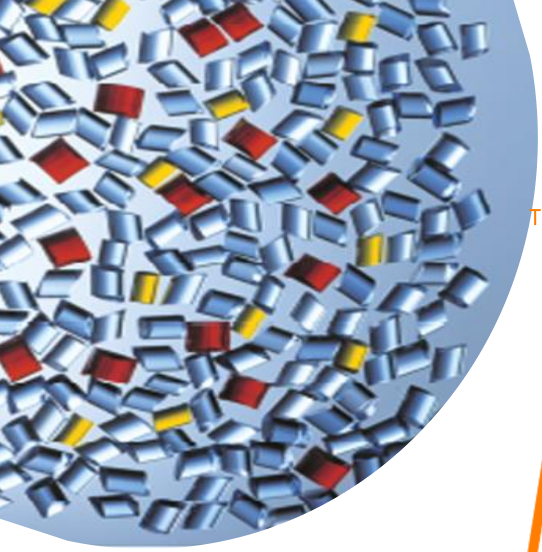

MMAtwo - This project has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 820687

The MMAtwo project results presented reflect only the author's view. The Commission is not responsible for any use that may be made of the information it contains.

SECOND GENERATION METHYLMETHACRYLATE

Deliverable

WP1 – Collection of scraps and pretreatment

D1.2 - Map of treatment centres and quantities of extracted PMMA produced

Project Information

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Name	Position in project	Organisation	Date	Visa
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Table of content

Executive summary

1 Description of the deliverable objective and content

D1.2, written by French WEEE Scheme Ecologic, gives an outlook on PMMA use in EEE sector, especially in screens, and the organization of WEEE treatment through France case study.

Indeed, PMMA from electronic waste is one of the main potential waste streams among end-of-life products that contain PMMA and could be a large source of feedstock for the MMAtwo projected business model.

Three main outcomes are expected:

1. the PMMA share per technology of screen,
2. the evolution of screen waste generated in France, extrapolated to Europe
3. the quality of the PMMA stream and market share per screen sorting technology

2 Brief description of the state of the art

Few studies on e-waste generated have been made, including screens, that proved being far from the real amount of flat panel displays (FPD) waste generated and collected due to the limitations of the calculation methods.

There are also studies on FPD technologies and FPD recycling technologies in Europe, made by the Joint Research Center (JRC) for ecodesign reglementation's implementation, some thesis, European projects (RevolV), and studies conducted by local consultants for specific missions. Those studies sometimes provide details about screens composition, including PMMA share, but only for very small batches (<10 pieces).

However, no public studies were conducted on PMMA quantity and quality in screens flow.

3 Deviation from objectives and corrective actions

D1.2 could not be completed at due time, because of insufficient available data on LCD screens lifespan, and therefore uncertainty on the amount of waste to be generated in coming years.

It has been completed by M36 with every data that could be obtained.

A 'dating' study, consisting in analyzing a sample of waste screens collected per technology, age, and weight has been conducted to get more representative information. It shows that screens lifespan is sometimes longer than expected, around ten years in average. Therefore a large amount of LCD screens put on market the two last decades will be collected over the coming few years.

Data on screen waste generated calculated for the 28 EU-countries were also collected, providing global results.

Hence, this research will lead to an approximative but robust result on final objective: evaluating PMMA potential in WEEE in Europe.

4 Innovation brought and technological progress

No major innovation was brought through D1.2. The exercise consists in a methodological evaluation of a potential based on available data and collection of specific data to gain in accuracy and robustness.

D1.2 and its interviews, company visits and information exchange with FPD recyclers did however provide better understanding towards collection/recycling companies in the following fields:

- Identification of PMMA vs other polymer types: PC, PS, PET etc.
- Identification of PMMA in different grades: casting grade vs extrusion grade
- Recyclability of the subsequent PMMA streams and the impact of separation technology on its final recyclability
- Collaboration with WEEE waste collector on how to retain value in the waste by looking ahead in the recycling chain: mechanical recycling vs chemical recycling

5 Analysis of the results

The amount of PMMA from LCD screens collected per WEEE schemes in France in 2019 is high. The hypothesis is that PMMA counts for 7% of total FPD flow, remaining constant in 2020-2030 decades. It is built by considering that LCD (CCFL and LED, since the two technologies contains PMMA in backlight panels) will remain the major part of FPD flow, as plasma is becoming more scarce while OLED/QLED markets starts developing in Western Europe.

A forecasting on 2020-2030 period in Europe was made, despite uncertainties on spatial and temporal extrapolations:

- due to the evolution of waste screens technologies
- due to the difference between countries on the 'shift' from CRT screens to FPD screens.

Finally, there is a growing PMMA potential, more in TV (≈60%) than monitors (≈25%) and laptops (≈15%), because TV are bigger, and more in Western Europe (≈40%) than in Eastern (≈10%). Five countries represent around 70% of the potential: Spain, Italy, Germany, France and the UK.

Another uncertainty is potential in non-official treatment plants. It reduces by half the potential and lead to the following conclusion: exportation is the main leakage. Many waste FPD are collected in Western countries, then sent to Eastern Europe where the labour costs are lower. There the FPD are dismantled in non-official treatment plants after which the materials are exported to countries outside of Europe (mainly to Malaysia and Thailand). In the past untreated FPD and electronic waste was exported to African countries labeling it as electronics for re-use. Stricter control based on existing regulation has resulted in decreased illegal exports to African countries.

Ecologic currently works on exportation's statistical analysis at the combined nomenclature[1] level, that can be considered as an innovation since no schemes in Europe has conducted such a study. Results are not made public at the moment.

[1] https://ec.europa.eu/taxation_customs/business/calculation-customs-duties/customs-tariff/combined-nomenclature_en

Assessment of the quality of this PMMA stream is on-going at Heathland. Among the collected PMMA were different grades (extrusion, cast) and contaminants (PC, PS, PET, cellulose, printing, certain styrene additives). The grades is depending on the product (age, brand, technology), while the contaminants are often depending on the treatment technology: manual and mechanical dismantling leads to clean PMMA sheets compared to shredding.

6 Impact of the results

The estimated amount of PMMA from screens collected in Europe, is very high, makes it a key feature of MS10: reaching 27kt identified feedstocks.

7 Related IPR

Not applicable.

8 Publishable information

Reporting D1.2 is publishable. Raw data on European screens waste generated is not publishable.

9 Conclusion

Potential of LCD PMMA stream is clear. Challenges are to collect and treat screens in good conditions to allow enough quantity and quality of recyclable PMMA. This report gives some key elements to do so in the coming years, without claiming to be exhaustive.

Plus, among screens collected different quality of PMMA can be found. When the screen is shredded (mostly in Western and Northern Europe), or when the screen is found in small household appliances (SHA) flow, it's complicated to get PMMA out of the other plastics because of its density, and it is more likely to be contaminated. Semi-automatic and manual dismantling allows for more quality, as the whole sheet, even if broken in big parts sometimes, can be separated. Yet shredding is a minority, and plastic separation improves through processes such as electrostatic separation after flotation. The level and type of contamination regarding screens treatment technologies should be more assessed soon, as well as the PMMA potential (share and grades) in other WEEE flow: in SHA and specific professional equipment. By the way, understanding the use of PMMA in EEE will allow to know markets interested in using rPMMA (see D4.2).

1. Deliverable report

1.1 *MMAtwo and WP1*

The MMAtwo Project aims at constructing a novel and fast growing PolyMethylMethAcrylate (PMMA) recycling value chain based on the production of « Second Generation MethylMethAcrylate (MMA) » from post-consumer and post-industrial PMMA based products.

It is funded under the European Union's Horizon 2020 research and innovation program (project Number 820687)

The main goal for the MMAtwo project is to create a new value chain for PMMA depolymerization. This four-year European project comprises 13 partners from 6 different countries representing all the stages of the PMMA value chain.

PolyMethyl MethAcrylate (PMMA) is a well-established polymer known for its optical properties. About 300.000 tons of PMMA are produced in Europe every year, or close to 1 billion Euro of market value.

It is estimated that currently only 30.000 tons of PMMA waste in Europe is collected on annual basis (of which only 7.000 tons in actually recycled in Europe), or only around 10% of the yearly production, although PMMA can be turned back into its monomer by thermal depolymerization, thus saving precious resources and CO2 emission.

For a large part, recycling of PMMA in Europe is currently reliant on a lead-based process which does not allow to reprocess the lower PMMA qualities. Moreover, PMMA scraps current recycling processes focus on post-industrial PMMA, rather than end-of-live PMMA which represents the main share of the total PMMA waste stream which is either exported, landfilled or incinerated.

The challenge of this project consists in converting PMMA post-industrial scraps and end-of-life waste into high quality raw material and therefore contribute to the circular economy.

The project is divided into 7 work packages (WP):

- WP1: Collection of scraps and pretreatment
- WP2: Depolymerization
- WP3: Purification
- WP4: Exploitation, end-users tests, business analysis
- WP5: Techno-economic and environmental assessment
- WP6: Project management
- WP7: Communication, dissemination, and academic outreach

Figure 1: Value chain and consortium MMAtwo

The objectives of the WP1 are:

- To collect, sort and prepare PMMA scraps (post-production) and end-of-life products (post-consumer),
- To elaborate strategies for collection according to scraps or EoL products.
- To create new standards for the categorization of PMMA waste in order to generate guidelines for the PMMA scrap producer/supplier.
- To map sources of PMMA waste and identify PMMA waste as feedstock for the commercial plant, consisting of production waste and end-of-life waste

To do so, some deliverables and milestones have been set up:

Deliverable Number	Deliverable Title	Lead beneficiary	Type	Dissemination level	Date (in months)
D 1.2	**Map of treatment centres and quantities of PMMA produced**	**Ecologic**	**Report**	**Public**	**36**

Milestone number	Milestone title	Lead beneficiary	Due date (in months)	Means of verification
MS10	**27.000 t/y of feedstock PMMA scrap for depolymerisation in the commercial plant identified**	**Heathland**	**36**	**Report describing all the potential sources, commitment letters from suppliers to provide scraps and EoL**

Milestone 10 is served by Task 1.2: Mapping of sources. That task will lead to several deliverables, from D1.2 now to D1.5 at the end of the project. This task is therefore carried by every member of WP1 as follows:

- For every sample a report will be made by Heathland about the origin and potential annual available tonnage, together they will be included in a single deliverable. Ecologic will map the PMMA sources primarily from LCD screens in France, and will collect input from other countries throughout Europe for other PMMA sources.
- Ecologic will identify all LCD treatment operators in France and close to France and provide an estimate quantity of PMMA produced by each of those treatment centres, then extrapolate to Europe.
- Arkema carries a market survey to identify the scraps circulating worldwide, their current values, the plants processing them through depolymerization.
- Heathland will travel to various general waste companies to identify collection possibilities onsite. Heathland will identify PMMA waste sources counting up to 27.000 tons annually combined from postproduction waste and EoL PMMA. Data from custom databases will be considered, as well as the trade websites.
- Comet will characterize and quantify flows of PMMA in its basin of attraction, including from an economic perspective (type of end of life goods, origin, estimated annual quantity, sources of variations, etc) and determines required pre- and postshredding treatment to be communicate to the coordinator and other partners for further use (LCC analysis).

1.2 *Presentation of Deliverable 1.2*

MMATwo consortium has identified an important recycling potential in PMMA in some EoL[2] products. PMMA in EoL has two main differences with PMMA from postproduction waste:

- Its accessibility: identification on which products can contain PMMA, then an efficient way of collection (using strategic collection hubs and packaging that allows for compressed weight; this question is crucial for Covid-barreers), then an efficient sorting is necessary to separates it from other components of those products
- Its purity/quality: sorting process may lead to a contamination by other elements, depending on the product and the technology used at the waste treatment plant, age/additives/coatings/contaminants of the originating product may have affected the PMMA waste quality

Among the diversity of products using PMMA[3], electronic applications is one of the fastest growing sectors, through the development of LCD screens during the last decade.

