Avoided from Grid per m2 (mg)	Net Environmental Cd Impact (mg)*
2018 Base Case	23.74	1.85	21.89
BT2020 Future Case	23.74	9.67	14.07

*Assumes 0% recycling rate

It is important to note that while the QDEF in a television contains 23.74 mg of cadmium per m2 (a standard 65" cadmium QDEF television contains about 27.7 mg), the cadmium is contained within a physical device. The cadmium contained with the QDEF is bound to selenium in a core structure, encased within a zinc sulfide shell, surrounded by ligands, held in an acrylate polymer and encased in PET plastic within a television. This television could be disposed of properly ensuring that the contained cadmium does not contaminate the environment. Even if the television is not disposed of properly, the cadmium is well contained within the device. On the other hand the 9.67 mg of cadmium that is avoided in the BT2020 case through electricity savings, would be released directly into the atmosphere when the TV is disposed of improperly. With these airborne emissions there is significantly greater risk of contamination of soil, water, and breathable air. Furthermore, the European Union also has stringent regulations and high targets in terms of recycling of Electrical and Electronic Equipment Waste. It appears likely that the EU will achieve its target to recycle 85% of all electrical and electronic waste.[fg] Precise data on recycle rates for televisions and cadmium-based televisions in particular are not available, though Eurostat has published a recycle rate of 41% for e-waste inclusive of televisions[h] and ranges of 80-85% for household electronics.[g] Therefore, it is reasonable to assume that a significant proportion of this cadmium is captured, recycled, and diverted from landfills. Table 5 shows how the net environmental cadmium avoided changes based on varying recycling rate assumptions. Most notably,

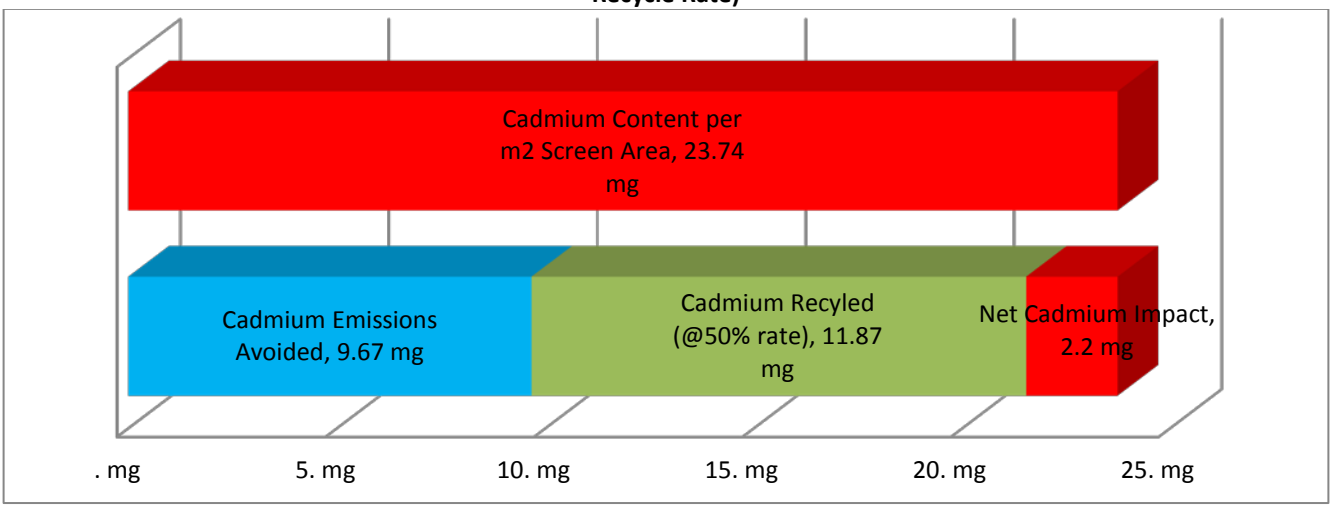
[e] EIA - European Union - Electric power transmission and distribution losses
[f] European Parliament and of the Council, Waste Electrical and Electronic Equipment Directive
[g] Eurostat, Waste electrical and electronic equipment (WEEE) by waste management operations (2016)
[h] Euostat, Record recycling rates and use of recycled materials in the EU (2019)

the net impact approaches 0 when 50% of screens are recycled, and this appears to be a reasonable if not conservative number given the ranges published by Euostat.

