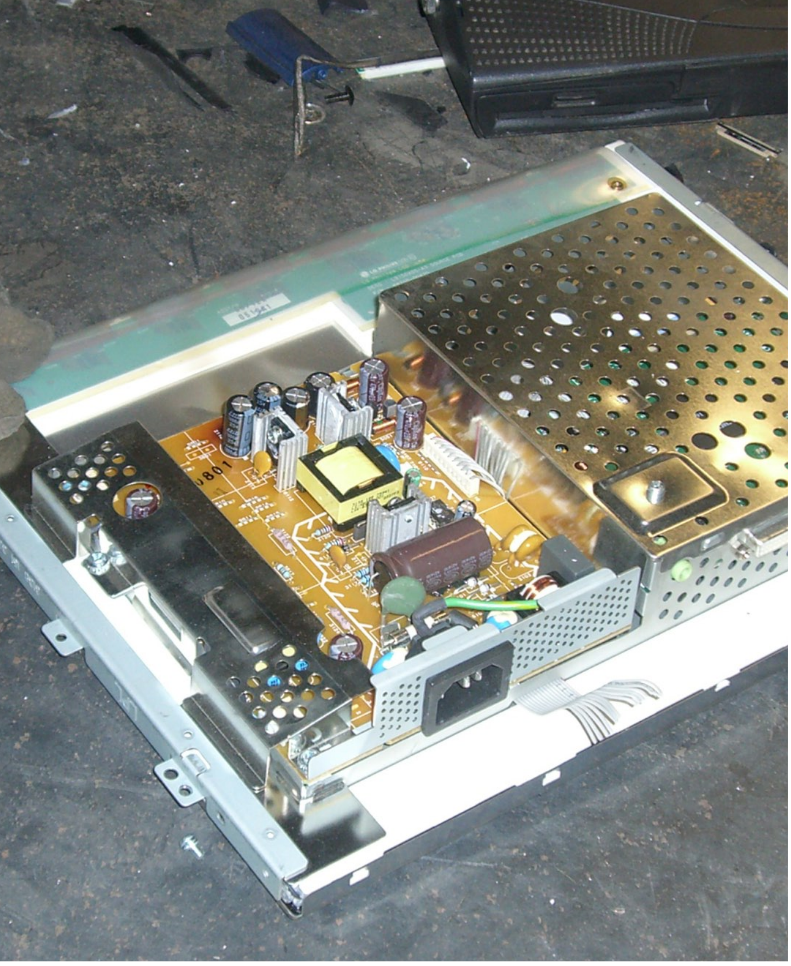

Disposal of Flat Panel Display Monitors in Switzerland

Final Report

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SWICO recycling

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List of Abbreviations

CCFL	cold cathode fluorescence light
CE	consumer electronics
CRT	cathode ray tube
DM	dry matter
EEFL	external electrode fluorescent lamp
EERA	European Electronics Recycling Association
Empa	Swiss Federal Laboratories for Materials Science and Technology
FOEN	Swiss Federal Office for the Environment
FPD	flat panel display
Hg	mercury
ICT	Information and communication technologies
In	indium
ITO	indium tin oxide
LCD	liquid crystal display
LED	light emitting diode
MSWI	Municipal solid waste incinerator
OEL	occupational exposure limit
OLED	organic light emitting diode
PbO	lead oxide
PDP	plasma display panel
PV	photovoltaic
SUVA	Swiss National Accident Insurance Fund
Swico	Swiss Association for Information, Communication and Organization Technology
TFT	thin film transistor
TLV	threshold limit value (MAK value)
WEEE Forum	Waste Electrical and Electronic Equipment Forum, i.e. European association representing the operators of electrical and electronic waste collection and recovery systems

Abstract

In 2009, about 300‘000 PC LCD monitors, about 60‘000 TV FPD monitors and about 240‘000 laptops were disposed in Switzerland through Swico Recycling. In parallel with the sales volume these amounts will increase considerably in the course of the coming years. Hence, FPD monitors are nowadays the fastest growing waste fraction within the electronic waste processed by Swico Recycling.

The backlight of conventional LCD FPD monitors contains mercury. FPD monitors further include in their composition one or two layers indium tin oxide (ITO), transparent thin conductors, which are enclosing the metal indium. Indium, an accompanying metal in zinc mining, is considered a rare metal due to its scarce occurrence in the lithosphere.

The present study examines the current and future disposal of FPD monitors in Switzerland, indicates the volumes of sold and disposed of FPD monitors, their composition and forecasts the amounts to be expected in future, with the mercury and indium flows involved.
Based upon the existing legal framework, possible options for a future disposal system are being rated: thermal recovery in Municipal Solid Waste Incinerators (MSWI), manual disassembly and mechanical processing.

The incineration leads to a relatively minor additional mercury load in the waste incineration plants. Considering the insignificant calorific value of FPD monitors and the loss of the precious metals they embody, this option is inappropriate.

The manual disassembly appears to be a feasible disposal alternative. Per hour, 3 to 4 FPD monitors can be dismantled manually. Broken backlights reach a share of about 20% for TV’s and less than 5% for PC monitors. The amounts of mercury emitted by the breaking of mercury containing backlights in the disassembling process are not exceeding the existing Swiss OEL value of 50 µg/m^3.

With the mechanical processing, there are chances that the mercury amounts, bound to solid matters, cluster in the fine fraction which ends up in the disposal. The adhesions to recyclable metals amount to less than 1 mg Hg/kg. However, the mechanical processes cause gaseous emissions in the area of approximately 65-75% of the total mercury amounts fed. These air emissions condition a closed, low-pressure operated plant. By now, such plants are available, but there are no appropriate acceptance controls for the processing of FPD monitors done yet.

According to the model calculations, the economic value of the maximum amounts of indium ending up in the waste disposal in Switzerland approximates 66’000 USD per year. From an economic point of view, there is no incentive to recover it. But considering the shortage of indium, its recovery would indeed make sense.

The study recommends to adjust the existing Technical Guidelines of Swico Recycling and SENS and to proscribe the thermal recovery of entire or partly disassembled FPD monitors. With manual disassembly, the work health and safety requirements must be met with and mechanical processing shall be performed according to the state of the art, i.e. only in closed, encapsulated units operated in underpressure.

1 Introduction

1.1 Situation

From 2003 to 2007, the worldwide sales figures for flat panel display monitors, i.e. FPD's (TV FPD and PC monitors) nearly tripled from approx. 85 million to 230 million pieces. Estimations quote some 670 million pieces for 2012 (Becker 2009), which corresponds approximately to eight times the amounts of 2003.

In Switzerland, 49'000 TV FPD monitors were sold in 2003, 648'000 in 2008 or around 12 times more (Swico 2008). Within the same time span, the number of cathode ray tube or CRT TV's sold dropped from 308'000 to 10'000 (Swico 2008).

In opposition to the TV segment of industry, the transition to FPD monitor technology for PC monitors occurred earlier: already in 2000, 162'000 PC FPD monitors were sold and since 2004, their number stagnated around 750-800'000.

With computers, a trend reversal took place in the same period. While only about every fourth PC was a laptop in 2000, the share of marketed laptops outran that of desktop computers in 2008, to reach even 65% in 2009.

In parallel with the growth of the FPD devices sold, also the electronic waste amounts collected by Swico Recycling increased considerably. The share of FPD monitors on the disposed total number of computermonitors rose from 13% in 2006 to more than 50% in 2009. During the same period, the share of TV FPD monitors climbed from 1% to 16%. Approximately 300'000 PC FPD monitors, more than 60'000 TV FPD monitors and 240'000 laptops were disposed of in 2009. This amount almost doubled every year from 2006 to 2009. Also in the past year, the number of disposed devices will have increased again considerably.

The technological transition from cathode ray tubes to flat panel display monitors on PC's and TV sets creates new challenges in the electronic waste disposal. Backlights (cold cathode fluorescence lights or CCFL) of current LCD FPD monitors are thin sealed glass tubes containing mercury (Hg). Also camcorders, cameras, audio equipment, fax machines, copiers and printers are equipped with such CCFL backlights. Considering the low limits for mercury allowed by occupational safety and health rules, i.e. 50 µg/m^3 (OEL value), the question arises about the possible release of mercury in recycling processes.

FPD monitors have, in their sandwich-like construction, one or two layers of indium tin oxide (ITO), transparent thin conductors which contain the metal indium (In). As accompanying metal in zinc mining, indium is considered a rare metal, due to its scarce occurrence in the lithospheric mantle. In the course of the past years, the increasing demand for indium in electronics and photovoltaics (PV) led to a significant rise in prices. Because of its scarce occurrence in the earth crust and its fine spreading in FPD's, the recovery of indium in the recycling process becomes an important matter of discussion.

1.2 Goal of the Study

The present study aims at laying down the future basis requirements for an environmentally sound and economic disposal of FPD monitors.

The following questions are being dealt with:

Amounts, composition and loads

- Which components do FPD monitors consist of?
- What are the quantities of FPD monitors to be expected in future and what loads of mercury (Hg) and Indium (In) are contained in the total amount of the FPD monitors?

Manual disassembly

- What are the immissions and exposure risks related to the manual removal of mercury containing CCFL backlights from FPD monitors?
- Which workplace requirements must be met for the manual dismantling of FPD monitors?

Mechanical processing

- What are the immissions and exposure risks related the mechanical processing of FPD monitors?
- How is mercury spread into the different fractions from the recycling process?
- Which basis requirements must be met for the mechanical processing of FPD monitors?

Disposal in waste incineration plants

- Which problems can arise with the waste disposal of FPD monitors in WIP's?
- Should an incineration of unfractionated or previously fragmented FPD monitors in WIP's be admitted further?

Intermediate storage

- What is the space requirement if the sandwich-like panels of FPD monitors would be stored intermediately and is such intermediate storage economically worthwhile?

2 Background

2.1 FPD Technologies

A monitor is an output device or part of such, on which visual information can be displayed (Behrendt, Fichter et al. 2008). Actually, "monitor" (or "FPD monitor") prevails as term in English for all kinds of output devices with a screen, while "display" is the window presenting data, pictures and signals.

A FPD monitor, i.e. flat panel display is a monitor with little depth. There are diverse technical principles to produce them. These technical principles may be divided in three classes: projection displays, direct view displays and screenless displays (Theis 2000). The output devices analysed in the present study belong all to the class of direct view displays, distinguished between auto-glow and non-glow displays. Compared to non-glow displays which need an external light source, the light of auto-glow displays is integrated as own light source. Liquid crystal displays (LCD) with cold cathode fluorescent light tubes (CCFL) or light emitting diodes (LED) as backlights and also plasma displays with the gas discharge principle belong to the non-glow category. On the other hand, organic light emitting diode monitors (OLED) are auto-glow displays. Table 1 shows a combination of today's most current FPD technologies.

Table 1: Overview of the most current FPD technologies

Categories	Most Frequent Applications	Backlight
LCD monitor LCD - liquid crystal display	desktop PC's, laptop PC's, TV sets	cold cathode fluorescence lights (CCFL) light emitting diodes (LED)
PDP monitor PDP - plasma display panel	TV sets	not required
OLED monitor OLED - organic light emitting diode	cell phones, laptop PC's	not required

Compared with plasma and CRT monitors, light emitting diode monitors with CCFL backlight present a disadvantage due to lower contrast value and an irregular lighting. The image generating liquid crystal cell is trans-illuminated by means of the CCFL. In most of the cases, several CCFL tubes are used placed side by side along the edge of the monitor (laptops, PC's and PC monitors) or over its whole surface (TV's). For a regular lighting, a light conducting plastic material, a diffusor, is being used to generate as much as possible a homogenous light density. Even so, zones of varying luminance may appear on the monitor, mostly in places where the CCFL tubes are situated.

LCD monitors with LED backlight rectify this disadvantage to a large extent, as a great number of LED's can be spread over the whole surface of the monitor, which ensures a regular lighting. Furthermore, there is the possibility of activating individually the different coloured LED's, which allows to dim or cut off separately single parts of the lighted surface, in order to display an intensive black, for instance, generating so a more contrast-rich picture. LED's are also more energy-saving, which allows laptops to have a longer battery use. Many of the new laptop models are already functioning with this principle, but also desktop PC's and TV FPD monitors have found their way to this new technology.

In opposition to LCD TV's, plasma TV's are of minor importance on the market (less than 5%). Additionally, the majority of the suppliers only offer plasma monitors from a diagonal screen size of 37" (94 cm) on.