The ProSUM project[4], that aims to deliver the first Urban Mine Knowledge Data Platform, estimated in 2015 that 430kt of LCD screens could reach end-of-life by 2019 in Europe (see Figure 17).

[2] EoL= end-of-life = post-consumer products.
[3] https://www.altuglas.com/en/markets/
[4] http://www.prosumproject.eu/

Since this potential is acknowledged, a need to better understand this flow has emerged. This document, *written by French WEEE Scheme Ecologic*, gives an outlook on PMMA use in EEE sector, especially in screens, and the organization of WEEE treatment through France case study.

Three main outcomes are expected:

1. PMMA share per technology of screen
2. Evolution of screen waste generated in France, extrapolated to Europe
3. Screen sorting technologies analysis: concepts, evolution and quality of the PMMA outputs

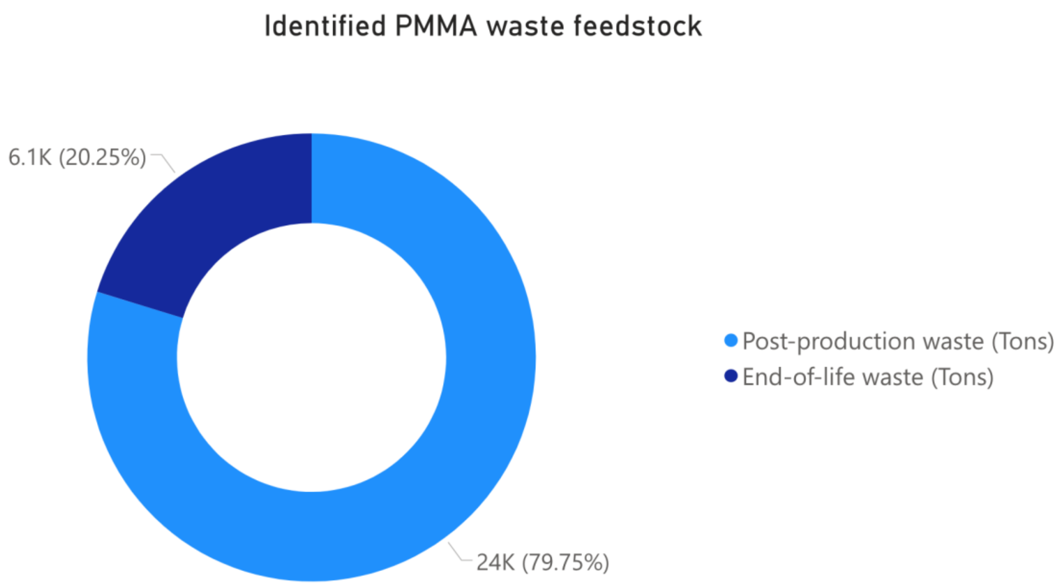

Figure 2: Identified MMAtwo feedstock regarding MS10

2. Use of PMMA in EEE

2.1 Context of WEEE treatment

2.1.1 The EU WEEE directive

The regulation of e-waste varies significantly between countries, as well as the development level of WEEE management systems. In the EU, WEEE management is regulated by the WEEE Directive. The first version of the WEEE Directive (Directive 2002/96/EC) came into force in 2002 parallel with the RoHS Directive (Directive 2002/95/EC) that restricted the use of certain hazardous substances in EEE products.

In August 2012, a new version (Directive 2012/19/EU) entered into force[5].

The WEEE Directive aims to prevent the generation of e-waste, as well as to improve the performance of the treatment operations for the reuse, recycling and other forms of recovery (Wager and Hischier, 2015). The WEEE Directive establishes three technical indicators to monitor WEEE systems efficiency: collection rate, recycling, preparation for reuse rate, and recovery rate (art. 3 of the WEEE Directive)[6]. The WEEE categories are presented in Table 1 below.

Before August 15th 2018:
1. Large household appliances
2. Small household appliances
3. IT and telecommunications equipment
4. Consumer equipment and photovoltaic panels
5. Lighting equipment
6. Electrical and electronic tools (with the exception of large-scale stationary industrial tools)
7. Toys, leisure and sports equipment
8. Medical devices (with the exception of all implanted and infected products)
9. Monitoring and control instruments
10. Automatic dispensers

Table 1: Categories of WEEE

In the new Directive, the collection targets for Member States changed from a “flat-rate” of 4 kg per inhabitant to a percentage-based approach related to products placed on the market (POM), or alternatively, WEEE Generated (WG). This is despite that the WEEE Directive and the Waste Framework Directive fail to provide a formal definition of waste generated[7].

[5] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012L0019&from=EN

[6] *Novel indicators to better monitor the collection and recovery of (critical) raw materials in WEEE: Focus on screens*, Horta et al., 2019

[7] https://ec.europa.eu/environment/waste/weee/pdf/Final_Report_Art7_publication.pdf, page 7

The fixed percentage were:

- 65% of POM, considering the average of the three previous years
- 85% of WG

The scope of the directive changed in August 2018. More equipment was included and new categories were set up. Collection target is not based on categories and has not changed.

Nevertheless, it has an impact on treatment target. Equipment from new categories has to be collected and sent for treatment separately (except categories 5 and 6).

The table below describes treatment targets related to each category for every UE member state, based on WEEE collected.

Categories	Recovery target	Recycling target
1. Temperature exchange equipment	85%	80%
2. Screens, monitors, and equipment containing screens having a surface greater than than 100 cm2	**80%**	**70%**
3. Lamps	80%	80%
4. Large equipment (any external dimension more than 50 cm) including, but not limited to: Household appliances; IT and telecommunication equipment; consumer equipment; luminaires; equipment reproducing sound or images, musical equipment; electrical and electronic tools; toys, leisure and sports equipment; medical devices; monitoring and control instruments; automatic dispensers; equipment for the generation of electric currents; photovoltaic panels. This category does not include equipment included in categories 1 to 3.	85%	80%
5. Small equipment (no external dimension more than 50 cm) including, but not limited to: Household appliances; consumer equipment; luminaires; equipment reproducing sound or images, musical equipment; electrical and electronic tools; toys, leisure and sports equipment; medical devices; monitoring and control instruments; automatic dispensers; equipment for the generation of electric currents. This category does not include equipment included in categories 1 to 3 and 6.	75%	55%
6. Small IT and telecommunication equipment (no external dimension more than 50 cm)	75%	55%

Recovery target is higher than recycling as it includes energetic valorization. Besides that, some pollutants must be eliminated to complies RoHS directive. Values are based on tonnages, which can lead to aberrations on some categories, especially on screens. That issue is developed in chapter 3.

The sector is improving and ranks first on e-waste collection and treatment compared to other continents[8], but also on waste generated. Plus, the objectives fixed in the WEEE directive in terms of collection and recycling rate aren't reached yet.

[8] http://ewastemonitor.info/wp-content/uploads/2020/07/Chapter_two_GEM_2020_def_july1.pdf, page 6

2.1.2 Producer Responsibility Organizations (PROs)

Compliance with the directive is the main mission of Producers Responsibility Organizations, also named ‘compliance schemes’ or ‘collection schemes’, like Ecologic. In France the rate of return for e-waste is more than 50% (based on the EEE weight put on the market), improving every year.

Ecologic is a French Extended Producer Responsibility scheme accredited by the French government for Waste Electrical and Electronic Equipment collection depollution and valorization on the national territory.

Invested with a general interest task, Ecologic has contributed to develop a circular economy based on waste prevention and recycling activities with all the stakeholders (producers, retailers, local and national authorities, NGOs, social enterprises, treatment operators, ...).

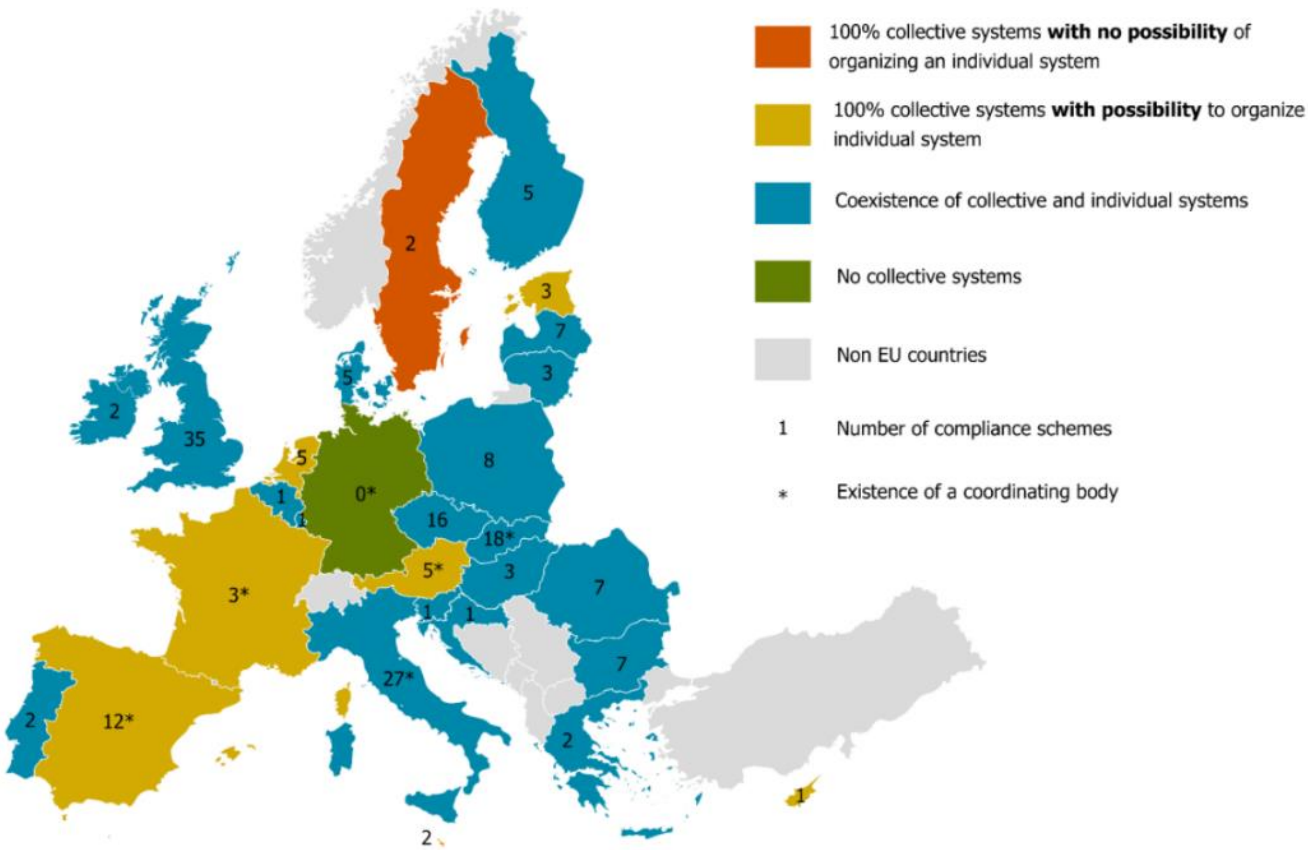

Figure 3: overview of the European WEEE organization (Horta Arduin et al. 2019)

The role of the collection schemes is to organize and monitor the end-of-life value chain, as described below.