Table 4 – Sensitivity Analysis. Net Cadmium Avoided through Recycling (BT2020 Case)

Recycling Rate*	Net Environmental Cadmium Avoided per m2 Screen
0%	-14.07 mg
10%	-11.70 mg
20%	-9.32 mg
30%	-6.95 mg
40%	-4.58 mg
50%	-2.20 mg
60%	.17 mg
70%	2.55 mg
80%	4.92 mg
85%	6.11 mg
90%	7.29 mg
100%	9.67 mg

Figure 2 – Breakdown of QDEF Cadmium Content and Cadmium Emissions Avoided (BT2020 Future Case, estimated 50% Recycle Rate)



Greenhouse Gases from Power Plant Emissions

In addition to decreasing the amount of cadmium emissions produced by power plants, the use of QDEF in televisions also decreases the amount of Greenhouse Gases released into the atmosphere. This decrease is directly related to the electricity savings. GHG emissions were calculated using the EEA National Emission Report, which provides GHG emissions for EU-28 for each sector of activity. Nanosys projects that between the years 2020 and 2025, its cadmium QDEF technology will be installed in over 8.3 million screens sold across the EU each year. Assuming that the BT2020 standard is adopted as anticipated, the lifetime CO2-Equivelent avoidance of those annual screen sales would approach 6,000 ktones compared to the next most efficient technology.

Table 5 – Quantum Dot Enhancement Film Green House Gas Avoided Emissions (BT2020 Case)[i]

Gas	GWP	Grid Emission EU28 (ktones /year) (2016)	Grid Emissions (kg/kWh)	Emissions Avoided (kg per m2)	CO2-Equivalent Emissions Avoided Per Annualized Projected Sales Volume (Ktones)
CO2	1	1,012,150	3.11E-01	1,070.68	5,907
CH4	25	155	4.77E-05	1.64E-01	23
N2O	298	22	6.84E-06	2.36E-02	39
		Total CO2 Equivalent Emissions Avoided Per Year (ktones):			5,967.97

Carbon Dioxide is the weakest of the GHGs in terms of atmospheric effect per unit of gas, but it is responsible for the large majority of the greenhouse effect caused by manmade emissions. However, both CH_4 and N_2O are also emitted by power generators. Emissions of these gases are shown converted to lbs CO_2-equivalent (CO_2-e) based on their Global Warming Potential (GWP). The GWP of a gas is equal to how many pounds of CO_2 it would take to create the same atmospheric effect as one pound of that gas. For example, CH_4 is 25 times more potent than CO_2 as a GHG, thus one pound of CH_4 can be counted as 25 lbs CO_2-e.

Under the BT2020 case, if 50 million televisions utilizing Quantum Dot Enhancement Film are sold in the EU over the 2020 – 2025 timeframe, as Nanosys is projecting, there would be approximately:

- 114 TWh of avoided electricity generation over the lifetime of those units (cumulatively this represents about 3.5% of what the EU generates each year)
- 320 kg of cadmium emissions avoided due to power efficiency
- 466 kg of net cadmium e-waste generated assuming no recycling and 72 kg of cadmium e-waste generated assuming a 50% recycling rate. Rates above 60% would have a net withdrawal impact.
- 35,800,000 metric tons of avoided CO_2-e emissions – the equivalent of approximately 7.8 million cars removed from the road for one year

[i] EEA http://www.eea.europa.eu/data-and-maps/data/ds_resolveuid/E065EBF8-36B4-40D1-A413-7EC914054A82