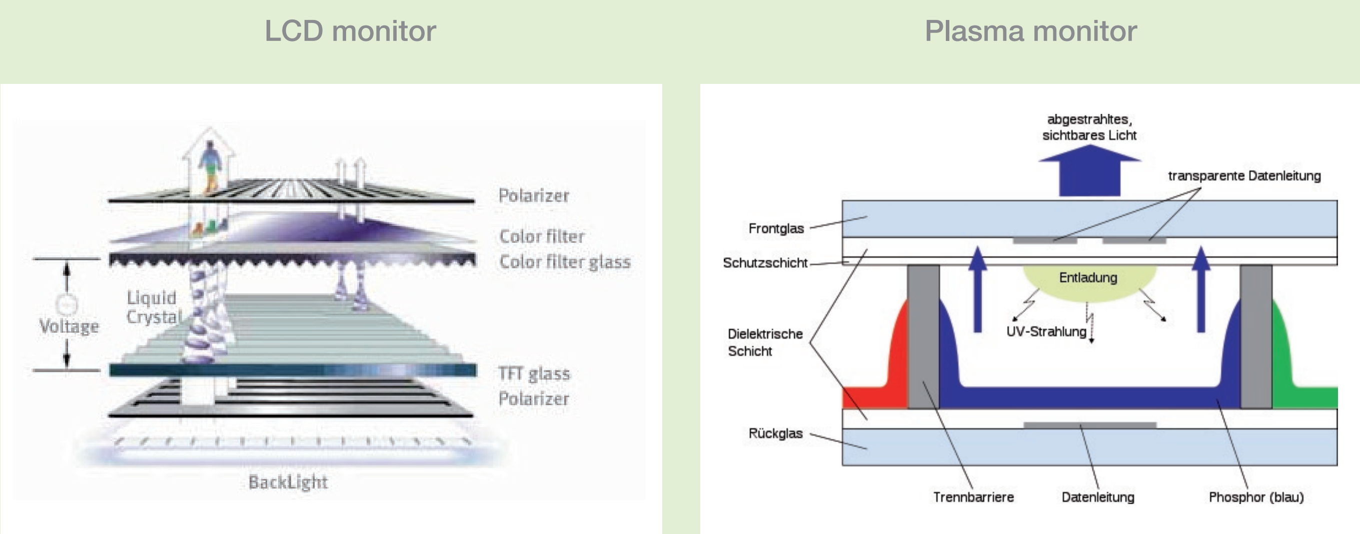
OLED (organic light emitting diode) monitors will replace the LCD technology in the coming years. OLED's are very thin glass panels or plastic sheets, printed by means of inkjet technology with organic polymer compounds and subsequently sealed. Semiconductor elements stimulate the OLED's to glowing. OLED monitors are extremely thin and flexible and can, thus, be used as good as everywhere. For smaller screen formats and devices (like cell phones, laptops), the OLED technology is already being applied with success. The biggest problem is the high sensibility toward oxygen and moisture, which can decompose the polymer material by chemical reactions.

2.2 Components of FPD Monitors

A LCD PC monitor or a LCD TV monitor, respectively, consists of casing, base, cable, LCD module and electronic components. LCD panel, backlight and electronics compose the LCD module. As to the LCD panel, it comprises two plastic plates with the LCD liquid inside, diverse filter and diffusor sheets, and a transparent protective plate, all held together in a frame like a sandwich (Fig. 1 and Fig. 2).

The plasma monitor differs from the LCD monitor by the fact that the LCD panel is replaced by a plasma panel. Hence, a plasma panel does not need a backlight. In contrary to the LCD monitor, the plasma plates in the panel are mainly made of glass (Fig. 1).

Fig. 1: Structure of LCD and plasma monitors



Source: Wikipedia

Fig. 2: Constructive elements of LCD monitors

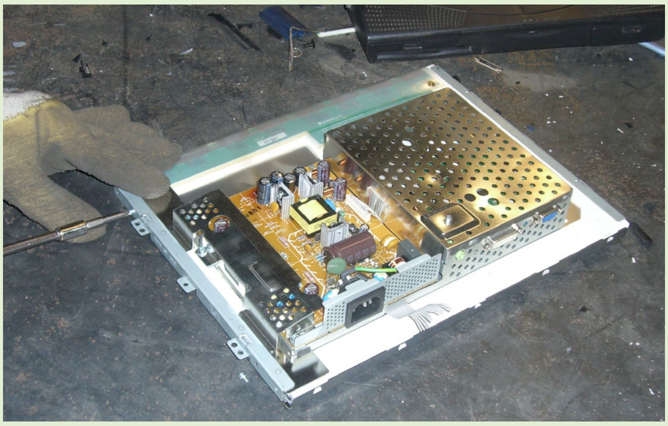


Photo 1: LCD module of a PC monitor

Photo 2: LCD panel

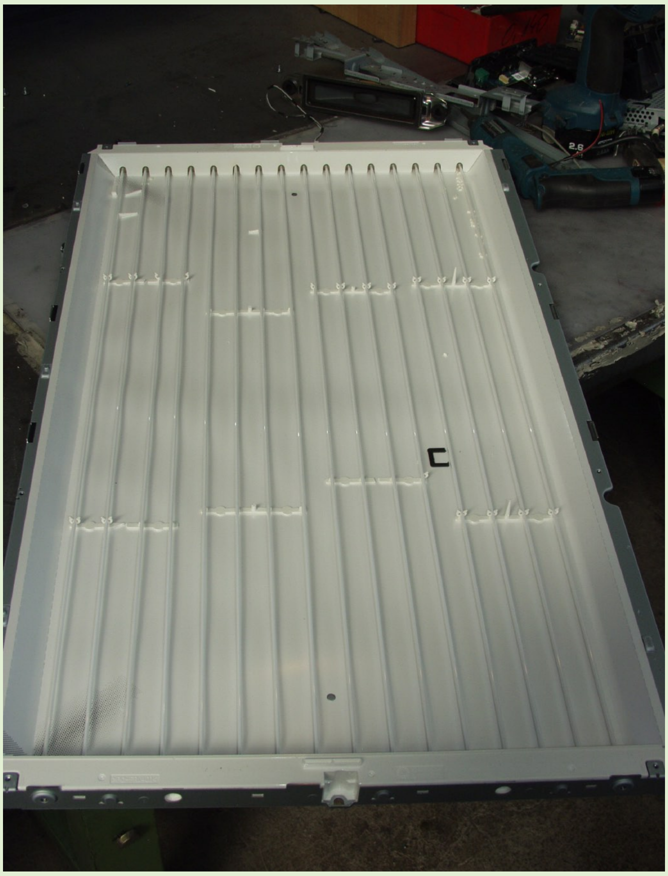


Photo 3: CCFL backlight of a LCD TV

Photo 4: LCD panel

2.3 Legal framework

2.3.1 Europe

WEEE Directive

Annex II of the Directive 2002/96/EG of the European Parliament and of the Council of January 27, 2003 on waste electrical and electronic equipment (WEEE Directive) stipulates that liquid crystal displays (where applicable with the casing) with a surface exceeding 100 cm^2 and backlights with gas discharge lamps must be removed from separately collected waste electrical and electronic equipment.

RoHS Directive

The Directive 2002/95/EG of the European Parliament and of the Council of January 27, 2003 on the restriction of hazardous substances in electrical and electronic equipment (RoHS Directive) invites the member states to ascertain that from July 1, 2006 on, newly marketed electrical and electronic equipment does not contain lead, mercury, cadmium, hexavalent chromium, polybrominated biphenyl (PBB) or polybrominated diphenylethers (PBDE) respectively. On August 18, 2005, a maximum concentration value of 0.1 weight per cent each was tolerated for lead, mercury, hexavalent chromium, polybrominated biphenyl (PBB) or polybrominated diphenylethers (PBDE) per homogeneous material and of 0.01 weight per cent for cadmium per homogeneous material.

Mercury in lamps has been exempted from prohibition, although among others, the Commission needs to examine preferentially the use of mercury in rod-shaped fluorescent lamps for specific purposes. A subsequent examination of the list was expected to take place in 2010. Since July 1, 2006, the Hg threshold value in CCFL's for new devices is 5 mg per tube.

Lead oxide is admitted in structural elements of plasma panel displays (PDP) and surface conduction electron emitter displays (SED), such as the dielectric layer of front and rear glass, the bus electrode, the black stripe, the address electrode, the barrier ribs, the seal frit and frit ring, as well as in print pastes.

2.3.2 Switzerland

ORRChem, Ordinance on Chemical Risk Reduction

Following Annexe 1.7 of the Ordinance on Chemical Risk Reduction of May 18, 2005 (ORRChem, SR 814.81), putting in circulation mercury containing formulations and objects is strictly prohibited. This prohibition does not affect formulations and objects if, according to the state of technology, there is no alternative without mercury. In the case of electrical and electronic equipment, including lamps, the dispositions on electrical and electronic equipment of Figure 5, Annex 2.16 ORRChem are applied according to the latest amendment of ORRChem. In substance, they correspond to those of the RoHS Directive 2002/95/EG (Restriction of Hazardous Substances). As to constructive elements of devices which still may contain mercury and other controlled heavy metals, ORRChem refers to the Annex of the RoHS Directive. Upon the Commission Decision 2010/571/EU of 24 September 2010, this Annex was reedited in a revised version. Among others, it stipulates in detail the admissible mercury contents of lights, distinguished according to performance, size and/or service life.

SUVA Limit Values at the Workplace (Swiss National Accident Insurance Fund)

The occupational exposure limit (OEL value) serves as basis of assessment, whether concentrations of substances represent a risk or are harmless at the workplace. It stipulates the maximum permissible average concentration of a gaseous, vaporous or powdered chemical agent in the air, which, according to current knowledge does not harm the health of persons at their workplace, taking into account a daily exposure of 8 hours and up to 42 hours per week, even over longer periods, and that the number of healthy people prevails greatly at the workplace.

The OEL values are 8 hours averages. In practice, the present concentrations of the substances in the breathing air often vary considerably. For many substances, the exceedance of the average needs to be limited to avoid health hazard. Based on criteria for toxicology and work health and safety, short-term deviations of currently measured ambient air concentrations above the published thresholds for such agents are restricted with regard to level, duration and frequency per workday or shift.

For locally irritating agents, the short-term limit for 15 minutes sampling corresponds, as a rule, to the shift average, i.e. the OEL value of these agents should not be exceeded, even if measured in a 15 minutes time span. The short-term limits of substances exceeding the OEL value are indicated as 15 minutes average. Per shift, a minimum interval of one hour is imperative between the four tolerated exposure peaks. At any rate, the 8 hours average must be observed. Highly irritating agents may pass the effect threshold by short-term concentration peaks.

SUVA established the OEL values and also the short-term limits for mercury (Hg) (cf. Table 2). The OEL value for mercury in Switzerland is 50 µg, while 20 µg/m^3 ordained on the European level (SCOEL May 2007).

Table 2: OEL values and SUVA short-term limits for mercury air emissions (SUVA 2009)

	OEL Value mg/m³	**Short-term Limit** mg/m³
Mercury (vapour and aerosol)	0.05	-
Mercury compounds, organic (calculated as Hg)	0.01 **e**	0.4
Mercury compounds, inorganic (calculated as Hg)	0.1 **e**	0.8 **e**

e = inhalable dust; inhalable dust stands for the totality of particles in the inhaled air, which can be breathed in through mouth and nose.

Swico-SENS Technical Guidelines

In the prevailing technical guidelines by Swico Recycling and SENS of June 10, 2009 on the disposal of electric and electronic waste, the following dispositions regarding mercury containing components and liquid crystal displays are specified:

General Technical Guidelines (Excerpt)

D.6.1 Mercury containing components must, as a rule, be disposed of, and mercury air emissions prevented appropriately. The components must be disposed of separately, adhering to the relevant safety provisions.

Guideline 2: ICT and CE Devices (Excerpt)

1.1 Cold cathode fluorescence lamps in liquid crystal displays, which are bigger than 100 cm^2 must be removed and recovered or disposed of appropriately.

1.2 Processing liquid crystal displays without having previously removed the cold cathode fluorescence lamps may be admitted upon referring to the controlling body, provided that it has been secured that none of the toxic substances inside the cold cathode fluorescence lamps, especially mercury, are spread to the processing fractions, and that they are recovered or disposed of appropriately.

1.3 Depollution and processing of liquid crystal displays condition that the emissions of toxic substances – especially mercury – are kept low enough to prevent impacts on the environment or the health of employees.

Guideline 3: Lamps (Excerpt)

1.3 Lamp recycling companies have the technical and organizational qualifications to treat lamps properly, so as to grant, as much as possible, the total recovery of contaminant-laden fluorescent layers and the full re-use of the lamp components.