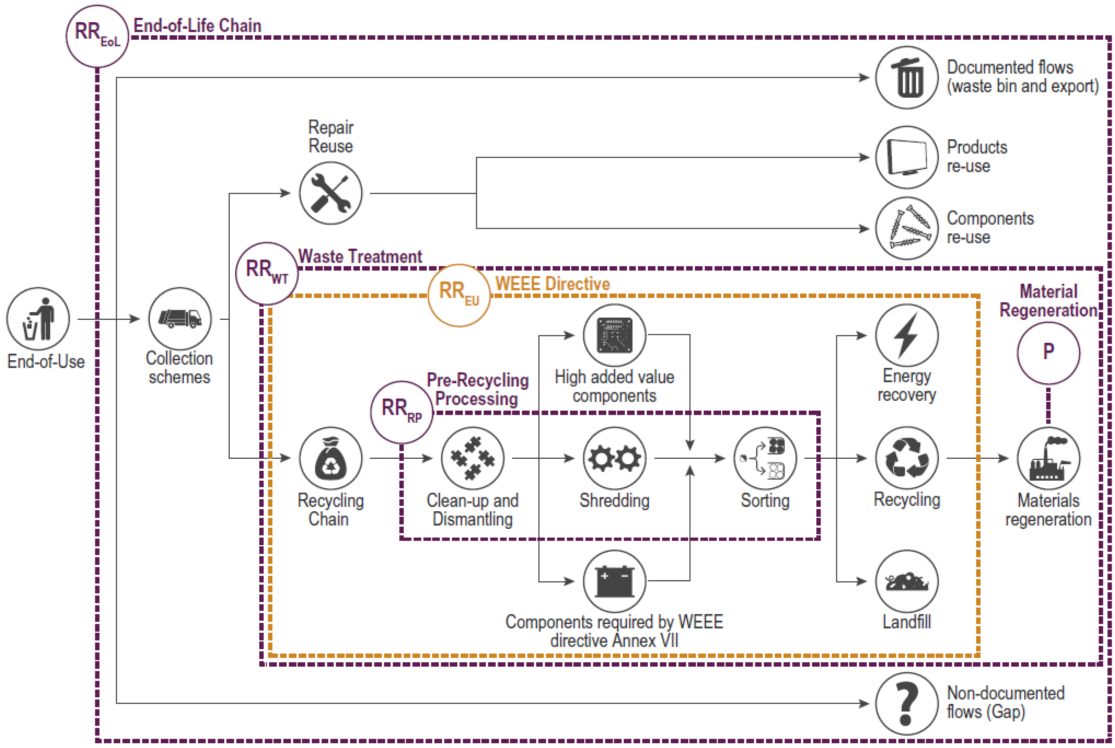

Figure 4 Representaiton of the WEEE end-of-life chain and the various recycling rate calculation scopes. Adapted from Horta Arduin et al., 2016

Through its role, a PRO has information on WEEE, and also on EEE, as producers' duty is to declare the equipment put on a country market to a PRO accredited in this country. The contribution paid during the declaration is indeed financing the end-of-life chain costs.

2.2 *EEE and PMMA*

In electrical and electronical industries PMMA can been used in various applications. Items concerned are;

- Those with a need to see through, as PMMA has highly transparent optical grades
- No important mechanical properties, as PMMA is more be beautiful but more brittle than other plastics such as Polycarbonate (PC)

Lighting panels at the bus stop or self-contained emergency lighting units are rather made of PC, whereas the advertising for a shop at the top of a building can be PMMA.

Large household appliances (LHA) may contain PMMA too but the share regarding the weight of the equipment is very low, making it hard to access, especially after shredding.

Two examples from samples characterizations:

- Dashboard of washing machine: around 0.004 %, 2.5g/product
- Spoke reflectors on electrical bikes[9]: around 0.3%, 60g/product (and a very low collection)

[9] New specific category in France starting in 2022

2.2.1 Solar panels

PolyMethyl(MethAcrylate) can be used as a cover material for solar panels, since it's half the weight of glass, and highly stable in sunlight. Indeed, "*PMMA has high resistance to UV light and weathering. Most commercial acrylic polymers are UV stabilized for good resistance to prolonged exposure to sunlight as its mechanical and optical properties fairly vary under these conditions, Hence, PMMA is suitable for outdoor applications intended for long-term open-air exposure*" according to the plastic platform Omnexus[10].

Photovoltaic (PV) panels market has been developing quickly during the last decade. Tonnage placed on the market (POM) reached 94 000 tons for 4.24 million units in France according to the scheme PV-Cycle.

Nevertheless, according to French experts of the domain, PMMA is for now just a 'candidate' to replace glass. And more important: waste potential from PV panels is complicated to predict. It's average lifespan according to UNU model is 22.5 years, but the lifespan profile is unclear.

Therefore, there are mainly two types of products collected by now :

- Disposal of deficient series: it's the major part, but unstable.
- Disposal of old panels reaching their end of life: stable but low quantities, as it's the beginning of the curve

PMMA potential from PV panels is low at the moment, however PV market evolution should be followed.

2.2.2 Professional equipment

As for PV panels, PMMA is a candidate to replace glass in some professional cooling equipment such as refrigerated display cabinets (freezers in supermarket, medical display case etc.): indeed, its mechanical and optical properties are adapted to such a use.

A recent study with producers, coupled to Ecodesign prefiguration study concluded that waste from refrigerated display cabinets generated is around 26kt/year in France.

For the same reasons as for PV (low POM, long lifespan, temporal shift between POM and end-of-life), the potential is considered as low at the moment.

The potential is very little here. Special big screens (transport station display, advertising) collected by Ecologic is around 100t a year, and it's unknown whereas it uses PMMA or not. Professionals (restaurants, hotels, hospital, meeting rooms) use mainly household TV. The point is to be able to collect it correctly.

A special attention will concern order terminal (train stations, restaurants…) and automatic cash register. Those very new products are not yet collected, sometimes not even declared as put on the market. No producers could be contacted yet to confirm or infirm the use of PMMA.

[10] https://omnexus.specialchem.com/selection-guide/polymethyl-methacrylate-pmma-acrylic-plastic

Outdoor lighting counts for around 12kt/year waste generated in France, and emergency lighting unit is around 1kt/year. Treatment operators experience suggests the use of polycarbonate for its robustness, despite some may use PMMA. For those type of equipment, there are very few producers.

Therefore, **a strategy towards all those professional equipment** would be to characterize the few models existing to list which ones use PMMA, and then work on an agreement with both the producer, schemes (plus an operator for the depollution of the lamp) to collect batches.

2.2.3 Laptops, tablets and SHA

Besides the professional equipment listed above, PMMA can be found in the category 'Small Household Appliances' (SHA) either in 'Small IT' when placed on market (POM). It is then collected in the same waste stream, along with mobile phones and tablets less than 100cm^2.

This collection flow is named 'mixed WEEE', and includes the larger number of different products. Some may contain PMMA with a better share than for SHA. Such products are: mini vacuum cleaner, food scales, food processors, lids or hoods, hi-fi systems, lighting and ceiling lights, big printers' trays, laptops, tablets[11], smartphones, remote control etc.

But the majority does not contain any PMMA. As for SHA it would not be economically sustainable to extract PMMA manually from products in this stream before it get shredded.

After the shredding, a separation of plastics is done. This separation often takes place in a second treatment site specialized in plastics, where the PMMA is more complicated to access as it can be contaminated (see section 3.3).

Laptops has more potential than tablets that are too small. It contains around 5% PMMA (Talens Peiro et al., 2016, Tecchio et al, 2018[12]), and sometimes dismantled manually as described in the table 1 below. Results on laptops and tablets waste generated in Europe are in section 6.2.2. The potential is growing.

The shares mentioned in table 1 are approximative.

[11] tablets POM are included in screen stream when the screen is bigger than 100 cm^2. In practice, it's only found in SHA collection flow. Laptops also is more often found in SHA than screens collection flow

[12] https://www.eceee.org/static/media/uploads/site-2/ecodesign/products/personal-computers/jrc_technical_report_-_analysis_of_material_efficiency_aspects_of_personal_computers_2018-02-06.pdf p28

UNU-keys[13]	Path A		Path B		Path C	
	Description	Share (%)	Description	Share (%)	Description	Share (%)
0303 Tablets	Shredding of the whole device via cross-flow shredder and fractions sorting	85	Deep-level manual dismantling of the subassemblies	5	Direct treatment in copper smelter after removal of the battery	10
0303 Laptops	After removal of the battery and display panel, the entire device is treated in a medium shredder followed by fractions sorting	50	Manual dismantling of battery display panel and high value components. Remaining parts are forwarded to a medium shredder followed by fractions sorting	50	-	-

Table 1: Share of different treatment paths for screens stream in France. Adapted from thesis 'From waste management to supplier of secondary raw materials: development of indicators to support WEEE chain management - focus on the French system', R.Horta (2019)

[13] The UNU-keys are 54 keys associated to type of EEE household equipments. It was developed by UNITAR for the European commission to allow the calculation of waste generated at a product level. It was also used by ProSUM, and for the European 2020-2030 forecasting in section 6.2.2

3. Screens

The most recent and most important development of PMMA use in EEE are light guide panels (LGP). These light conductors can be used in panel boards using compact fluorescent lamp or LEDs (Light Emitting Diodes) of the new generations Flat Panel Displays (FPD) monitors and TV, which started replacing the traditional cathode ray tubes (CRT) TV receiver around 2007.

This application of the LED-backlight guides of the LCD (Liquid Crystal Display) plates and display screens accounts for a large part of the PMMA market. LCD screens are made of heavy sheet that can typically reach a thickness of 3 or 4mm.

Figure 5: PMMA sheets from LCD screens in Heathland samples

There are three main technologies of FPD:

1. LCD: the main part of FPD screens, using PMMA
2. Plasma: a smaller category whose production has stopped around 2015, but likely to be found in waste over the next few years, not using PMMA
3. OLED: the new trending, not using PMMA

Majority of FPD screens collected are LCD. Indeed, predictions on TVs lifespan are known to be underestimated, leading to no OLED collected yet. Plus, contrary to the previsions around 10 years ago, Cathodic Ray Tube (CRT) monitors and TV are still the main screen flow in 2020 due to its long lifetime and other reasons.

Those considerations are developed in section 4.

3.1 *LCD overview*

Liquid crystal displays (LCD) are the most commercialized type of electronic displays. In the last decade, LCDs mainly used cold cathode fluorescent (CCFL) tubes as a backlight system.

However, CCFL technology has progressively being replaced by light emitting diodes (LED) due to the lower efficiency and quality of the image as well as the absence of mercury, a substance catalogued as hazardous by the RoHS directive[14] which is the main depollution for screen flow (see part 3.3).

Besides the change of the type of backlight, the general structure of the electronic displays has been maintained. Although there is a large variety in the design of electronic displays, generally the main parts included are:

- a front cover and a plastic frame
- a main printed circuit board (PCB)
- speakers
- an inverter board
- a switched mode power supply (SMPS) board and a timing controller (TCON[15])

All are assembled to a steel sheet, and the screen which contains the backlight system.

Other parts can include connections (such as cables and thin films), secondary PCB, fans (optional), and several different frames and supports. The place of the backlight system varies for each type of screen. Generally, in CCFL screens, the backlight is placed behind the screen, whereas the backlight is on the side of the screen for LED.

Below is a description of these two technologies.

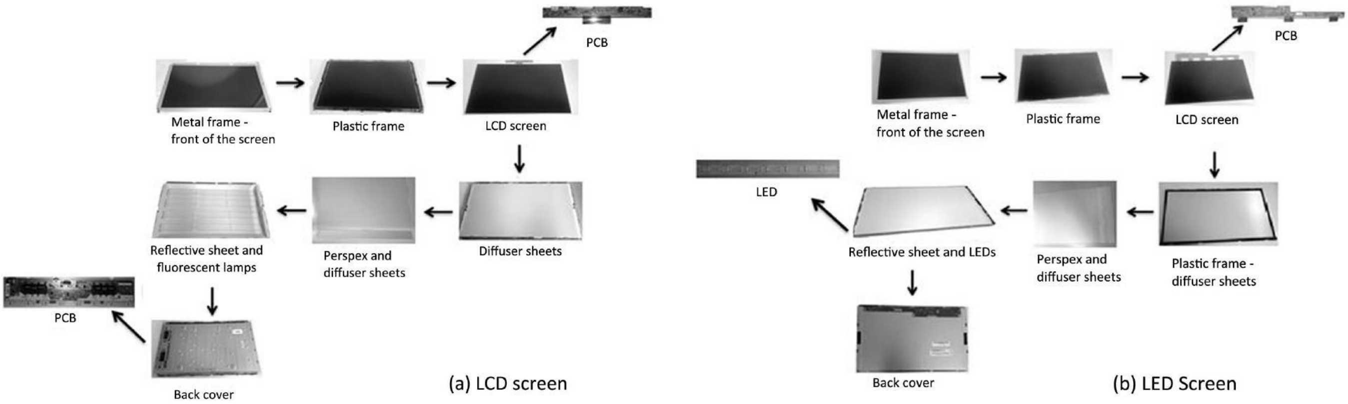

Figure 6: Parts of typical CCFL and LED screen (Perspex is PMMA). Adapted from Veit et al. (2013)

[14] Analysis of material efficiency aspects of Energy related Product for the development of EU Ecolabel criteria - Product groups: personal computers and electronic displays, JRC (2016), page 40
[15] One of the main causes of screen breakdown, together with the capacitor of the PCB and the LED diodes

3.2 Screens treatment sites and technologies

There are three mains technologies to sort FPD fractions, potentially leading to different level of purities of the PMMA:

1. Manual dismantling (≈ 50% of FPD treated in France)
2. Automatic dismantling (≈30%)
3. Direct shredding (≈20%)

There are 9 centers for household FPD in metropolitan France plus two in oversea departments. The majority is using manual dismantling, but there is a change toward automatic dismantling along with improving in those sorting technologies.

Ecologic was also working with treatment facilities in Spain and Belgium until 2019 but the tonnage proceed were small, around 100t a year, compared to more than 5000t in France. It was stopped due to higher costs.

3.2.1 Manual dismantling

Manual dismantling is the preferable option for recovering PMMA from a single screen, since it allows no contamination during the sorting process.

No very special tools are needed, except protecting workers from mercury exposure. PMMA sheets are 5% broken in collection point and transportation, and 95% complete when it arrives to screen treatment center.

Advantages	Disadvantages
• Low investment requirement • Quality of output fractions - high • Not FPD size dependent • Customised output fractions • Low maintenance costs	• Low treatment capacity • High workers' exposure • Removal of lamps with low breakage rate • Labour intensive process (high cost man hours) • Will need accessory filtering system and regular air quality controls

3.2.2 Automatic dismantling

Automatic dismantling is basically using mechanical treatment to separate some parts of the screen whereas others are still manually dismantled.

It can take various forms. The two mains are as follow:

1. Manual dismantling of pollutants (backlight components) and valuable materials (external cables, printed cardboards ...) then shred the remaining parts
2. Using a robot first to separate the frame of the screen, especially the backlights components in order to lower workers' exposure. Then manual dismantling is operated to get high quality material.

Robots can treat every FPD technology providing it fits in. Big screens, measuring more than 1,60m wide approximately, and 0,1m thick, don't fit in. Those are separated beforehand and treated fully manually. It still represents a minority of the screens for now (<25% of FPD screens collected are more than 49 inches, far from the limit). The thickness is not a problem since LED screens are getting thiner.

The sheets are sometimes broken because of the robot cutting (see Figure 7 and Figure 8). The trend goes in this direction to face better the variety of FPD technologies.

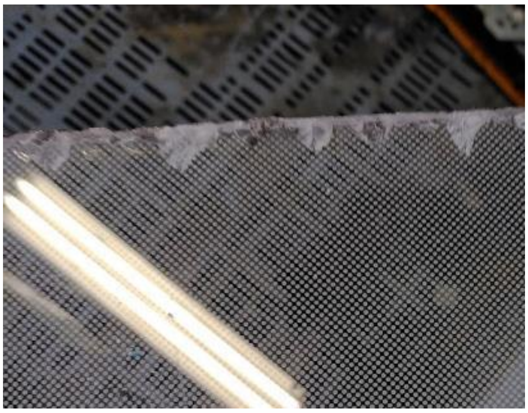

Figure 7: Damaged PMMA sheet

Figure 8: Input of a FPD screen in the cutting robot, La Boite à Papiers, France

Advantages	Disadvantages
• Quality of output fractions - high • May include filtering system (see section 3.3.1) • Medium treatment capacity • Good pollution control, due to low breakage of lamps	• Medium investment needs • FPD size dependent • Limit on types of FPDs treated

Figure 9: PMMA from an an automatic dismantling. On the left: PMMA strip from external side after cutting the frame (LED technology). On the right: broken sheets

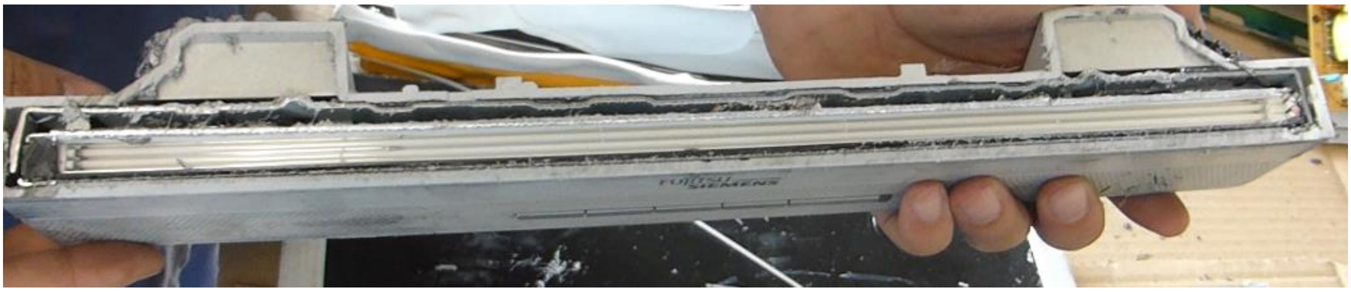

Figure 10: Frame of a LED screens after being cut. Backlights are intact and eliminated. Extract from a video of sorting robot constructor MRT

3.2.3 Direct shredding

Direct shredding is used in less facilities than manual dismantling because a precondition is an accessibility to enough tonnage for a fast return on investment.

It allows a fastest treatment without creating more pollution, otherwise it would not be compliant and would not be selected by a scheme to process under agreement. Screens are put on a conveyor (after keyboard is removed for laptops when possible) then go to a confined shredder. After the shredder, screens piece are pushed to a rotating drum, where it stays around one hour, time to get of the mercury. Mercury from backlights is being aspired by an extractor hood and then active carbon capture it to eliminate it accordingly, as for the other sorting processes. Active carbon filters should be changed every year.

After the Hg is off, overbands and eddy currents separate ferrous then non-ferrous metals. Some manual or optical sorting can be made to get some valuable components, and flotation is made on plastics to separate those with BFR. The light ones can be separated through different process. Electrostatic separation works well on PMMA.

But as PMMA is around 1.18 density, it has a risk to be eliminated with BFR, especially if it has additives (see part 3.3).

Advantages	Disadvantages
• High treatment capacity • Low workers' exposure • Not FPD size dependent • Includes filtering system	• High investment requirement • High operation cost (energy) • Lower quality of output fractions • High installation requirements

3.2.4 Comparison

The figure below compares the three technologies mentioned above by chronological order of parts sorted[16]. It does not include the semi-automatic process using first a robot before manual dismantling.

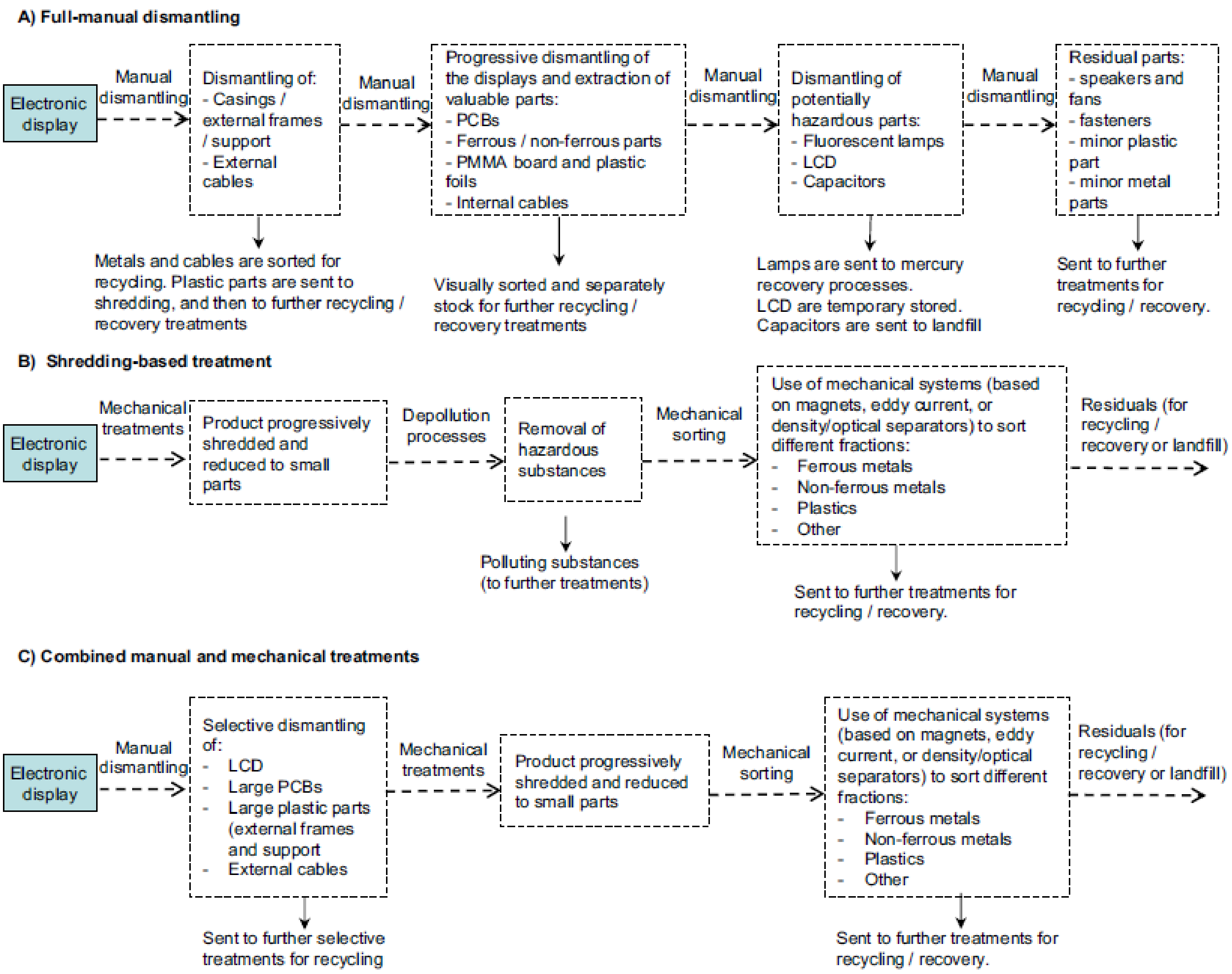

Figure 11: Possible recycling treatment of electronic displays. Adapted for Ardente (2014)

[16] Fulvio Ardente, F. M. (2014). Resources, Conservation and Recycling, Volume 92, 2014, 158–171. *Recycling of electronic displays: Analysis of pre-processing and potential ecodesign improvements* Retrieved from http://www.sciencedirect.com/science/article/pii/S0921344914001955

3.3 *Grades and contamination*

3.3.1 Contamination

3.3.1.1 Mercury

Mercury (Hg) is an hazardous substance regarding RoHS directive, and the main point in CCFL screens depollution. Mercury in lamps has been exempted from prohibition.