2.1 The processing steps and plants for the treatment of lamps must be built and organized adequately, in order to keep emissions of gaseous and powdered mercury and of other noxious substances from the fluorescent layer as low as possible.

2.2 The facilities have to be equipped with appropriate air emission capture systems and operated in such a way that the functional efficiency can be checked constantly.

2.3 Recycling plants must dispose of industrial vacuum cleaners with fully functional activated carbon filters and closable bags for mercury containing fractions and broken lamps.

2.4 Fractions fed directly or over a further treatment to material recycling dare not exceed the following total mercury (Hg) contents per kg dry substance (DS):

glass fractions:	5 mg/kg
metal fractions:	10 mg/kg
other fractions:	10 mg/kg

4.1 It is essential to control continually the air emissions of mercury from production rooms and facilities with process exhaust air, so as to detect their increase in case of disturbances or technical failures at any time.

4.2 Regular controls of immissions in critical workplaces shall occur, according to the requirements of the results and of the directives of the labour law enforcement authorities. In addition, employees at exposed workplaces must undergo medical examination of mercury uptake and exposure at least once per year.

3 Composition and components of FPD Monitors

3.1 LCD Monitors

3.0.1 Main Components

LCD monitors of both TV's and PC's, mainly consist of metals and plastics (Fig. 3 and Table 3).

Fig. 3: Composition of LCD monitors

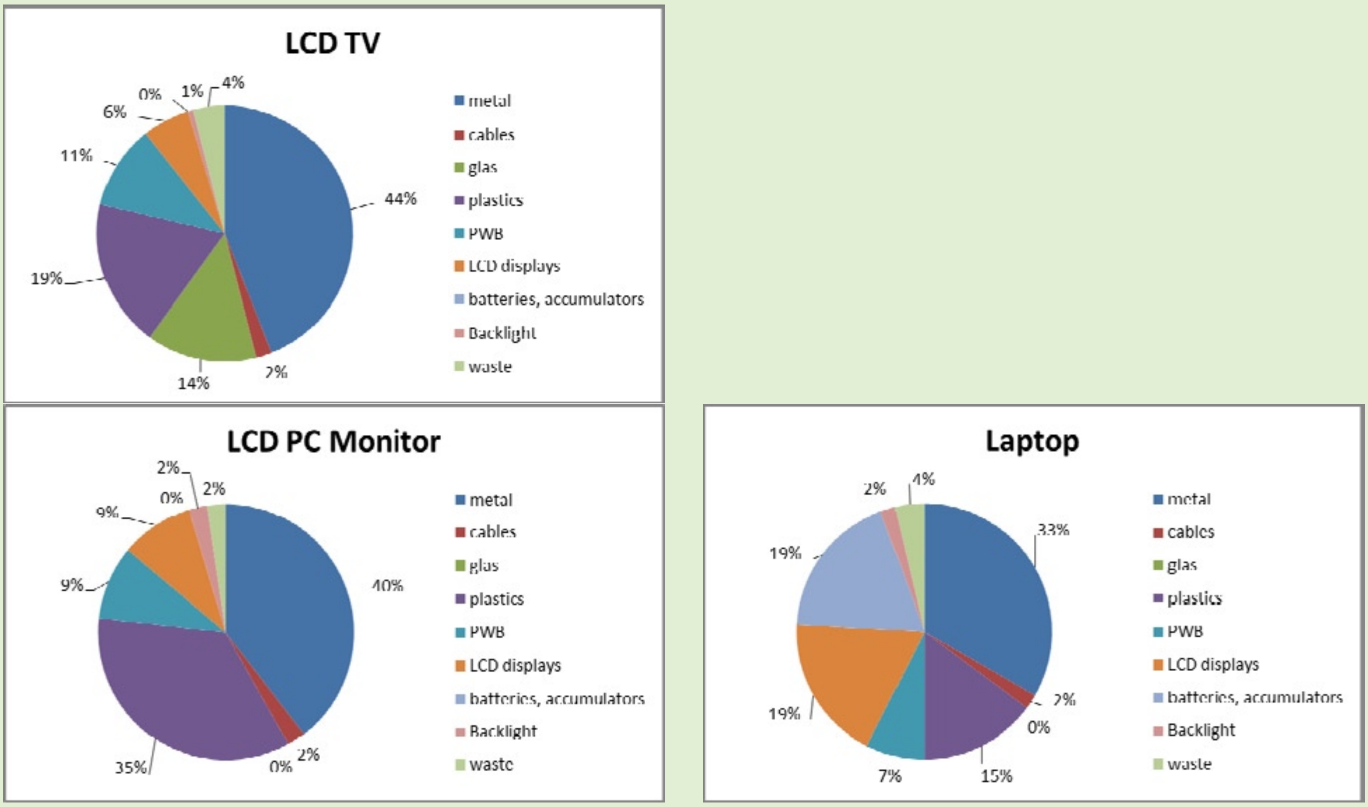


Table 3: Composition of LCD monitors (results batch test of September 2009)

	LCD PC Monitor		LCD TV		Laptop	
Composition	[%]	[kg]	[%]	[kg]	[%]	[kg]
Metals	39	1.7	44	6.6	35	0.9
Cables	2.5	0.1	1.5	0.3	1	0.05
Glass	-	-	14	2.1	-	-
Plastics	36.5	1.5	18.5	2.8	14.5	0.4
Printed wiring boards	8.5	0.4	11	1.6	6.5	0.2
LCD displays	9.5	0.4	6	0.9	18.5	0.5
Batteries/accumulators	-	-	-	-	19.5	0.5
Backlight	1	0.1	1	0.1	1	0.05
Waste	3	0.1	4	0.6	4	0.1
Total	**100**	**4.3**	**100**	**15.0**	**100**	**2.7**
Number of devices dismantled	*182*		*57*		*119*	

Mercury

Properties, Deposits and Global Flows

Mercury is the only metal of the periodic table, which is liquid under normal conditions. It is found in the lithosphere of regions with former volcanic activity, most frequently in the form of the mineral cinnabar (HgS). The main mining areas are situated in China, Kyrgyzstan, Russia, Slovenia, Spain and Ukraine, whereat China presently supplies about 60% of the yearly amounts of mining. Mercury is used in diverse areas. Liquid and contact thermometers take advantage of the high thermal expansion of mercury in proportion to temperature. Mercury switches (prohibited in the EU since 2005) have been using it for its electrical conductivity and high surface tension. In dental medicine, mercury serves as silver amalgam dental filling. It is also employed in gas discharge lamps, including fluorescent, compact fluorescent lamps (CFL) and cold cathode fluorescent lamps (CCFL).

Mercury and its compounds can affect the function of enzymes and structure proteins in the human body. Depending on the substance involved, the symptoms of poisoning can vary considerably, whereat the central nervous system represents the most vulnerable target organ.

The inhalation of *mercury vapours* represents the most significant uptake path for elemental mercury. These vapours are retained in the lungs up to 80%, from where the mercury penetrates the blood circulation.

In case of oral ingestion, *bivalent inorganic mercury compounds* cause heavy chemical burns in oral cavity, pharynx and oesophagus, as well as nausea and vomiting of blood. Inorganic mercury compounds in the gastrointestinal tract can lead to circulatory collapse, shock and result in death. The smallest lethal amount for humans is about 3 – 15 mg per kg body weight.

With *organic mercury compounds*, the high toxicity of methyl mercury is most significant, as it accumulates in the food chain, in particular in fish. Methyl mercury damages the central nervous system, and heavy loads can provoke convulsions, spastic paralysis, further blindness, deafness or retarded mental development. Regarding organic mercury compounds, the highest risk is posed by chronic intoxication with small amounts ingested every day over a longer period (Gesundheit 2010).

Table 4: Global, anthropogenic mercury air emissions (Pirrone et al. 2010)

Source	Mercury Air Emissions (t/year)	Share
Coal and oil burning	810	35%
Local gold mining	400	17%
Metal production (excl. iron)	310	13%
Cement production	236	10%
Waste disposal	187	8%
Caustic soda production	163	7%
Mercury production	50	2%
Iron ore and steel production	43	2%
Coal bed fire	32	1%
Vinyl chloride monomer (VCM) production	24	1%
Other	65	3%
Total	***2320***	100%

There are numerous sources of anthropogenic mercury air emissions, ranging from coal and oil as main emitters to local gold mining, metal and cement production, waste disposal and special processes (cf. Table 4). According to an estimation by the European Union (EU) for 2006, the amounts of mercury contained in LCD backlights, just for Europe, are assumed to total 2.8 t, additionally to the 4.3 t in fluorescent tubes (Huisman, Magalini et al. 2008).

Mercury in Switzerland

In the past years, the mercury air emissions dropped considerably in Switzerland. If the total all-Swiss output was reaching as much as 7‘800 kg in 1985, merely 1’100 kg were emitted in 2005 (Hügi M et al. 2008). One of the main mercury air emission sources are still the municipal solid waste incinerators (MSWI), although their share decreased in the course of the past years. In 1985, Swiss MSWI emitted 4’400 kg Hg, which corresponded to 56% of the total Hg emissions, and by 2005, approximately 290 kg Hg or 26% of the total Hg emissions (Hügi M and et al. 2008). This reduction is the result of the successful application of the Swiss Ordinance on Substance, voluntary measures or agreements and also of the introduction of separate waste collection systems for batteries (Morf 2006). Further mercury air emission sources are the melting of metal and crematoria, the latter emitting approximately 40 to 80 kg Hg per year (Rietmann). About 1 g Hg per ton dry substance (DS) yearly are being disposed of over the sewage sludge, which adds up to some 210 kg Hg per year for 210’000 t DS of sewage sludge[1].

[1] about ¼ of the sewage sludge is being disposed of over MSWI and this share is already included in the WIP loads

Mercury in LCD Backlights

Mercury is fed in gaseous form to CCFL tubes in the backlights of LCD monitors. In service, the electrically ionised mercury yields UV rays, which are transformed into visible light by the fluorescent layer. But with increasing operating time, the mercury amalgamates to clusters inside the tubes and finally causes the failure of the backlights. Durability and brightness depend on the quantity of mercury used (Getters 2010).

It is assumed that CCFL tubes contain between 4 and 5 mg mercury each (Socolof, Overly et al. 2005), while other estimations are quoting 5 to 10 mg (King County Solid Waste 2008). (McDonnel 2010) refers to an average of 3.5 mg per tube, basing on manufacturer's information. What is crucial is the number of the tubes and not their length, i.e. short and longer tubes are all dosed with approximately the same quantity of mercury.

The present study supposes 5 mg mercury in the CCFL tubes of TV's and 3 mg in those of laptops and PC monitors. That CCFL tubes of laptops and PC monitors contain less mercury than of TV's may be explained by a significantly higher brightness of most TV screens, which typically emit between 450 and 700 cd/m^2, in opposition to the majority of PC monitors and laptops having a usual brightness within a 250-300 cd/m^2 range (CNET 2010).

In TV's, an average interval of 3 cm is assumed to exist between the individual CCFL tubes. Hence, the number of CCFL tubes in the TV's depends on the diagonal size of the screen.
As to PC monitors, the CCFL tubes are integrated by pairs on top and bottom. Following the diagonal size of the screen, PC monitors dispose of two, four, six or eight CCFL tubes. According to their size, laptops have one or two CCFL tubes.

Table 5 shows an evaluation of a mercury analysis on CCFL tubes from PC monitors. On average, 166 ppm mercury was determined from 5 samples in the solid phase. Referring to the weight of the samples and assuming a volatilised gas share of 50-70%, a total mercury content of 1.33-2.63 mg per tube results. The assumption of the gaseous share is determining for the result. Up to now, no analyses are known, in which the mercury content of CCFL tubes was chemically determined in both the solid and vaporous phase[2].

[2] A first examination will be performed at Empa in 2011 on behalf of the Swiss Federal Office for the Environment (FOEN).