However, since July 1st, 2006, the Hg threshold value in CCFL's for new devices is 5 mg per tube[17].

Different technologies exist to sort it: either full backlight panel is sent to elimination, either Hg is absorbed.

In some robotized treatment of CCFL, after the backlight panel is separated, some kind of wax is applied to prevent the mercury to flow off (see Figure 12).

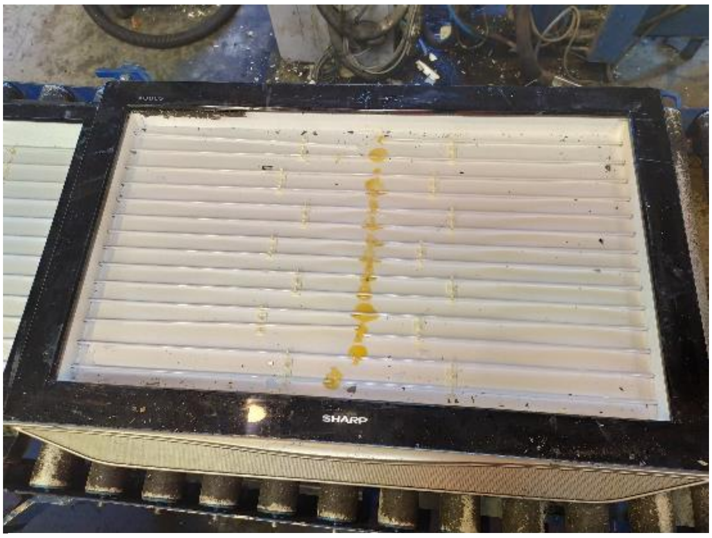

Figure 12: Backlight of a CCFL screen after an automatic dismantling.

Besides that, a filtering system is often required, as for shredding. It combines extractor hoods above and on the side of the confined area, then carbonate filter and activated charcoal filter outside the building. Workers' exposure is regularly controlled by the sanitary authorities.

Mercury recovery can reach 95% after depollution, while mercury emission can be less than 0.5µg/m³.

3.3.1.2 Indium

The LCD contains the Thin-Film-Transistor (TFT) panel, which is relevant for its indium content (Chou et al. 2009). Indium in electronic displays is generally also used together with other substances such as arsenic, phosphorous, and tin. Indium arsenide (InAs) and indium phosphate (InP) semiconductors, and ITO are potentially hazardous and can cause lung disease and cancer.[18]

Indium is currently considered a critical raw material worldwide. According to recent studies in the literature, more than 80% of indium in the world is produced for indium tinoxide (ITO) coatings used in LCDs (Park et al., 2009. Anyway, the concentration is very low, less than 0.01% in on FPD, that prevent it from R&D to recycle it[19].

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[17] H. Böni, R. W. (2011). *Disposal of Flat Panel Display Monitors in Switzerland, Final Report, March 2011.*
[18] National Toxicology Program 2001; Chou et al. 2009; Lim and Schoenung 2010
[19] https://cewaste.eu/wp-content/uploads/2021/04/CEWASTE-Final-Public-Raport.pdf (2020)

3.3.1.3 Other substances

Depending on the sorting process, other substances may alter the purity of PMMA sheets extracted. Those are difficult to predict without characterizing PMMA samples from LCD sorting process.

More information will be available after pre-treatment tests conducted by Heathland at the end of the year.

Theoretically, the maximum contamination is from direct shredding treatment, up to 10-15%. A majority of those contaminants are other plastics that couldn't be separated with processes such as flotation (densimetric sorting) and/or optical sorting.

Among it, the three main ones are classical EEE plastic: PC, PS/HIPS and ABS. PP and PE appears less frequently as its density is far from PMMA: between 0.94 and 0.96 compared to 1.18.

Nevertheless, it is important to note that if PMMA sheets are not removed before shredding, it becomes harder to recover by densimetric sorting because of additives. Laws on brominated flame retardants (BFR) makes PMMA being eliminated together with those pollutants.

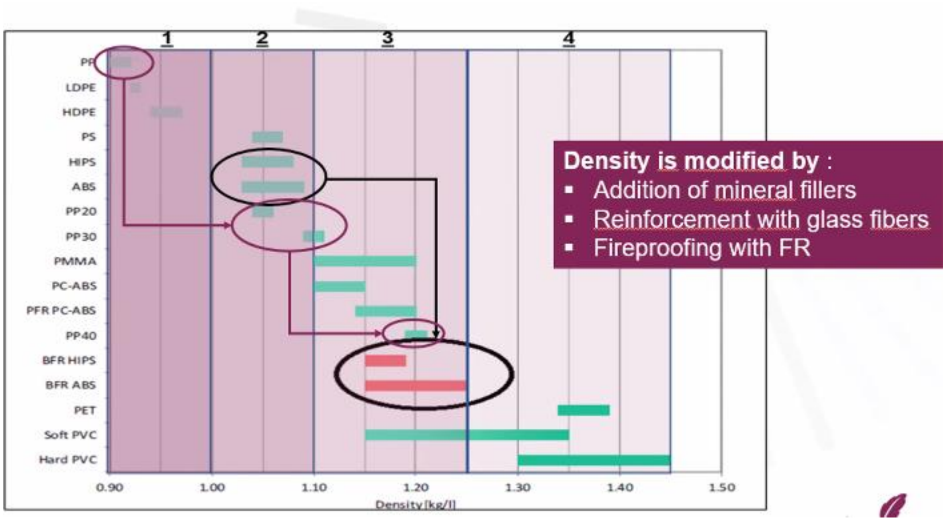


Figure 13: Plastics per density. Source: Lavoisier Circular Transition

Finally, it is important to note that no contaminants should ideally be present in feedstock for depolymerization to achieve a high quality MMA. Therefore any contaminants remaining at collection should be removed during the pretreatment stages, either at WEEE collection level or PMMA pretreatment level.

3.3.2 Grades and recycling

Mechanical recycling of PMMA LCD sheets is only possible for extrusion grade sheets. For cast grade sheets this is not possible. Cast grade sheets can only be recycled chemically (MMAtwo). When there is a mixture, the sheets must either separated or chemically recycled as a mix.

When recycling chemically, the sheets are first crushed, then cleaned in a pretreatment processes and then fed into the reactor.

When recycling mechanically, the sheets, which must be whole sheets (not broken), are manually inserted sheet by sheet in a device that removes the top, bottom and side layers of the sheet. Water is used to cold down the sheet while its external surface is being scratched by a machine. This scratching is used notably to take off dots and other irregularities that may prevent the recycling.

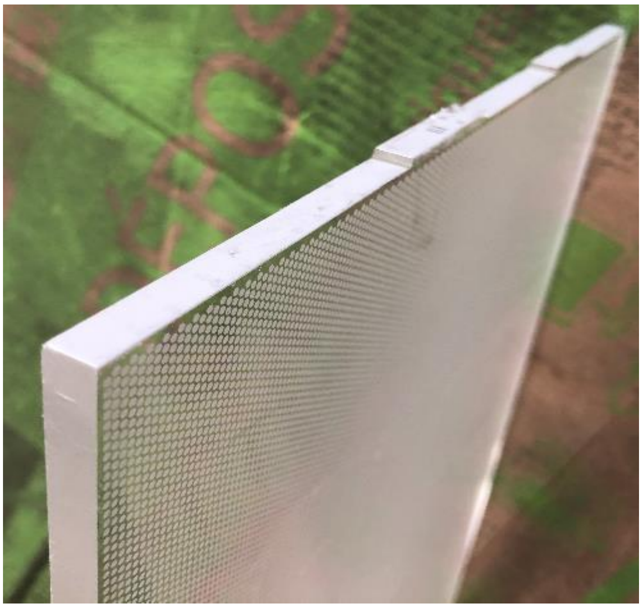


Figure 14: A PMMA sheets with dots, Heathland

The disadvantage of this method typically used in Asia is that it produces a lot of contaminated wastewater and is therefore not very environmentally friendly compared to chemical recycling[20].

There are two PMMA grades used for LCD: Extrusion grade and casting grade. Extrusion is supposed to be the majority. Besides its disadvantages, mechanical recycling is suitable for extrusion grades PMMA sheets. Nevertheless, it can not be used on shredded screens, as the plastics are coming with too much impurities.

[20] See MMAtwo WP5 intermediary deliverable on environmental assessment

4. Screen waste flow

The first thing to care about is the difference between equipment placed on the market (POM), waste generated (WG), and waste effectively collected. At the moment, major part of the screens collected in France are still CRT screens, whereas POM is only FPD for more than 10 years in France (see Figure 15).

4.1 *Tonnage of screens POM*

4.1.1 The development of FPD since 2000

Data on POM aren't exact. It's based on the declaration made by the producers since 2006, when Producers' Responsibility Organizations (PROs) such as Ecologic set up, and where estimated by a method named apparent consumption methodology[21] beforehand. Since the declaration is made, data on products are more reliable, especially tonnages and units. But the translation between customs code, categories of EEE and product leads in some case to approximations on the exact nature of the device. It has an impact when it comes to FPD screen technologies. However, it's robust on distinguishing FPD from CRT, and TV from monitors.

The table below presents the evolution of the POM in France by type of products as estimated at the moment.

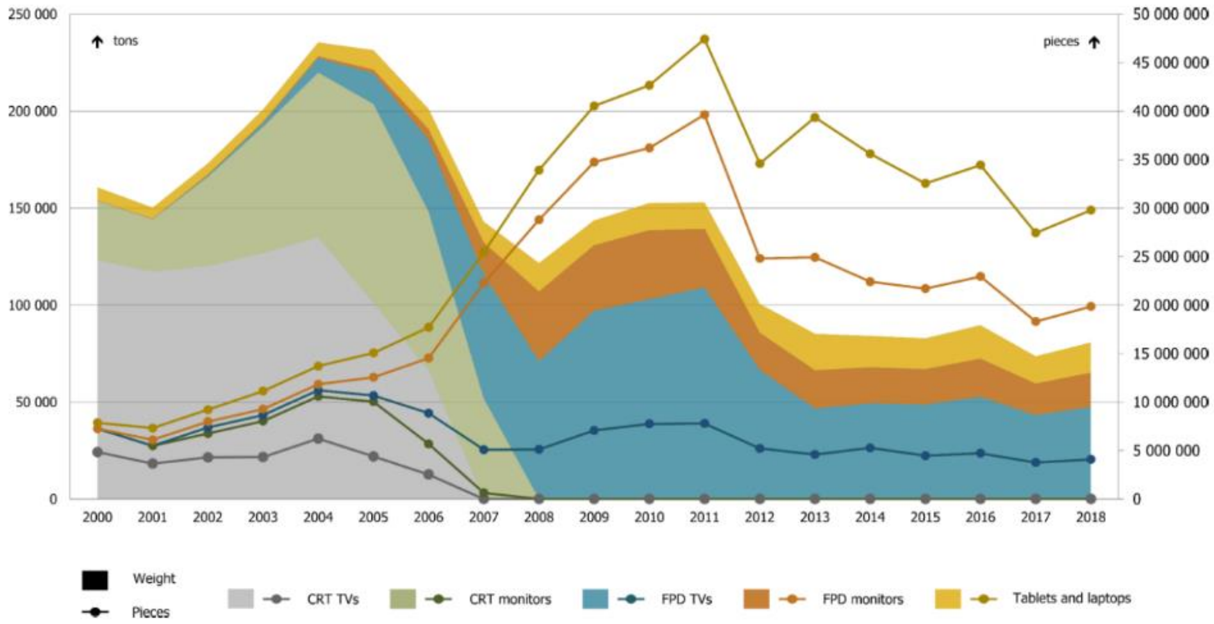


Figure 15: Screens placed on the market per UNU-Keys in France. Source : R.Horta (2018)

It's remarkable that TVs represents more than 60% of the weight POM, while being around 10% of the units POM, due to higher unitary weight (≈10-12kg) compared to laptops/tablets (≈1-2kg) and monitors (≈3-5kg)[22].