Table 5: Analysis of the mercury content in CCFL tubes

Analysis Hg content in mixed sample from different fluorescent tubes			166	µg/g Hg
Weight of samples		min.	3	g
		max.	15	g
Calculated Hg content per sample		min.	0.50	mg
		max.	2.49	mg
Calculated Hg content per tube	solid	min.	0.25	mg
	solid	max.	0.83	mg
Calculated share of vaporised gaseous Hg	with a 50% gas share		1.08	mg
	with a 50% gas share		1.80	mg
TOTAL Hg content per tube		**min.**	**1.33**	**mg**
		max.	**2.63**	**mg**

Source: Empa Test Report N° 447'606 „Quantitative Bestimmung von Quecksilber in Leuchtstoffröhren aus Flachbildschirmen" vom 23. Januar 2008 („Quantitative Determination of Mercury in Fluorescent Tubes from FPD Monitors" of January 23, 2008)

Indium

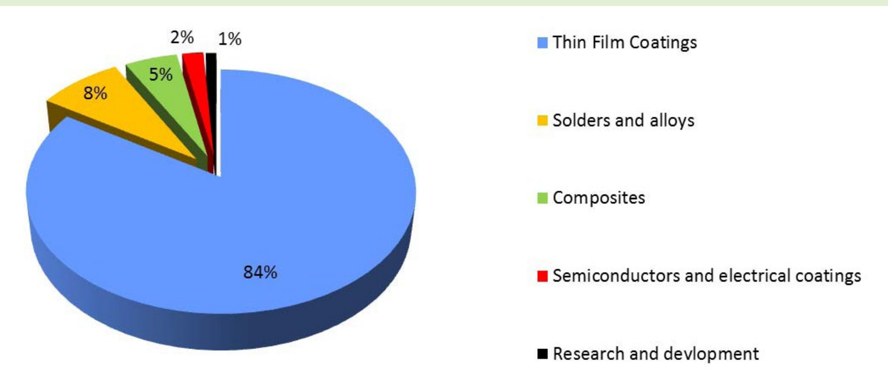
Properties, Deposits and Global Flows

Indium, a by-product of zinc and lead mining, ranks among the rare elements. Its share is some 0.05 ppm in the continental and about 0.072 ppm in the oceanic lithosphere. Therewith, indium is positioned right behind silver on the 68^{th} rank of abundance of the elements (Angerer, Erdmann et al. 2009). Other sources indicate an indium content of 0.24 ppm in the lithosphere, which would come up to three times the deposit of silver (Jorgenson and George 2005).

Today's major use of indium focuses on indium tin oxide (ITO) in flat panel displays and in photovoltaics. The compound is formed by 90% In_2O_3 and 10% SnO_2, which makes a 78% mass fraction of indium in ITO (Angerer, Erdmann et al. 2009). ITO is conductible like a metal and simultaneously transparent, as visible light with a wave length of 0.4 to 0.8 µm is not being reflected. Another advantage is the heat-resistant property of ITO. All these qualities make it an ideal material for the production of thin-layer electrodes for FPD monitors. The amounts of indium used in the photovoltaic sector are, compared to FPD monitor production, still minor. Indium is thereby applied as thin-film coating on cadmium telluride (CdTe) solar cells (Angerer, Erdmann et al. 2009).

Indium is also a component of light emitting diodes (LED), for instance as aluminium indium gallium phosphide and indium gallium nitride with varying colour properties. Additionally, indium can be enclosed in solders, as substitute for toxic lead. Further application areas are dental medicine, high temperature thermometers and control rods in nuclear reactors. Compounds with non-metals are, for instance, used as seals and coatings to improve the resistance of the coated materials, or for other purposes, such as special batteries or infrared reflectors. As another, relatively insignificant consumer of indium we may mention the research and development sector (Fig. 4).

Fig. 4: Use of indium in 2007 (Tolcin 2008)



The yearly consumption of indium nearly doubled from 1990 till 2000, above all because of the production of FPD monitors, from 123 to some 225 tons (Jorgenson and George 2005). The prices for indium reacted to the increased consumption and rose in this time span up to 400 USD/kg. In the ensuing ten years from 2000 to 2010, the consumption augmented further (fig. 6) and catapulted the prices in 2006 to the second highest level since indium is being used.

Temporarily, the high prices had a positive impact on the search of indium recycling solutions. Especially in Japan, some recycling efforts were made to prevent shortage.

In 2009, the consumption of indium reached some 600 t throughout the world. The U.S. Geological Survey estimated in 2007 the global indium reserves to approximate 11'000 t (Tolcin 2008), but there were no specifications on them regarding 2008 and 2009 (Tolcin 2010).

Fig. 5: Price evolution of indium from 1936 to 2010 according to USGS (U.S. Geological Survey)

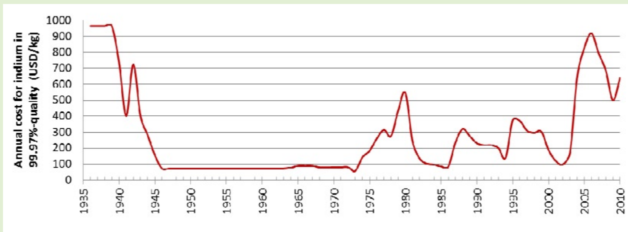


Fig. 6:
Production of indium and zinc from 2000 to 2009 following USGS

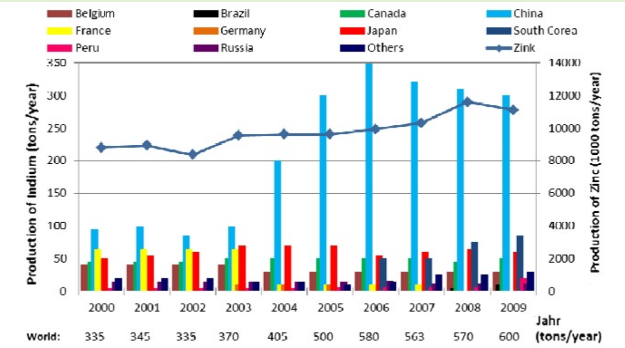
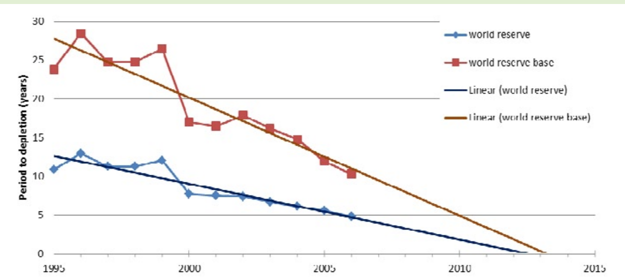


Fig. 7 illustrates the estimated static life time for the current or, to be more precise, the technically and economically minable world reserves, plus for the world reserve base. According to the estimations before 2007, the depletion of the indium reserves might become apparent in the coming three to four years already. The estimations for 2007 turned out noticeably higher than in the previous years. The outcome is a trend reversal, which argues for longer lasting reserves at a linear trend, but with extreme inaccuracy, considering the wide deviation. Still, the significantly higher estimate of the reserves in 2007 suggests a far less dramatic shortage of indium.

Fig. 7:
Estimated static life time of the global indium reserves, following USGS



As principal customer, the FPD industries consume more than 50% of the primarily extracted and up to 80% of the globally available indium, including the recovered share. The method employed for thin film coating with indium tin oxide deposits less than 30% of the raw material on the carrier material. As to the remaining 70%, they are left behind as abrasive slurry or as deposit on the walls of the spray chamber and can be recovered. The residues add up to nearly 1‘000 t per year and represent, so, the double of the primarily extracted indium amounts, which can be reduced again over a recovery cycle of less than 30 days (Mikolajczak 2009).

Also the production of thin film solar cells is dependent on indium. Like with the FPD monitors, a thin film coating with indium tin oxide is used as electrode. NanoMarkets' analysts expect a growing indium consumption almost by factor nine in the photovoltaic sector, from 2009 (25 t) to 2016 (225 t). At the same time, statements say that with regard to the indium reserves, there would be no risk of growth on the market for thin film solar cells (Osborne 2009).

Uncertainty about future supply and the price fluctuations for indium have pressed the search for alternatives to indium tin oxide (ITO) in the FPD industries. Indium in ITO, for instance, can be substituted by antimony. Antimony tin oxide (ATO) is applied with a process resembling that of ink jet printing on the carrier material. Secondly, nanotechnology developed carbon nanotubes are another potential substitute. The coatings of carbon nanotubes are suitable for flexible touch-sensitive monitors and solar cells. As a third alternative, conductible polymers, such as, for instance, poly-3,4-ethylenedioxythiopene (PEDOT) are used, processed as printed electronics in flexible monitors or in organic light emitting diode displays. Furthermore, ITO in solar cells and FPD monitors can also be replaced by a layer of graphene quantum dots or zinc oxide nanopowder. Graphene is the term for two-dimensional hexagonal crystal structures of carbon. The zinc oxide nanopowder is not yet market-ready, but could reach that stage in about three years. The indium phosphide used in the semiconductor industries can be substituted by gallium arsenide, while in the production of control rods for nuclear reactors, hafnium reveals to be a suitable alternative for indium. The adequate indium substitutes (antimony, gallium, hafnium and arsenic) are also mostly rare by-products in the mining of other mineral raw materials, or, as with arsenic, very toxic and therefore also problematic in the long run.

Indium in FPD Monitors

While two ITO layers are incorporated in LCD panels to control liquid crystals and with that the brightness of the monitor, only one single layer is fitted in plasma and OLED monitors, as alone the electrode facing the viewer needs to be transparent.

Indications in literature about indium content and layer thickness of ITO electrodes are varying much. Depending on the specifications, figures are converted into layer thickness, ITO content per m² or indium content per m², applying respectively the density of ITO (1.2 g/cm³) and the mass share of indium in ITO (78%) (Sigma-Aldrich 2010). It is assumed in the present study that the ITO layer thickness amounts to 125 nm, which corresponds to **234 mg indium/m².**

Table 6: Layer thickness, ITO and indium content in LCD's

	(Angerer, Erdmann et al. 2009)	(Socolof, Overly et al. 2005)	(Martin 2009)	(Becker, Simon-Hettich et al. 2003)	(Becker, Simon-Hettich et al. 2003)	(Bogdanski 2009)	(Bogdanski 2009)
mg ITO/m²	4000	7176	700	192	240	72	192
nm/layer	1667	2990	292	80	100	30	80
mg In/m²	3120	5597	546	150	187	56	150

Liquid Crystals

Liquid crystals used in LCD's are persistent, organic compounds featuring both properties, that of liquids and that of solid matters, i.e. on the one hand, they are more or less liquid, and on the other hand, they show characteristics such as double refraction. They consist of phenylcyclohexane and biphenyls. There are great numbers of varied liquid crystals, which can render in each case the required physical and optical properties when merged. They are hardly soluble and have a low vapour pressure. Many among them also include fluorinated components.

Liquid crystal compositions are not easily biodegradable (Becker, Simon-Hettich et al. 2003) (Becker and Simon-Hettich 2007). A major part of the research into toxicity of liquid crystals was, so far, conducted by the manufacturers themselves. The substantial tests and analyses confirm that there is no acute oral toxicity, mutagenicity and carcinogenicity with the liquid crystals used, and that they are not bio-accumulable. According to the German Federal Environment Agency, liquid crystals are considered inoffensive: "Based on the test results concerning the ecotoxicology of liquid crystals, we do not regard special requirements for the disposal of LCD's justified, due to the content of liquid crystals.[3]" In order to reach the recycling rate of 65% or the recovery quote of 75%, respectively, for monitor devices, as specified in the WEEE Directive, also the LCD module which typically contributes about 30% of the total weight of a monitor, must be salvaged. In this relation, Merck proposes a metallurgic recovery or an industrial waste incineration.

[3] German Office for the Environment, letter of March 16, 2001

3.2 Plasma Monitors

3.2.1 Main Components

PDP TV's are about twice the weight of a medium sized LCD TV. The largest part consists of glass, metals and electronics, while metals and plastics take the lion's share with LCD TV's.

Table 7: Composition of a 42" PDP TV and comparison with a LCD TV

	PDP TV 42" (Baudin 2006)		LCD TV*	
Composition	[%]	[kg]	[%]	[kg]
Metals	34	11.0	44	17.0
Glass	40	12.8	14	5.4
Plastics	4	1.3	18.5	7.2
Electronics	14	4.6	11	4.3
Other	8	2.8	12.5	4.8
Total	**100**	**32.5**	**100**	**38.7**

*Results batch test by Immark of April 2010, cf. Table 3

3.2.2 Toxic Substances and Recyclable Fractions

Lead Oxide

The glass in a plasma monitor contains some 0.6% or about 0.2 kg tin oxide (PbO) (Baudin 2006). Cone glass[4] of CRT devices contains 20-25% PbO or, when converted, an average of 1.0-1.2 kg PbO, i.e. 5 to 6 times more than a plasma monitor.

Indium

A 125 nm ITO layer thickness is assumed in the present study, which equals to 117 mg indium/m², or about half the indium content of LCD's, respectively.

[4] approximately ⅓ of the weight of a cathode ray tube

Table 8: Layer thickness, ITO and indium content in plasma monitors

	PDP-TV (Angerer u. a. 2009)	PDP-TV (Baudin 2006)
mg ITO/m²	94	202
nm/layer	78	168
mg In/m²	73	158

3.3 OLED Monitors

3.3.1 Main Components

So far, there is no information regarding data or analyses on the composition of these novel OLED monitors.