[21] POM = national production + importations – exportations
[22] According to UNITAR, it decreases for laptops/tablets and TVs by respectively 20-30% and 10-20% for the next decades, while monitors would increase by 10-20%. Of course, it highly depends on countries.

4.1.2 Perspectives on OLED

A risk on PMMA potential from FPD is the progressive replacement of LED technology by the new OLED/QLED, which does not contain PMMA as it does not use backlights. Anyway, some market studies on TV suggests it will not occur soon. In 2021 first trimester, OLED market share is around 15% of the sales (€), but less than 5% of the units. Other perspectives from market studies includes:

- A growth of OLED sales (> 50% annual growth)
- A global growth of the POM after Covid crisis, not only OLED
- A growth of very large screens especially (> 100% annual growth for >75 inches screens)

Moreover, the shift from sales to waste is quite long, and very few OLED are treated by French WEEE schemes currently, as well as in other European countries. Prevention suggests making a new assessment after 2025.

4.2 Screen waste generated

WEEE generated is changing every year, influenced by numerous parameters such as :

- miniaturization and innovative technologies
- average lifespan of each technology
- economical circumstances, leading to more storage or quick change
- specific events such as Olympics of football world cup

Those parameters are highly unpredictable, leading to a long-going mistake: an underestimation of CRT waste generated (WG), and an overestimation of FPD WG. The diagram below is a good example. Dated from 2011 in Switzerland[23], where the market is comparable to France (size excepted) it predicts screens uses per technology until 2030.

CRT should then have disappeared completely in 2015, and OLED should start being collected as it would represent more than 50% of the screens in service. As seen in section 4.1, the forecast was inexact.

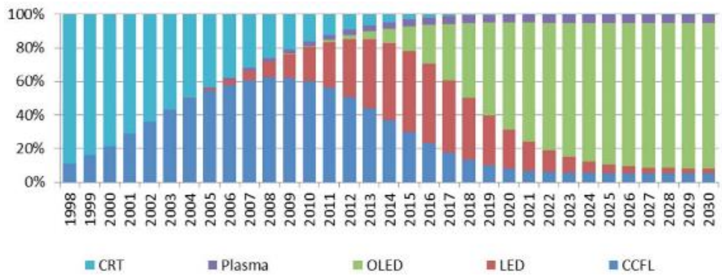


Figure 16: Predictions on screens tonnage evolution, EMPA 2011

[23] H. Böni, R. W. (2011). Disposal of Flat Panel Display Monitors in Switzerland, Final Report, March 2011

4.2.1 ProSUM estimation : a first approach

This table from the EU project ProSUM is interesting in a first approach. It was used at the beginning of MMATwo project to roughly estimate the potential of PMMA.

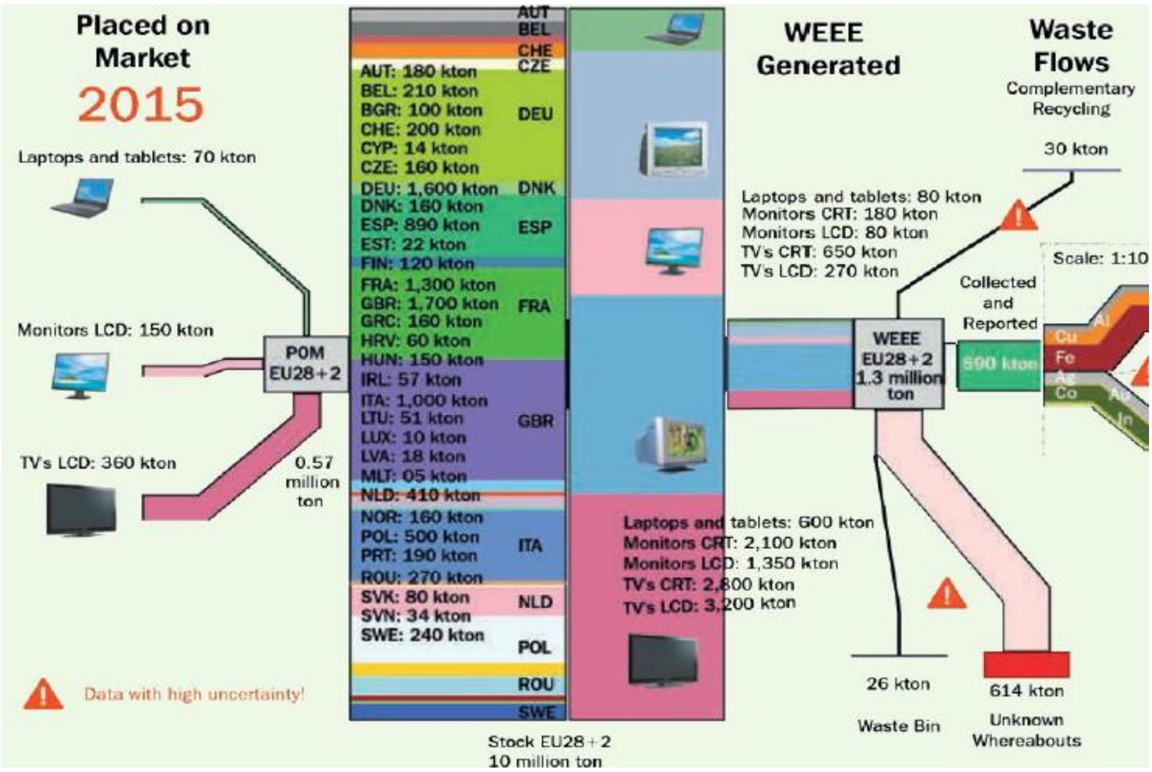


Figure 17: Estimation of screens tonnages in Europe. Adapted from ProSUM final report

It shows 430kt waste LCD screens generated in Europe in 2015, leading to a potential of 30kt PMMA considering the hypothesis '*PMMA accounts for 7 wt% of LCD screens*'.

Those data come with uncertainty, because of the calculation process. Made by United Nations University (UNU, now UNITAR), it is combining POM and estimated lifespan (Weibull statistics distribution) of a product family to estimates waste over time.

A sales-lifespan methodology is also used by the European Commission in the WEEE Calculation Tool (WCT) to establish collection rates objectives on WEEE for member states. It will be referred as the 'common method'.

Main limits on the number of 30kt/year are:

- The difference between WEEE generated and waste flows. Sales lifespan methodologies aren't focus on waste real flow. The unknown whereabouts includes illegal treatment in metal scraps, or exportations, that are hard to get.

➔ **out of the 590kt collected reported (with high uncertainty), which is around half of the waste generated, the hypothesis of 33% FPD, and 7% PMMA in FPD would lead to a potential of 13,7kt/year PMMA**

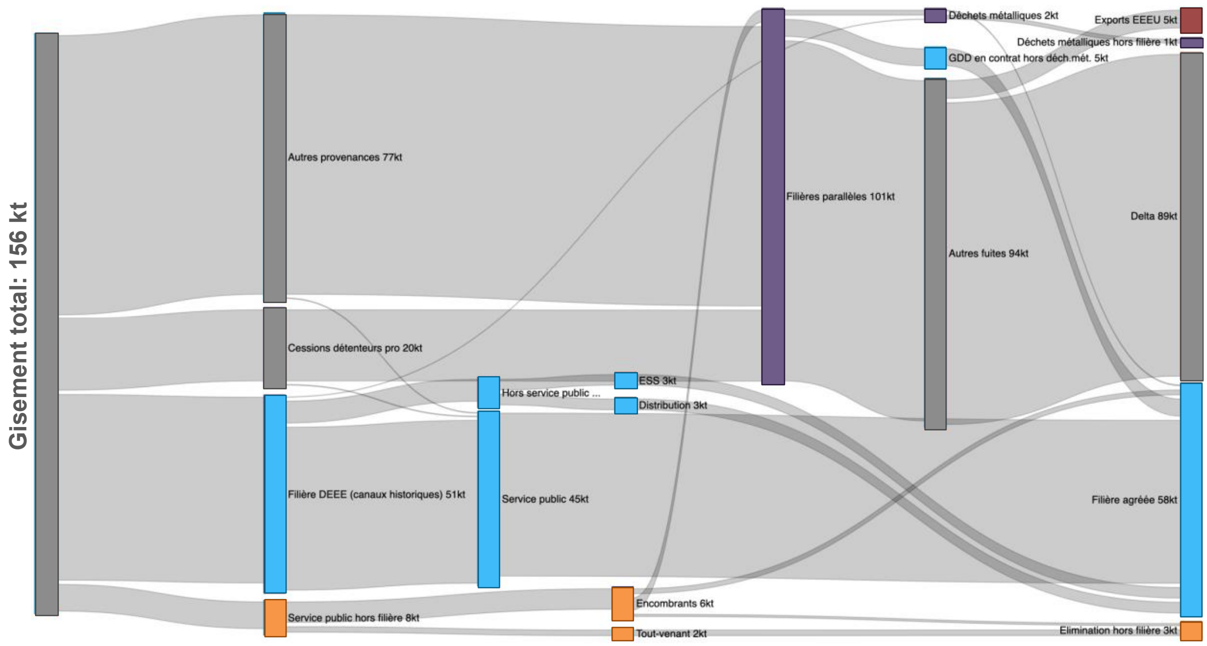
- A wrong estimation of waste generated at first, which is difficult to analyze intrinsically (≈ +/- 10%)

A more detailed study was made in France in 2020 to evaluate the potential among screens. It is combining both the common method and on-site surveys on destination. For EU-28, no work on destination could be made, but the common method provided approximated figures for 2020-2030 period (section 6.2.2).

4.2.2 WEEE availability study in France

The study conducted in France by the schemes, together with recycling and producers organizations made survey and calculations of the WEEE generated in the country and its destination per flows. The results on screens are below, including the 5 sub-categories (UNU-keys) used at European level:

- Laptops and tablets (0303)
- CRT monitors (0308)
- FPD monitors (0309)
- CRT TV (0407)
- FPD TV (0408)



The main outputs, for the 156kt screens (included CRT) theoretically generated in France in 2019, are:

- 58000t collected
- 1000t going to unofficial recyclers, underestimated (on-site measurements to be continued)
- 3000t eliminated
- 5000t screens legally exported for reuse (but not proven to be functional)
- **More than 80 000t unknown**, that could either be illegally exported, treated by unofficial recyclers, or still stored at people's home

Between 10 and 15% of the waste screens are detained by professionals, growing with Covid crisis and teleworking. Schemes' strategies include efforts on collecting directly these equipment.