3.3.2 Toxic Substances and Recyclable Fractions

Indium

A 125 nm ITO layer thickness is assumed in the present study, which equates to 117 mg indium/m², or about half the indium content of LCD's, respectively.

Table 9:
Layer thickness, ITO and indium content in OLED monitors

	OLED (Angerer et al. 2009)	**OLED** (Steinfeldt et al. 2004)
mg ITO/m²	188	120
nm/layer	157	100
mg In/m²	147	94

4 Quantities and flows

4.1 Recent development

4.1.1 Sales Figures Switzerland 2000-2008

The number of PC monitors sold rose in the time span 2000-2008 by some 75%. The technological change from CRT to LCD monitors started before the turn of the millennium and was as good as completed by 2004 (Table 10 and Fig. 8).

In parallel to the technological change after 2004, the sales figures for *TV monitors* grew noticeably.

Accompanying the technological change from desktop PC's to *laptops*, the robust sales growth for laptops started right after 2002, while the number of desktop PC's sold remained almost on the same level. Currently, around 1 million laptops are sold every year in Switzerland.

4.1.2 Amounts disposed in Switzerland 2006-2009

The amounts of *PC LCD monitors* disposed in 2009, some 300'000 devices, correspond approximately to the number sold in 2001. Regarding the *TV FPD monitors*, the number of disposed devices in 2009 approximates the sales figures of 2003. In 2000, about as much *laptops* were sold as disposed of in 2009 (Table 11).

It is striking to see the strong increase of the PC LCD monitors ending up in the waste disposal from 2008 to 2009. This share increased continually since 2007 with TV FPD monitors. The technological change to LED backlights will amplify this trend in the coming years.

Table 10: Swiss sales figures for PC monitors, TV monitors and desktop PC's / laptops, 2000-08

	2000		**2002**		**2004**		**2006**		**2008**	
	[pieces]	[%]	[pieces]	[%]	[pieces]	[%]	[pieces]	[%]	[pieces]	[%]
PC CRT monitors	274'000	63	120'000	18	20'000	3	5'000	1	1'000*	0
PC LCD monitors	162'000	37	540'000	82	780'000	97	755'000	99	762'000	100
TOTAL	**436'000**	**100**	**660'000**	**100**	**800'000**	**100**	**760'000**	**100**	**763'000**	**100**
TV CRT monitors	472'000	99	373'000	99	268'000	71	75'000	15	10'000	2
TV FPD monitors	3'000	1	10'000	1	107'000	29	414'000	85	648'000	98
TOTAL	**475'000**	**100**	**374'000**	**100**	**375'000**	**100**	**489'000**	**100**	**658'000**	**100**
Desktop PC's	800'000	75	691'000	68	789'000	60	724'000	53	726'000	42
Laptops	265'000	25	322'000	32	518'000	40	649'000	47	994'000	58
TOTAL	**1'065'000**	**100**	**1'013'000**	**100**	**1'307'000**	**100**	**1'373'000**	**100**	**1'720'000**	**100**

Sources: Swico Secretariat IG CE, Weissbuch; *no data available, own estimation

Table 11: Swiss amounts of disposed of PC monitors, TV monitors and desktop PC's / laptops, 2006-08

	Gewicht	**2006**		**2007**		**2008**		**2009**	
	[kg]	[pieces]	[%]	[pieces]	[%]	[pieces]	[%]	[pieces]	[%]
PC CRT monitors	17-20	546'000	87	471'000	83	331'000	63	292'000	49
PC LCD monitors	5.3-6.4	82'000	13	95'000	17	195'000	37	306'000	51
Total PC monitors		**628'000**	**100**	**566'000**	**100**	**526'000**	**100**	**598'000**	**100**
TV CRT monitors	29-31	234'000	99	258'000	93	293'000	89	327'000	84
TV FPD monitors	15	2'000	1	18'000	7	38'000	11	64'000	16
Total TV displays		**236'000**	**100**	**276'000**	**100**	**331'000**	**100**	**391'000**	**100**
Desktop PC's	13-16	536'000	91	443'000	77	351'000	77	471'000	67
Laptop PC's	3.2-4.4	53'000	9	129'000	23	106'000	23	237'000	33
Total PC's		**589'000**	**100**	**572'000**	**100**	**457'000**	**100**	**708'000**	**100**
TOTAL FPD's[1]		**137'000**		**252'000**		**339'000**		**607'000**	

[1] PC LCD monitors, TV FPD monitors and laptop PC's, Source: Swico Annual Activity Reports 2006-2009

Fig. 8: Swiss sales figures for desktop PC monitors, TV monitors and desktop PC's / laptops 2000-2008 [pieces]

Fig. 9: Swiss amounts of disposed of PC monitors, TV monitors and desktop PC's / laptops, 2006-2008 [pieces]

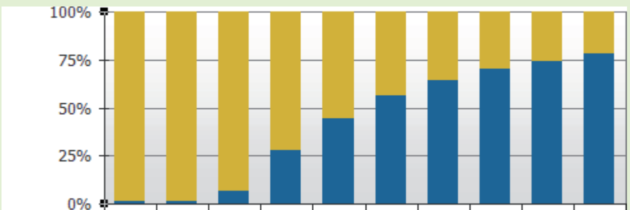
4.2 Future Development

As part of a bachelor's thesis, a dynamic model for the estimation of the amounts of FPD monitors to be disposed of was elaborated in cooperation with the Chair of System Design of the Swiss Federal Institute of Technology (ETH Zurich) (Benedetti and Zumbühl 2010). The subsequently quoted quantity forecasts have been taken from this report.

4.2.1 Technological Development

The conversion to FPD technology has been completed regarding the sale of TV and PC monitors. For TV's, a change from CCFL to LED backlights is occurring since 2009. So as to shape the change from CCFL to LED backlights up to 2030, the data of a forecast by (Camaroto 2009) were referred to.

Fig. 10:
Technological change from CCFL to LED backlights for PC monitors, TV's and laptops (Camaroto 2009)



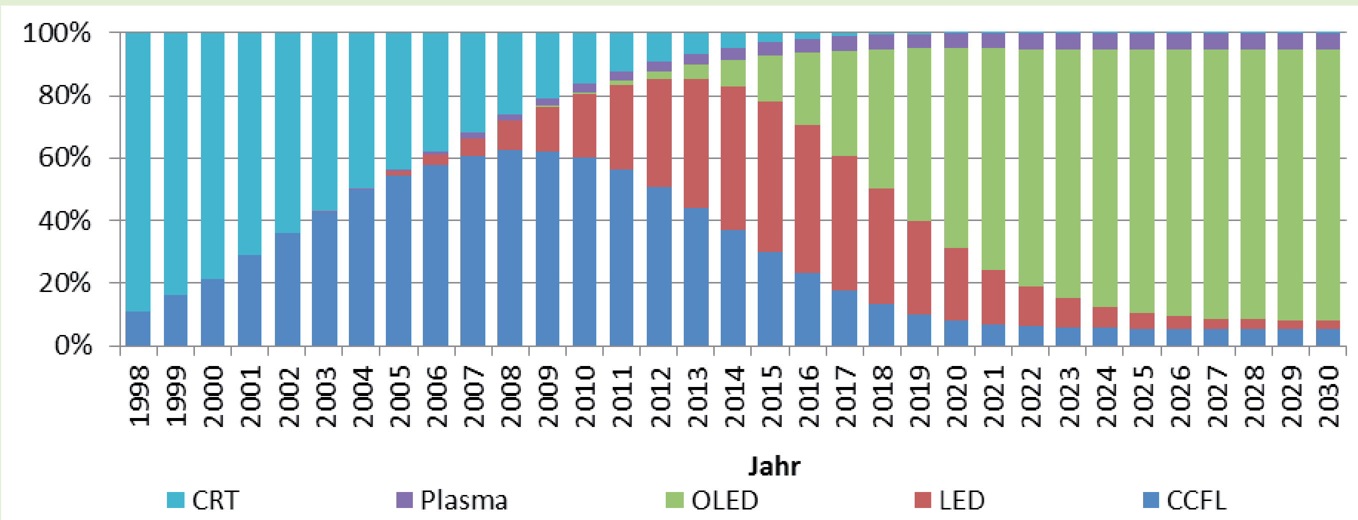
	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
CCFL/EEFL	99.0%	99.0%	93.3%	72.2%	55.7%	43.6%	35.8%	29.8%	26.1%	21.7%
LED	1.0%	1.0%	6.7%	27.8%	44.3%	56.4%	64.2%	70.2%	73.9%	78.3%

Source: Displaysearch

For smaller screen diagonals, monitors with OLED technology are already being proposed, but it is still indefinite, how fast OLED monitors will supplant LCD's on the market with the increasing demand for larger surfaces and more durable products.

Fig. 11 shows the development of the shares of the different monitor technologies for the whole quantity stored (market penetration) in the time span 1998 to 2030.

Fig. 11: Share of different monitor types stocked in Switzerland 1998-2030



4.2.2 Forecast for the disposed quantities in Switzerland, 2012-2020

With the dynamic model, the yearly stock and output quantities (Table 12) were calculated on the basis of the predicted sales figures (drawn upon a supposed market developments). The output quantity refers to the quantity which is discarded from the stocks, due to the lifetime (obsolescence) of the devices. Lifetime varies in time and depends on the type of device and of its use. The time dependent obsolescence rate, multiplied with the number of devices sold in a defined year, produces for that year the totalised number of devices, which end up as output in the waste disposal. In the reference scenario, the average obsolescence rate for monitors is assumed to be 5, for TV's 6 and for laptops 3 years.

The output quantity in Table 12 specifies a theoretical value as not all the devices diverged from initial use will end up in the waste flow. A larger part of devices is stored temporarily, second hand used or exported abroad (by internet commerce, foreign workers or similar).

Table 12: Forecast of disposed of PC LCD monitors, TV FPD monitors and laptops, 2012-20

	2012		2014		2016		2018		2020	
	[pieces]	[%]	[pieces]	[%]	[pieces]	[%]	[pieces]	[%]	[pieces]	[%]
PC CRT monitors	19'000	3	2'000	0	0	0	0	0	0	0
PC LCD monitors	479'000	97	543'000	100	597'000	100	649'000	100	711'000	100
Total PC monitors	**498'000**	**100**	**545'000**	**100**	**597'000**	**100**	**649'000**	**100**	**711'000**	**100**
TV CRT monitors	298'000	65	208'000	40	124'000	20	60'000	9	23'000	3
TV FPD monitors	158'000	35	306'000	60	474'000	80	616'000	91	706'000	97
Total TV monitors	**456'000**	**100**	**514'000**	**100**	**598'000**	**100**	**676'000**	**100**	**729'000**	**100**
Total Laptops	**465'000**		**654'000**		**876'000**		**1'104'000**		**1'293'000**	
TOTAL FPD's[1]	**1'102'000**		**1'503'000**		**1'947'000**		**2'369'000**		**2'710'000**	

[1] PC LCD monitors, TV FPD monitors and laptop PC's; sources: (Benedetti and Zumbühl 2010); (Widmer)

Fig. 12: Forecast for disposed PC LCD monitors, TV FPD monitors and laptops, 2012-20

4.3 Mercury

The amounts of mercury ending up in the waste disposal will total, according to model calculations, **about 36 kg at most** in 2014, with some 20 kg from TV sets. In 2020, this quantity is estimated to be still 10 kg. The maximum stock quantity amounts to approximately 150 kg (Fig. 13). The overall amount of mercury to be disposed of adds up to 388 kg for the time span 1998-2030.

In Switzerland, 80 kg of mercury are disposed of every year over the separately collected fluorescent lamps (SENS Technical Report 2009). Energy saving lamps include an average of 4-8 mg mercury. Assuming a yearly amount of 6 million energy saving lamps to be disposed of (Germany: 59.3 million), a maximum mercury load from energy saving lamps of 48 kg/a should result for Switzerland.

4.4 Indium

The amounts of indium should reach their **115 kg maximum** in 2017 (Fig. 14). Also with indium, the major part comes from TV sets, due to the large display surfaces (Fig. 14). The maximum stock quantity totals about 250 kg. The incidental overall amount of indium in the time span 1998-2030 totals 2’065 kg.