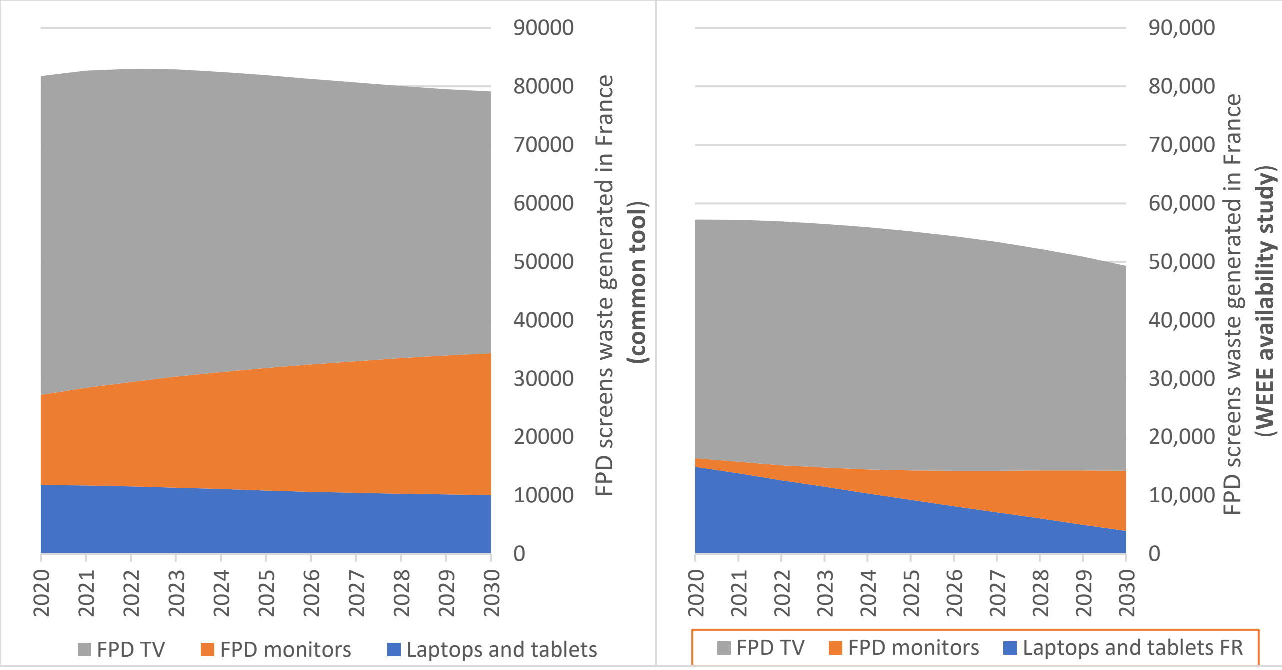


Figure 18: FPD waste generated using two calculation methods

The figure above shows the difference between the two models for FPD screens waste generated. **Both consider it quite stable,** but French study consider it lower, 50kt VS 80kt by common method. Monitors potential is growing, contrary to laptops. TV remains the first target.

4.2.3 The question of lifespan and reuse

The amount and the share of FPD in WEEE generated is definitely overestimated compared to the real collection rate. One of the hypotheses behind this is a wrong estimation of average lifespan for FPD and CRT.

Indeed, with phenomenon such as reuse (more than 30% of FPD screens according to previous study's consumer survey), and storage (more than 5%), lifespan is complex to apprehend, as explained on Figure 19. It makes consumer survey useless to determine total lifespan of a products since it underestimates the real age. The previous study tried to do so, by asking the age of eventual screens waste people have waste in the last 24 months.

UNU Key	Equipment		
		WCT (POM 2010)	Consumers
0303	Laptops and tablets	5,9	4,9
0308	CRT (cathodic ray-tube) Monitors	10,8	9,2
0309	FPD (flat panel display)	6,3	7,6
0407	CRT TV	8,9	13,1
0408	FPD TV	10,4	7,1

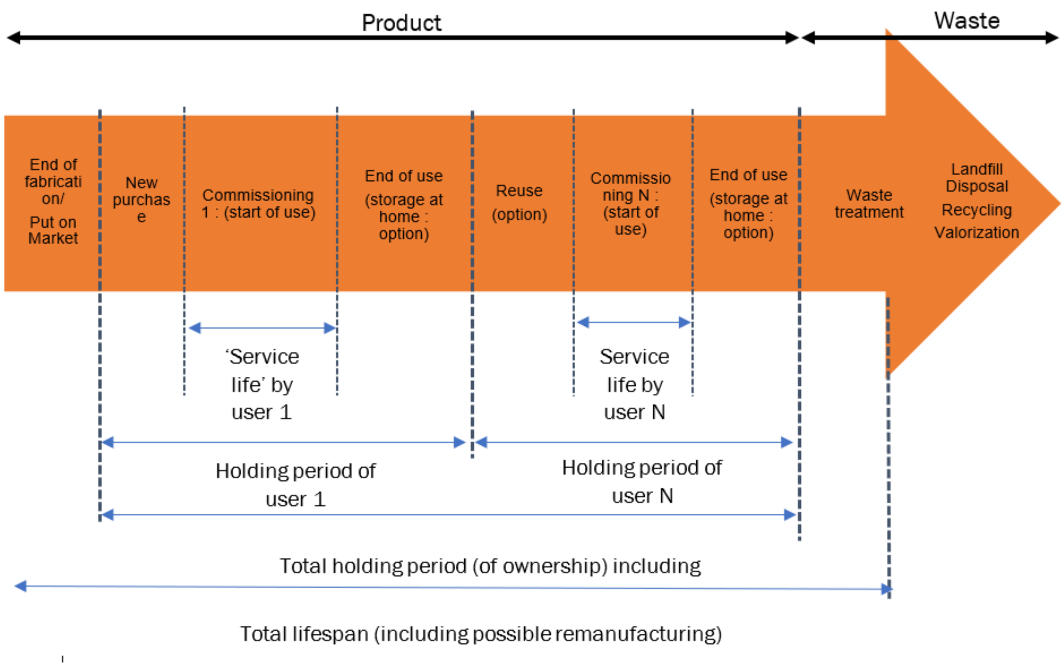


Figure 19: Principle of lifespan, possible reuses and storages

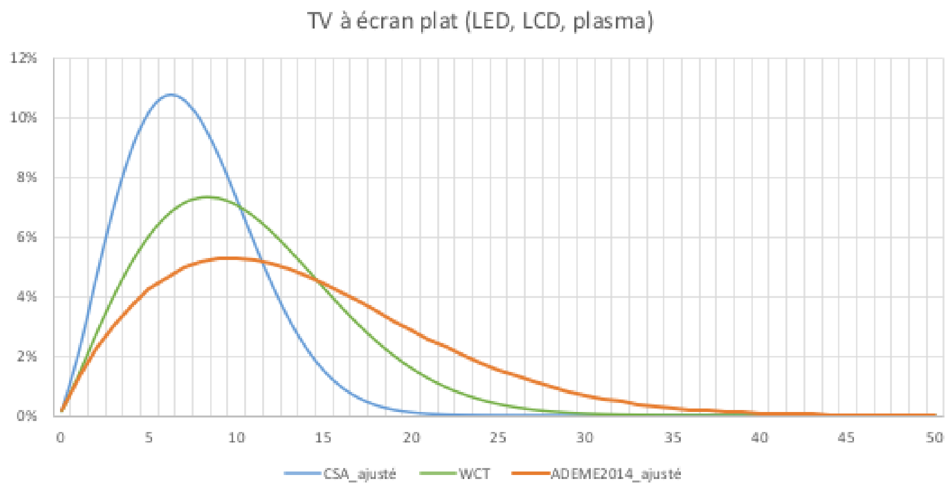


Figure 20: Lifespan profile of TV FPD according to three studies

The estimation is used to be made by a Weibull distribution. The shape of the curve, the average lifespan and other parameters depends on input data (mainly POM). Therefore different inputs leads to very different curves as it can be seen on Figure 20. WEEE availability study tried a method to combine the common method (WCT) and a consumer survey (CSA). It leads to a substantial difference, as well as for a precedent study on audiovisual equipment[24]. Reliability of those data could not be concluded.

24 https://www.ademe.fr/sites/default/files/assets/documents/duree-vie-equipements-audiovisuels-112014-synthese.pdf

4.2.4 Dating study

Lifespan is a key question. Knowledge about it is improving, as more and more data are collected to set up durability and other environmental targets. An option to see the age of collected devices is to look at it directly at the treatment plant, an on-site statistical study. The methodology and results are below:

1. Pictures of the screens and nameplates reading:

- Manufactured year directly written
- Serial number or model number by asking major producers how to read it. Information is existing, but sometimes impossible to translate

2. Analysis of data: weight X type of screens X manufactured years → average lifespan

Screen manufactured in Oct 2014 (sometimes harder to read)

Type	Number of screens analyzed	Average lifespan	95% confidence range
CRT TV	168	19,1 years	[17,5 years - 20,9 years]
CRT monitors	59	22,3 years	[19,8 years - 24,7 years]
FPD TV	538	9,2 years	[8,3 years - 10,1 years]
FPD monitors	378	13,9 years	[13,1 years - 14,7 years]

Among FPD screens:

LCD CCFL	332	9,5 years	[8,6 years - 10,4 years]
LCD LED	140	6,3 years	[5,4 years - 7,2 years]
Plasma	66	13,0 years	[12,1 years - 13,9 years]

Few commentaries:

- Laptops and tablets could not be analysed, not enough samples collected. This is due to the flow: it's often collected with SHA
- Around 300 equipment are enough to know the average lifespan with a +/- a year
- Type of collection changes the age: B2B collection and distributors equipment are younger than municipal recycling center
- CCFL TV is the most collected item

Based on this, lifespan curves of the common method could be replaced by on-site data, showing screens last longer than expected. Below is the example of monitors:

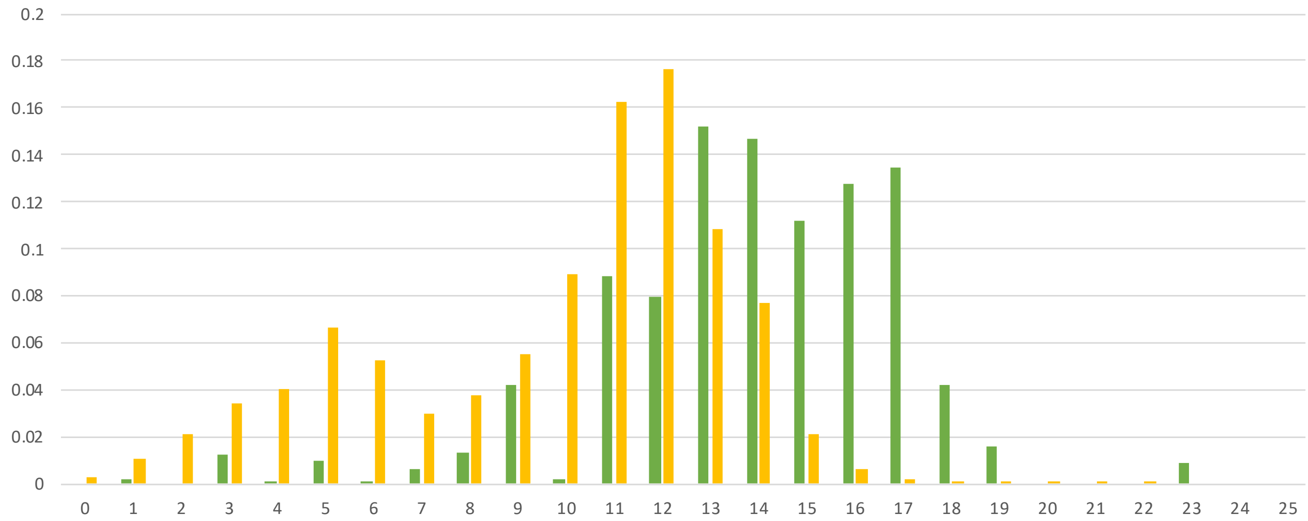


Figure 21: lifespan curve of FPD monitors. Yellow is the theoretical model, green is the on-site observation

Advantages	Limits
- Robust and reliable method, with proven traceability	- Devices with no readable information (around 50%), especially old equipment.
- Measurement of the total lifespan	- No data of non-collected equipment. Leakages are supposed to be valuable equipment, more likely LED or OLED.
- Distinction per type of FPD screens, while UNU-Keys aren't specific enough.	