Fig. 13: Development of mercury input, output and stock

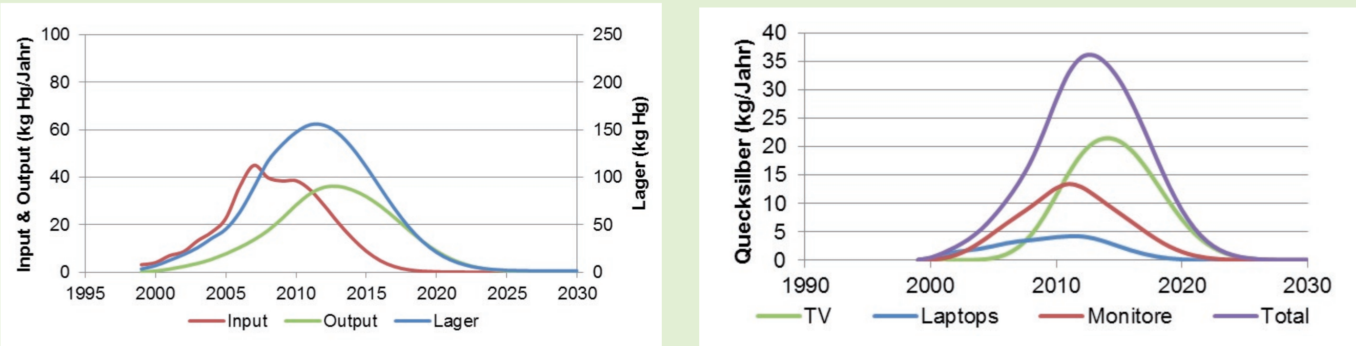
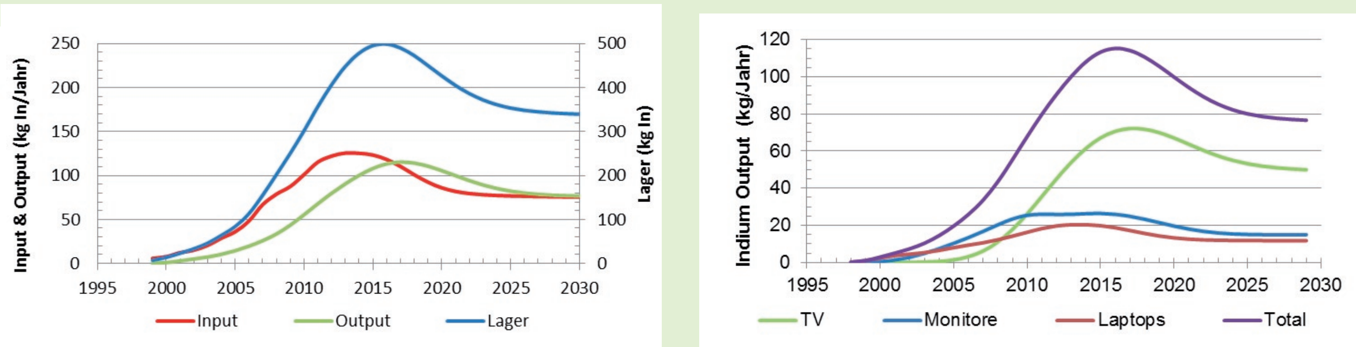


Fig. 14: Development of indium input, output and stock



5 Collection and Transport

The collection of electronic waste of categories 3 (ICT) and 4 (CE) happens in Switzerland for about 54% over municipal collection points, for about 17-18% each over enterprises and trade and for about 10% over producers. Most collection points convey these waste products together with other appliances in same containers or frame pallets to the recycling plant. Only larger collection points and major distributors are partly organising device-specific carriage (Fig. 15). Joint transport or improper charging may damage waste devices and, therewith, cause the leakage of mercury from backlights.

So far, no measuring of mercury air emissions during waste collection or transport was performed in Switzerland. In France, the system operator "Eco-systèmes" conducted measures of horizontally and vertically transported FPD monitors and could not trace any mercury air emission above the limit of detection (< 5 µg/m³) (LNE 2010).

In a study, the European Energy Research Alliance (EERA) measured the mercury air emissions from damaged FPD monitors (Tromp 2009). LCD displays were dumped with a crane from some 2.5 - 4 m height into a steel container, during which the mercury air emissions were measured. After about 1.5 hours, the concentrations measured in the closed container reached a maximum of 10 µg Hg/m³, which is five times less than the corresponding OEL value from Switzerland. In this connection, one or several backlights were broken in approximately 30% of the displays, totalling an average of about 20% of the backlights.

The manual disassembly (cf. Chapter 6.4) revealed, in a test series of 58 FPD monitors, that 3 of them had one or several defective backlights, which is the equivalent of a breakage rate of approximately 5%, considering the number of devices, and < 1% if referring to the number of backlights. By virtue of these results, it can be asumed that the mercury air emissions do not represent a health and safety problem at work with the storage, collection and transport of FPD monitors.

Fig. 15: Transport of FPD monitors

6 Disposal

6.1 Possibilities

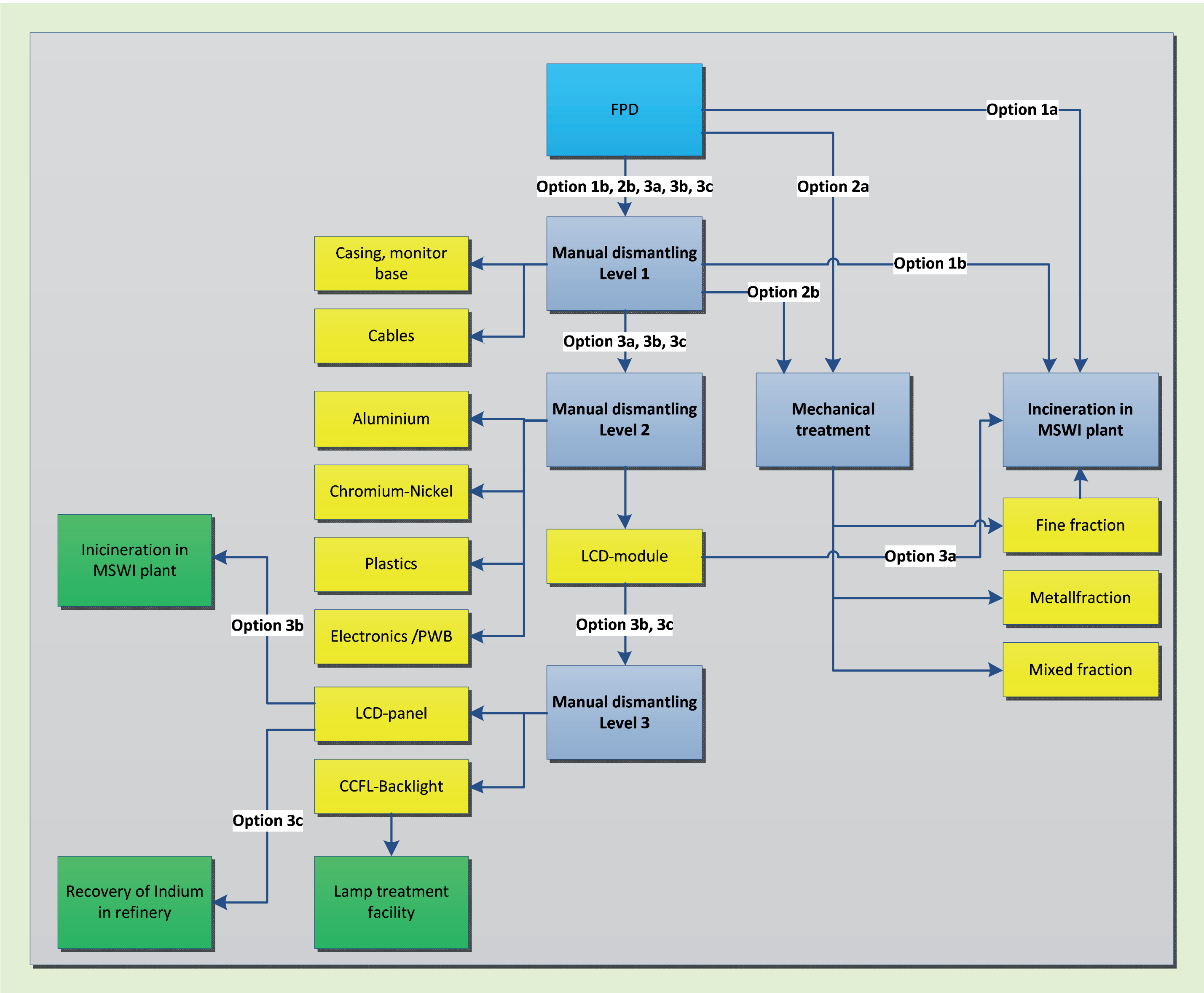
Basically, a distinction between three options may be drawn regarding the recycling and disposal of FPD monitors (cf. Fig. 16):

- **Option 1: incineration in a MSWI,** either undismantled (option 1a), dismantled after a 1st dismantling level (option 1b) or after a 2nd dismantling level (option 3a).

- **Option 2: mechanical processing,** either of the undismantled FPD monitors (option 2a) or after a 1st dismantling level, respectively (option 2b).

- **Option 3: manual disassembly** of FPD monitors. A distinction may be drawn between three dismantling levels:
  - 1st level (options 1b and 2b): removal of monitor base, cable and casing
  - 2nd level (options 3a, 3b und 3c): additionally to the 1st level, disassembling into metal and plastic fractions, printed wiring boards plus LCD module
  - 3rd level (options 3b and 3c): additionally to the 2nd level, disassembling of the LCD module into LCD panel and CCFL backlight. To recover the indium, the LCD panel can be treated in a precious metal furnace (option 3c), or be incinerated in a MSWI, respectively (option 3b).

Fig. 16: Possible waste disposal options for FPD monitors



6.2 Incineration in MSWI

Some of the electronic waste recycling plants dumped in the past years undismantled or partly disassembled FPD monitors in Municipal Solid Waste Incinerators (MSWI). The reason was the lack of recycling alternatives.

Devices consisting of 35-45% metals, 6.5-11% printed wiring boards and merely approximately 15-40% plastics are hardly suitable for thermal disposal. On the one hand, precious metals go lost and on the other hand, the calorific value or energy is far below the average calorific value of municipal waste. What's problematic besides the low calorific value of FPD monitors is also the loss of the rare metal indium and of the additional mercury load, which is, thus, fed to MSWI.

Table 13 shows an estimation of these possible additional mercury loads by assuming that in 2012, all FPD monitors would be incinerated in MSWI. About 1'379 kg mercury ended up in 2008 over the mass flow of all the Swiss wastes incinerated in MSWI (Morf 2006). Based on the assumption that in 2012, approximately 600'000 FPD monitors will be disposed of and that this quantity is split in 30% each for laptops and TV's and in 40% for PC monitors, a load of some 11 kg mercury results, amounting to mere 0.8% with regard to the said 1'379 kg. From an overall perspective, this additional load is relatively insignificant, but with a concentration of incinerated FPD monitors in few MSWI only, the emissions may, locally, reach higher concentrations.

Table 13: Estimation of the mercury load when incinerating FPD monitors entirely in MSWI

			Amount of Waste			**Hg Load**	
		supplied	moisture-	dry	content	load	share
		[t supplied]	content	[t DM]	[mg/kg DM]	[kg]	
Amount of domestic waste	2008	1'997'887	22%	1'558'352	0.64	997.35	72%
Direct supply	2008	1'052'336	21%	831'345	0.46	382.42	28%
TOTAL		**3'050'223**		**2'389'697**		**1'379.76**	100%
			Number of Disposed of FPD's 2012			**Hg Load**	
					content	load	share
			[pieces]		[mg/piece]	[kg]	
TV shares	30%		180'000		40	7.20	66%
PC monitor shares	40%		240'000		12	2.88	26%
Laptop shares	30%		180'000		5	0.9	8%
TOTAL	**100%**		**600'000**			**10.98**	100%
Share of Hg load from incinerated FPD monitors in MSWI versus total Hg load						**0.80%**	

Assuming that the maximum mercury amount of 36 kg/a, calculated on the basis of the forecast, ends up in incineration plants, the mercury share relating to the whole mercury load would rise to about 2.6%.

6.3 Mechanical Processing

6.3.1 Processing Test

On February 6 and August 17, 2010, RUAG Altdorf processed each time with the existing granulator some 1.5 tons of previously till 2nd level dismantled FPD modules.

The purpose of the test was to measure the gaseous mercury immissions during the processing phase and to determine the mercury contents in the resulting fractions. SUVA measured the gaseous mercury immissions in the plant area at commonly defined measuring points. The determination of the mercury content in the residues was carried out by the Empa Laboratory for Chemical Analysis. In order to take into account the impact of the ambient temperature on the gaseous mercury emissions, the test was performed in both summer and winter season. Table 14 depicts the parameters of the two tests.