This would lead to 57kt FPD (4005t PMMA) in 2019 instead of 66kt (4620t PMMA) as calculated at first, showing the potential is higher than expected in the coming years

It's important to know the reality of collection on year N, but it does not give information on the past or the future. For instance, average lifespan of CRT TV collected in 2021 is 19,1 years, but a lot were collected before: the average in total for this equipment can be lower.

4.3 Collection

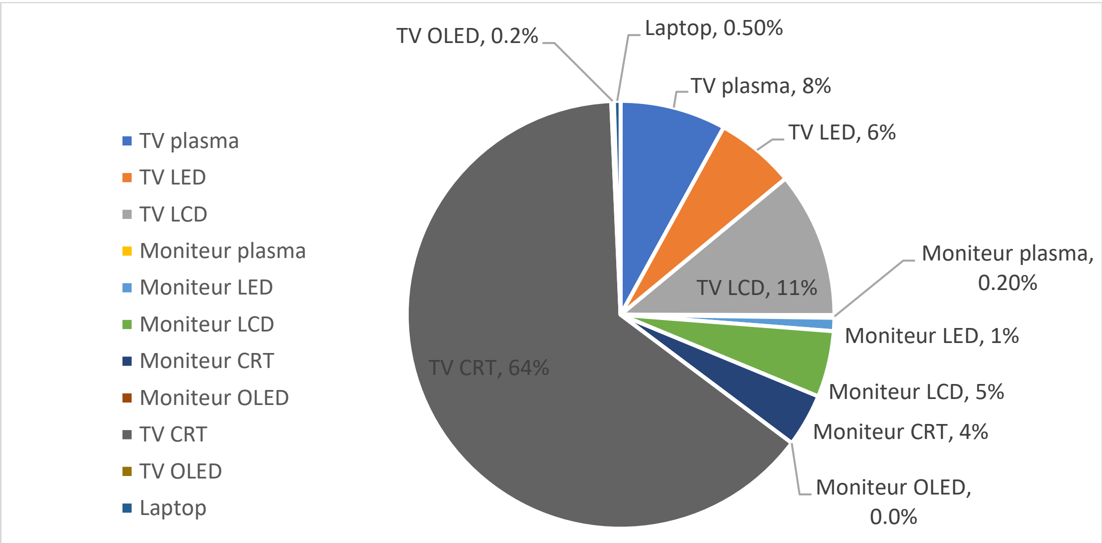
UNU-keys	2012	2013	2014	2015	2016	2017	2018
Tablets	≤ 0,1%	≤ 0,1%	≤ 0,1%	0,1%	0,1%	0,1%	0,2%
Laptops	0,5%	0,5%	0,6%	0,9%	1,2%	1,5%	2,3%
CRT Monitors	13,3%	13,3%	13,1%	12,7%	12,3%	11,9%	10,7%
FPD Monitors	2,1%	2,1%	2,5%	3,8%	5,0%	6,2%	9,5%
CRT TVs	81,7%	81,7%	80,9%	78,1%	75,7%	73,1%	66,3%
FPD TVs	2,4%	2,4%	2,9%	4,4%	5,7%	7,2%	11,0%

Figure 22: share of UNU-keys in screens collected in France by the official schemes, 'Development of indicators to support WEEE chain management - focus on the French system', R.Horta (2019)

The figure above presents the weight of screens collected per UNU-Keys (t). The main information is while ProSUM estimates a share of 34% FPD (FPD monitors, TVs, laptops and tablets) waste generated in 2015, the share was actually around 9% of the collection in France in 2015, going up to 23% in 2018.

Anyway, in terms of weight, the amount of FPD collected in France in 2018 (15,306t) is three times higher than the collection in 2012 (5,138t), and should increase in the following years. Indeed, a longer lifespan as showed un previous section is just shifting the waste production in the next years.

Below is the main shares, per technology, in 2020 on municipal collection, that represents 80% of the collection in France:



The shift to FPD is not done yet, and OLED especially are insignificant. From 30% FPD in 2020, it should reach 50% between 2022 and 2024.

It is important to note that depending on the collection mode, the share of recent screens may change. For instance, distribution, that represents around 6-7% of the collection, FPD share is bigger thanks to after sales service, more likely to take back recent screens under warranty. Collection mode is highly variable between EU countries.

5. PMMA per LCD screens

5.1 *Variation per equipment*

To estimate WEEE PMMA, tonnage of screens plus PMMA share in waste tonnage are needed. LCD screens characterizations can be found in the literature, giving different value for PMMA share.

- In J. Cryan, K. F. (2010). *Demonstration of Flat Panel Display Recycling Technology, Final Report.,* the amount is 2%
- ProSUM uses the hypothesis of 7% PMMA per screen
- In *Analysis of material efficiency aspects of Energy related Product for the development of EU Ecolabel criteria - Product groups: personal computers and electronic displays*[25], JRC, 2016: 21,78% on a 7,2kg LCD TV!

Indeed, the value is very different from a product to another. It depends on the size of the screen, and its technology.

A small LCD TV has the bigger PMMA share, whereas it's less for larger TV. An operator gave its PMMA share per type of screens proceed (see Figure 24). The total value is around 7% of the screen flow in 2019, but this % evolves as the equipment does.

For instance, plasma TV and monitors, that have no PMMA, have started decreasing recently, but still reaching to reach 8%.

Parts/Components	Description	Material	Mass (g)
Frames/covers	Back cover	ABS	920
	Main front cover	ABS	340
	Support	ABS	250
	Secondary front covers	PC	15
		Unspecified plastic	98
	Main metal frame	Iron/steel	1580
	Secondary metal frame	Iron/steel	261
	PCB support	Iron/steel	48
	Support for cable plugging	Iron/steel	34
		Unspecified plastic	38
	Internal support	Aluminium	353
	External support	Aluminium	30
Printed circuit boards (PCBs) and connectors	PCB 1	Various (rich in precious metals)	245
	PCB 2	Various (rich in precious metals)	61
	PCB 3 (smaller than 10 cm²)	Various (rich in precious metals)	1
	PCB 4	Various (Very rich in precious metals)	55
	Film connectors (linked to PCB 4)		4
	PCB 5	Various (poor in precious metals)	300
	PCB 6	Various (poor in precious metals)	8
Liquid crystal display (LCD) screen	LCD (larger than 100 cm²)	Glass, plastic, others (48.2 mg indium)	473
	Plastic light guide	Polymethyl methacrylate (PMMA)	1565
	Plastic foil	Unspecified plastic	100
	Fluorescent lamp	Glass and various (8 mg mercury, and 5.8 mg rare earths)	8
Fan		Plastic and steel	19
Speakers		Steel, plastic	196
Cables	External	Copper; plastic	120
	Internal	Copper; plastic	25
Others	Capacitors (with diameter greater than 2.5cm; linked to PCB 2)	Various	9
	Screws	Iron/Steel	30
Total			7,186

Figure 23: Composition of a LCD TV. Source: JRC, 2016

OLED, on the contrary, is now for around 0,2% of collected screens and will increase.

LED TVs are lighter, and larger. Larger TV means larger PMMA sheets. However it is difficult to tell to what extent the thickness of the TV influences the PMMA %wt. A characterization similar to the dating study, combined to a dismantling would be possible but time-consuming.

[25] https://publications.jrc.ec.europa.eu/repository/bitstream/JRC100785/lb-na-27793-en-n%20%28final%29.pdf p38

Equipment	PMMA share
Large TV LCD (CCFL/LED)	1%
Monitor LCD (CCFL/LED)+ small TV	17%/13%
Plasma	0%
OLED	0%
Laptops	5%

Figure 24: PMMA share per technology according to a French screen waste operator using semi-automatic process

Considering very large TV are still minor part, it would lead to a 6303t of PMMA in screens in France in 2019, compared to 4005t using the 7% average.

Unfortunately no other treatment center could give such a useful information. Using this extrapolation key is therefore not reliable enough.

5.2 *Variation per sorting technology*

A scheme characterizes materials in screen flow per treatment site every year, but not for the whole screen category, not for every type of screens. Plus, sometimes, no more information than 'plastics' is found, because separation of plastics is not absolutely necessary besides those containing brominated flame retardants (BFR) that are eliminated. Plastics without BFR should then be separated per type of polymers mainly for economic and environmental value.

PMMA share may then vary from a site to another, regarding the type of FPD treated and the process to extract PMMA (see chapter 2)

Ecologic works with nine FPD treatment centers in metropolitan France, plus two out of mainland. The sites are auditioned every year, and the characterization takes place.

The table below gives the evolution of the share of PMMA in characterized flow on 2015-2020. Indeed, before 2015, very few LCD screens were collected, and flow analysis were conducted on 'screens', assuming CRT it is the major part. FPD and CRT have been characterized separately from 2015 on.

Year	**2015-2019**	2015	2016	2017	2018	2019
Number of sites with information		3	3	6	6	8
Average	**7.20%**	5.36%	10.36%	6.21%	8.68%	5.37%

Table 2: PMMA share per screen in characterized flow, period 2015-2019

It leads to an average of 7.20% PMMA in FPD screens per year for 2015-2019, with no clear tendency.

Some sites were characterized but not enough details were given to be taken into account.

Some sites aren't active anymore. The average for treatment centers under contract in 2020 is 6.49%.

The characterized flow is representative of the activity of the site, but few differences can be noticed. To illustrate this, a site declared they have treated 30,6t of PMMA in 2019. It makes a share of 7,40%, ie 1,16% more than in the characterization conducted.

Automatic dismantling and semi-mechanical dismantling gives around twice more what shredding gets. No more details could be given because of confidentiality.

The choice after calculation is to keep the initial hypothesis of 7% PMMA.

Conclusion

Waste generation is hard to predict, and drivers such as ecodesign or an extension of restricted substances in the new WEEE directive to come could lead long-term predictions to non-sense.

Moreover, until the end of the decade, a better knowledge of other EEE containing PMMA, and general improvements in WEEE sorting technologies, as seen constantly since the setup of the first WEEE Directive in 2002, will surely allow to find other potentials, a lot more than a ball park figure with a BAU scenario. Stricter implementation of regulation surrounding WEEE waste will also prevent leakage of waste in the future. Indeed, at the moment, exportation to Asia for components reuse, such as electronics but also dPMMA and diffuser sheets, is a common practice. Last but not least, incentives planned by the regulation in using recycled plastics would push WEEE recyclers getting better quality outputs.

Besides EEE, general improvement and enlargement/expansion of Extended Producer Responsibility (EPR). As an example, French professional furniture scheme Valdelia claim its will to collaborate finding equipment under their agreement, such as Covid-bareers or points of purchase advertising.

Except for providing further information related to task 1.2, Ecologic will help collecting samples by playing a facilitator role between Heathland and WEEE operators, and organize sites visit to better understand this End-of-life (EoL) PMMA flow.

After M36 Ecologic will also help WP1 collaborators on task 1.3 to make guidelines toward companies producing PMMA and recyclers having the feedstocks. Another task will consist in probing among its members applications keen on using rPMMA grade A.