Table 14:
Test parameters of mercury vapour measures in the mechanical processing of LCD modules with CCFL backlight

Parameters	Test on February 6, 2010	Test on August 17, 2010
Volume of LCD modules	1‘450 kg	1‘518 kg
Number of LCD modules	1‘270 pieces	844 pieces
Average weight	1.14 kg	1.80 kg
Processing time	90 minutes	70 minutes
Processing performance	966 kg/h	1‘301 kg/h
Hall temperature	8° C	20.3° C
Air moisture	44% rel. air moisture	57.6% rel. air moisture
Air pressure	948 hPa	not measured

The two tests differed regarding inside temperature (8 and 20° C, respectively), average weight of the modules processed (1.14 against 1.8 kg; + 60%) and processing performance (966 beside 1‘301 kg/h; + 35%). It may be assumed that these three parameters explain largely the significantly higher Hg immissions in the second test (see Table 15).

Table 15:
Results of mercury vapour measures in the mechanical processing of LCD modules with CCFL backlight

Measuring Site		Test on February 6, 2010 Range µg/m³	Test on August 17, 2010 Range µg/m³
Outside		0	0
Inside (hall)		3-7	3-21
Delivery point		0-6	14-28
Rotary shear		0-15	5-27
Briquettes, discharge		4-87	6-725
Granulator, output	ground	not measured	4-15
	waist-high	not measured	6-26
	face level	24-172	3-32
Fe fractions container		4-44	12-168
Non-Fe fractions cont.		5-10	7-93
Residual materials cont.		5-39	22-114
Basement, fine fraction		13-34	19-25
Basement,”Zyklon B” cont.		13-50	19-54

In the second test, the highest values were measured next to the briquette discharge, right at the Fe fractions container and residual materials container. There are no permanent work places at these three points, i.e. the OEL values cannot be drawn upon as direct reference. Yet, the measuring values reveal, locally, noticeably higher mercury concentrations and that a part of the mercury escapes in gaseous form.

Fig. 17: Photos of processing test mechanical processing

Photo 1: Measuring rotary feeder, briquettes

Photo 2: Measuring rotary shear

Table 16 presents a compilation of mercury analyses results on the fraction of solid matters from the first test. About 4% of the measured mercury adheres to the recyclable fraction, while approximately 96% are accumulating in the fine fraction.

Assuming that one LCD module contains about 12 mg mercury[5], about 15‘250 mg mercury result with test 1 for estimated 1‘270 modules ending up in the plant. The difference between this volume and the amounts measured in the fractions is 11‘663 mg or 76% of the total mercury input quantity. This “missing volume” either escaped in gaseous form and/or settled in the plant. One could also imagine that the input quantity with 12 mg mercury per device was overrated. Still, even with only 8 mg mercury per device, the gaseous emission totals about 65% of the whole mercury volume.

[5] Assumption: a module averages 4 tubes with 3 mg Hg each.

Table 16: Results of solid matter analysis in the mechanical processing of LCD modules with CCFL backlight

Category	Fraction	Weight		Hg Content		
		[kg]	[share]	[µg/g]	[mg]	[share]
Recyclable fraction	Scrap steel granulator	135	9.3%	0.90 ± 0.42	122	3.4%
	Aluminium shredder scrap	121	8.4%	0.14 ± 0.04	17	0.5%
	Separation material neodymium	34	2.4%	0.08 ± 0.04	3	0.1%
Residues/ fine fractions	Briquettes	425	29.4%	6.90 ± 0.08	2‘933	81.8%
	Dusts, basement	8	0.6%	47.00 ± 4	376	10.5%
	Residual materials plastics / metals	722	50.0%	0.19 ± 0.08	137	3.8%
TOTAL		**1‘445**	**100%**		**3‘587**	**100%**

6.3.2 Encapsulated Units

Diverse producers propose encapsulated units to treat FPD monitors entirely. According to manufacturer information, these units should allow capturing mercury released by the process and generate simultaneously utilisable metals and metal/plastic fractions. Yet, processing technology, Hg separation efficiency and the whereabouts of mercury accumulations cannot be given in detail for any of the units (Table 17).

Table 17: Survey of suppliers and plants for processing FPD monitors (situation of October 2010)

Provider	Situation
Air Mercury AG, CH-Birrwil	Plant in Rubigen/CH (since November 2011)
Galloo N.V., B-Menen	Plant in Belgium
Récupyl, F-Domène	Plant in France
Stena Metall AB, S-Göteborg	GRIAG Glasrecycling (glass recycling) Ltd., plant in Werder

6.4 Manual Disassembly

On March 17, 2010, tests were performed in a dismantling plant of Immark AG, Regensdorf, on the manual disassembly of FPD monitors.

Since 2009, the dismantling plant disposes of 4 workplaces, arranged for the manual disassembly of FPD monitors and with a ventilation system for the working desks (fig. 19). During the test, continuous stationary (EPM measurement device), person-related (with personal dosimeter) and indicative measurements (Jerome mercury vapour analyser) were performed (table 18). To allow the measurements of significant mercury values in the working areas, tubes had to be broken intentionally in the course of the test.

The stationary measurements revealed, after more than 5.5 hours, an average Hg value of 2 µg/m^3 (OEL value: 50 µg/m^3). Also with the person-related measurements, the same value was obtained, but in the rest of the cases, this value is clearly lower.

With the indicative measurement device, 2-7 µg/m^3 Hg were quantified approximately at the level of the working desk area, immediately surrounding the work space of the dismantling personnel. The highest value was measured next to the barrel with the broken fluorescent tubes (> 1‘000 µg/m^3; see photos 7/8 (fig. 19). On aspiring directly the escaping gas on a freshly broken tube, the stationary EPM measuring device quoted a value of > 1‘999 µg/m^3, while the Jerome mercury vapour analyser indicated 86 µg/m^3.

Generally speaking, it may be concluded from the tests that the mercury immissions are, in orders of magnitude, below the OEL values, even with the intentional destruction of the fluorescent tubes. Under normal conditions, mercury manifestly escapes only slowly from the tubes and deposits on lower points, which is due to its specific weight heavier than air. With the ageing process of the devices, an increasing embedding of the mercury occurs inside the tubes, which might reduce the share of the escaping vaporous mercury.

Table 18: Results of mercury vapour measurements in the manual processing of LCD monitors with CCFL backlight

Parameters		Result
Hall temperature		19° C
Air moisture		29% rel. air moisture
Air pressure		966 hPa
Measuring value, individual-related (personal dosimeter)	4 h shift (with 3 persons)	0.06/1/2 µg/m³
Measuring value, stationary at the dismantling workplace (EPM measuring device)	average 5.5 hours	2 µg/m³
Measuring values, orienting (Jerome mercury vapour analyser)	workplace, after breaking of fluorescent tubes	4 µg/m³
	workplace, right after breaking of tubes, a few cm away	4-7 µg/m³
	workplace, about 2 min after breaking of tubes, a few cm away	2-5 µg/m³
	box with unbroken fluorescent tubes (see photo 7)	2 µg/m³
	in a barrel with broken fluorescent tubes (see photo 8)	> 1'000 µg/m³
	above the barrel, shortly after removing the cover/lid	180 µg/m³
	right on the freshly broken tube (with the air sucked from the tube)	> 1'999 µg/m³ (EPM) 86 µg/m³ (Jerome)

Additionally to the mercury vapour measurements, samples of the dust deposits were taken at diverse points and analysed by the Laboratory for Analytical Chemistry of Empa. The protection objective is set to 0.002 µg/cm², and the measuring values were situated around factor 10-20 under these values (Table 19), except for measuring point 5, where the value was situated slightly above the protection objective.

Table 19: Results of mercury determination in swipe samples

Parameters		Result
Hall temperature		19° C
Air moisture		29% rel. air moisture
Measuring point 1	restaurant/second-hand shop, floor	0.0001 µg/cm²
Measuring point 2	break room, floor	0.0001 µg/cm²
Measuring point 3	office, work surface	< 0.00003 µg/cm²
Measuring point 4	workplace, floor	0.0009 µg/cm²
Measuring point 5	workplace, upper ventilation cover	0.0026 µg/cm²
Measuring point 6	mercury waste barrel, floor	0.0001 µg/cm²
Measuring point 7	workplace with ventilation, work surface	0.0006 µg/cm²

Fig. 18: Photos of processing test manual dismantling

Photo 1: Disassembling, workplace

Photo 2: Extraction unit

Photo 3: Mercury vapour analyser „Jerome“

Photo 4: Measurement with personal dosimeter

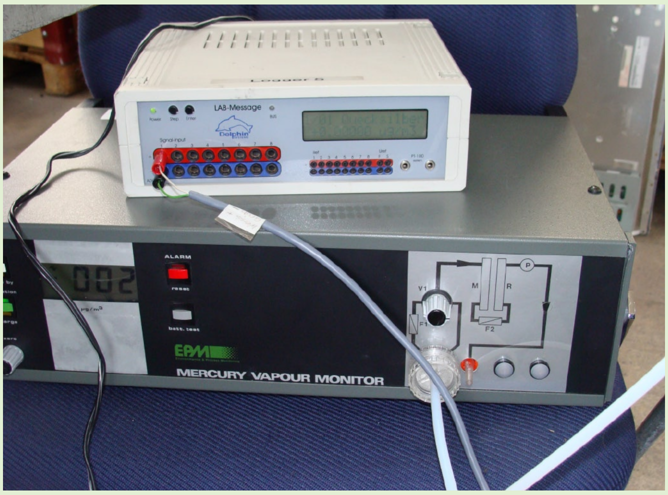
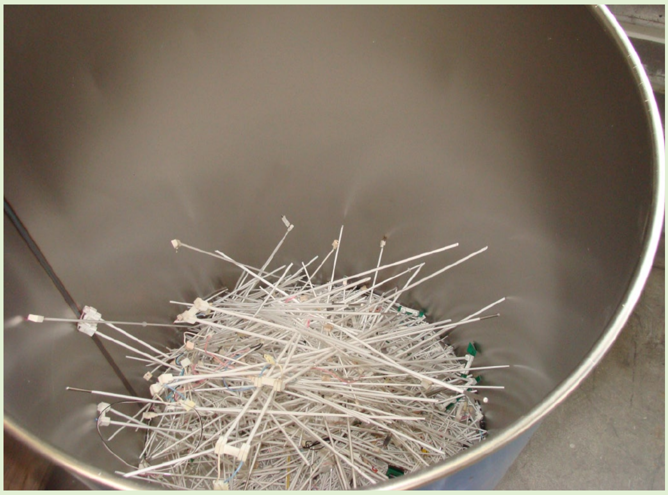


Photo 5: Measuring device “EPM“ for stationary Hg vapour measurement


Photo 6: Backlight TV FPD monitor

Photo 7: Storage of intact backlights


Picture 8: Storage of broken backlights

The current processing performance reaches 25-35 FPD monitors per workday (8 h) or 6‘250 to 8‘750, respectively per year and workplace (250 workdays). By supposing a yearly amount of some 600’000 FPD devices ending up in the waste disposal, a demand for 70-100 dismantling workplaces may be assumed if all the FPD monitors are totally demounted manually. At present, there are 85 dismantling companies in the Swico and SENS System with about 800-1‘200 manual disassembly workplaces in total, where waste electrical and electronic equipment is partly being disassembled. Alone for FPD monitor disassembling, the required dismantling workplaces would, thus, reach 5-10% of the existing ones.

Previous operational experiences show that with TV sets, the breaking risk is the highest, as up to 20 backlights must be removed from each. With well-trained e-waste dismantling operators and adequate instruments, these breaking rates are about 20% on TV sets, while on PC monitors these rates remain below 5%, as the tubes are mostly placed in aluminium frames.

6.5 Recovery of Indium

Until now, there is no technical method available in Europe, which enables the recovery of indium from FPD monitors. According to model calculations, the economic value of the maximum indium volume ending up in the waste disposal in Switzerland, amounts to some 66‘000 USD[6], with a maximum weight of 115 kg In in 2017. The question arises whether this revenue stimulates the recovery of indium or if the latter will depend on additional payments.

[6] Indium prices according to www.mineralprices.com; October 26, 2010: USD 576

6.6 Intermediate Storage

A possible solution to keep indium available for a later recovery would be an intermediate storage of the LCD panels. According to model calculations, the following numbers of pieces or intermediate storage volumes, respectively, can be anticipated in 2012, 2016 and 2020:

Table 20: Forecast for volume requirements of LCD modules in PC monitors, TV FPD monitors and laptops, 2012, 2016 and 2020

	LCD Panels	**2012**		**2016**		**2020**	
	[m³/piece]	[pieces]	[m³]	[pieces]	[m³]	[pieces]	[m³]
PC LCD monitors*	0.00036	479‘000	172	597‘000	215	711‘000	256
TV FPD monitors**	0.00352	158‘000	556	474‘000	1‘668	706‘000	2‘485
Laptops***	0.00018	465‘000	84	876‘000	158	1‘293‘000	233
TOTAL			**812**		**2‘041**		**2‘974**

Exceptions:
- * width 30cm, length 40cm, height 3mm
- ** in average 36“ screen diagonal: width 44cm, length 80cm, height 1cm
- *** width 20cm, length 30cm, height 3mm

If storing the LCD panels from 2012 to 2020, about 15’000 m³ would be needed, which would, with a storage height of 10 m, total 1‘800 m² shed area (including 20% circulation space). Based on CHF 80.-/m²* year, about CHF 150’000 rent cost per year or CHF 1.35 million over 9 years would have to be spent. In contrast, incineration costs of approximately CHF 0.9 million[7] over the whole time span would be saved and eventual proceeds of a later sale of the panels might add.

[7] Assumption: specific weight of LCD panels: 300 kg/m³, incineration cost CHF 200.-/t

7 Conclusions and Recommendations

7.1 Final Conclusions

Amounts of FPD monitors, mercury and indium flows

- The expected amounts of **LCD FPD monitors** to be disposed will grow considerably in the coming years[8]: Starting from presently 313‘000 PC LCD monitors, the volume will grow in 2014 to some 550‘000 per year. Concerning the TV sets, their number ought to rise from presently 80-100‘000 to about 300‘000 in 2014, and laptops with a current yearly disposal rate of 240’000, should reach approximately 650‘000 per year. An environmentally appropriate and safe disposal of FPD monitors herewith generates one of the most pivotal challenges for e-waste recycling in the near future.

- Considering the increasing number of **devices** sold **with LED backlight** or rather with OLED technology, the volume of recovered FPD monitors with traditional CCFL backlight is expected to decrease continually and relatively rapidly in approximately 4-6 years. It is assumed that in 2020, the stored TV FPD monitors with LCD backlights in Switzerland will reach less than 10%, with regard to the total volume of monitor units.

- In 2014, a maximum volume of **mercury** from disposed FPD monitors is expected to total about 36 kg. This corresponds to barely half of the mercury from fluorescent light tubes, which, today, is ending up every year in the recycling system. Relating to the mercury flow of approximately 1’380 kg arriving every year to Swiss MSWI, this volume corresponds to some 2.6%.

- The maximum disposed **indium flow** from FPD monitors will total about 115 kg in 2017.

Collection and Transport

- In the **collection and transport** phase of FPD monitors, about 5% of the backlights are being damaged. At no time will the resulting mercury air emissions represent a health risk for the people involved in the treatment process; hence, no particular measures impose themselves with regard to collection and transport.

Disposal Alternatives

- On principle, there are 3 different alternatives to dispose of FPD monitors: (a) incineration in MSWI; (b) mechanical processing and (c) manual disassembly, whereby these alternatives may be combined.

- On a Swiss level, the **incineration in MSWI** would cause a slight increase of the whole mercury flow in the MSWI. But in view of the low calorific value, FPD monitors are rather inappropriate for thermal disposal. Besides, depending on the level of the previous manual disassembly, more or less recyclable fractions go lost. In conclusion, incineration does not meet the state of the art.

- In the course of **mechanical processing,** the mercury contained in the CCFL backlights escapes for a major part as gaseous emission at diverse points of the plant. The mercury adhering to the materials accumulates in the fine fractions. An undefined share can spread over the plant. The adhesions on the metallic recycling fractions will probably be marginal. The air emission behaviour of mercury during the mechanical process depends on the materials, the processed amount and on the ambient temperature.

- **Encapsulated units** are available on the market, which are generating widely mercury-free and thus recyclable fractions and in which the gaseous emissions can be controlled. Until now, no independent measures on such units exist, which would document the promises of the manufacturers.

- The breaking rates on both PC monitors and TV sets in the **manual disassembly** process are only marginal. Even with increased breaking rates, the mercury air emissions will not reach the OEL values in the work space of the dismantling operators. However, the points where concentrated numbers of broken lamps are stored become critical. There, the OEL values are regularly exceeded. The breaking risk is the highest with TV sets and relatively insignificant with PC monitors.

Recovery of Indium and Intermediate Storage

- Until now, there is no technical method available in Europe, which allows the **recovery of indium** from FPD monitors. The economic value of the maximum disposed of indium in Switzerland accounts for about 66‘000 USD at most, according to model calculations. From a purely economic point of view, there is little incentive to recover the disposed of indium, considering the little importance of its economic value. But by virtue of the indium shortage, such recovery can make sense.

- The **intermediate storage** of indium containing LCD panels will involve some CHF 150‘000 annual storage cost. Taking into account the savings on incineration expenses, net costs of approximately CHF 50‘000 per year should arise, regardless of possible later sales revenues.

[8] Amounts determined from the model calculations, regardless of the waste volume, which would not be arriving in the recycling system. The latter (depending on the appliance category) account for 25-60% of the theoretical amount from the model calculations.

7.2 Goals of Future Processing of FPD Monitors

7.2.1 Guidelines and Principles of Environmental Law

The study reveals the dimension of the future disposal of FPD monitors in the whole e-waste management system. It has been demonstrated, what specific challenges arise with the three possible waste disposal alternatives, i.e. (a) MSWI, (b) mechanical processing and (c) manual disassembly, and the risks and environmental impacts they imply.

From the viewpoint of toxic substances, **mercury** constitutes the main challenge in the area of FPD monitor disposal. On defining the requirements for waste disposal, the basic question arises about applicable objectives. On the one hand, these latter derive from basic principles of environmental law and on the other hand, from existing or foreseeable international tendencies.

Regarding the recyclable fractions, **indium** is the prime element to be focussed upon for recoverability.

In connection with the mercury depollution of FPD monitors, the following *guidelines and principles* of environmental law need to be emphasised:

Precautionary principle
Art. 1 EPA

The purpose clause of the Swiss Environmental Protection Act (EPA) stipulates that "Early preventive measures must be taken in order to limit effects which could become harmful or a nuisance".

Prohibition on mixing of waste
Art. 10 TOW

Art. 10 of the Technical Ordinance on Waste (TOW) says that holders of waste must not mix it with other waste or additives, if that serves primarily to reduce the content of toxic substances by dilution, only in order to meet with prescriptions on delivery, recycling and recovery or landfilling.

Immission control
Art. 11 EPA

The Swiss Environmental Protection Act (EPA) stipulates that "Air pollution, noise, vibrations and radiation are limited by measures taken at their source (limitation of emissions)". Irrespective of the existing environmental situation, emissions are to be limited within the precautionary framework, as far as this is technically and operationally manageable and economically feasible.

The Swico-SENS Technical Guidelines (TG) proscribe the mixing of hazardous waste (C.3.1) in the processing principles. On principle, mercury containing components must be removed and mercury air emissions prevented adequately (D.6). The following separate prescriptions prevail for LCD backlights (Guideline 2 "ICT and CE Devices"):

Selective treatment of CCFL's
TG Swico/SENS
Guideline 2

Following Annex II of the DIRECTIVE 2002/96/EC OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL of 27 January 2003 on waste electrical and electronic equipment (WEEE Directive), cold cathode fluorescence lamps in liquid crystal displays exceeding 100 cm² are to be removed and fed to professional recycling or disposal.

Requirements on mechanical processing
TG Swico/SENS
Guideline 2

Annex II of the WEEE Directive demands a selective treatment of certain raw materials and components of waste electrical and electronic equipment. But that equivalent to manual disassembly (Annex II also issues, for instance, prescriptions on the selective treatment of plastics with brominated flame retardants or of conductor boards, which are both being processed mechanically). According to the Technical Guidelines of Swico and SENS, the treatment of liquid crystal displays without previous removal of the cold cathode fluorescence lamps may be admitted, provided that, after consultation with the control body, it is granted that none of the toxic substances contained in the cold cathode fluorescence lamps – notably mercury – is spread to the fractions generated in the process, and that the toxic substances are fed to professional recycling or disposal.

Immission control
TG Swico/SENS
Guideline 2

When depolluting and processing liquid crystal displays, it must be arranged for keeping toxic emissions – especially of mercury – so low, that no impairment to the environment or the health of the personnel is being caused.

7.2.2 Trends on Global and European Level

The United Nations Environmental Programme (UNEP) recognises mercury as a chemical of global significance. In February 2009, it was agreed to elaborate an international mercury convention as legally binding instrument, destined to rule the handling of mercury on a worldwide level. Switzerland assumes a pioneering role in the preparation of the mercury convention. On February 10, 2010, the UNEP Conference in Nairobi made a decisive break-through by initiating common international negotiations for the elaboration of such a convention, which are to be finalised till about 2013.

The European Commission decreed a mercury strategy[9] in January 2005. The latter comprises, among others, a strategy for emission control, reduction of mercury release into the environment and protection against mercury contamination.

On the European level, indium is considered as critical[10].

7.2.3 Trends in Switzerland

As a general rule, the use of mercury and of its preparations, as well as putting into circulation mercury containing preparations and objects by a manufacturer are prohibited in Switzerland. In this context, Switzerland has widely adhered to European legislation. Also exceptional rules issued by the latter are adopted in each case by Switzerland.

For the time being, there are no prescriptions regarding the recovery of indium from FPD monitors. Within the current revision of the Ordinance of 14 January 1998 on the return, take-back and disposal of electrical and electronic equipment (VREG), alternatives are examined, whether it would make sense to implement prescriptions, demanding the recovery of critical elements.

7.3 Adjustment of the Swico-SENS Technical Guidelines

The existing Technical Guidelines of Swico Recycling and SENS rule in large parts the requirements for the disposal of FPD monitors. Thus, a selective treatment of backlights from 100 cm² on is demanded, following the WEEE Directive (but there is no compelling need for manual treatment). Mechanical processing is admitted after having previously referred to the control bodies, as far as no spreading of mercury occurs on the resulting fractions and that an environmentally sound disposal of the toxic substances can be secured. An emission control will be requested in any case to make sure that neither the environment nor the health of the personnel will be harmed.

Basing on the results of the present study and on the goals exposed in chapter 7.2 on the future disposal of FPD monitors, we propose the following principles for the adjustment of the Technical Guidelines of Swico Recycling and SENS:

Determination of Clear Framework Conditions for Mechanical Processing

Mechanical processing of FPD monitors should be enabled, provided that clear quality requirements are established for the fractions destined to recovery. In this relation, the residue quality is being adapted to the existing regulations for lamp recycling in Switzerland.

Restriction of Incineration

The incineration of manually dismantled FPD monitors should be allowed from disassembly level 2 on only, i.e. the thermal disposal of combustible fractions (plastics) and LCD panels or LCD modules shall be accepted, but in no case the incineration of whole monitors. On the other hand, organic residues from manual processing are admitted.

To be concrete, we propose the following adjustments to the existing Technical Guidelines of SENS and Swico Recycling:

[9] See: http://www.toxcenter.de/artikel/EU-Quecksilberstrategie.php
[10] European Commission. 2010. Critical Raw Materials for the EU. Report of the Ad-hoc Working Group on defining critical raw materials.

Guideline 2: ICT and CE Devices

FPD Monitors

1.1 The method applied for the processing of FPD monitors needs an efficient retention of contaminants and the highest possible recovery rate for recyclable fractions.

1.2 Liquid crystal displays with a surface exceeding 100 cm^2 and cold cathode fluorescence lamps from FPD monitors must be removed and recycled or disposed of appropriately.

1.3 In the manual disassembly process of FPD monitors, appropriate measures are to be taken to meet at all times with the environmental and health protection requirements at the workplace.

1.4 Broken cold cathode fluorescence lamps from backlights must be stored and transported separately in closed containers. Taking adequate precautions when filling the containers is imperative and the containers must also be stored in suitable places.

1.5 When processing FPD monitors mechanically, without having removed the cold cathode fluorescence lamps previously, the following requirements must be met:
   (a) Gurantee at all times an efficient retention of the mercury contained in the cold cathode fluorescence lamps during the process and also the fulfilment of the legal requirements on environmental protection and health at the workplace with regard to gaseous immissions;
   (c) Make sure that the glass fraction for material recycling does not contain more than 5 mg mercury per kg dry matter (DM), the metal fraction for material recycling not more than 10 mg mercury per kg dry matter (DM) and all the other fractions not destined for special waste disposal (landfills) not more than 10 mg mercury per kg dry matter (DM).

1.6 Thermal recycling of plastics from FPD monitors and LCD panel disassembly in MSWI is admitted, but entire FPD monitors or modules, respectively, are prohibited from incineration.

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