

EuP Preparatory Studies “Televisions” (Lot 5)

Final Report on Task 6 “Technical Analysis BAT”

Compiled by Fraunhofer IZM

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Introduction

This is the final report on Task 6 “Technical Analysis of Best Available Technology (BAT)” for the EuP Preparatory Studies on televisions (lot 5). The findings presented in this report are results of the research conducted by the IZM consortium and the continuous feedback from a wide range of stakeholders. The statements and recommendations presented in the final report however are not to be perceived as the opinion of the European Commission.

We like to acknowledge the fruitful collaboration and trustful working relationship with various industry partners, non-industry stakeholders, and the European Commission throughout the study. We like to thank all stakeholders for their contributions and critical reviews of our reports.

2nd August 2007

6 Technical Analysis BAT

Introduction

Task 6 has the objective to identify, describe, and evaluate best available technologies (BAT) and technologies that are currently in the development (laboratory or prototype level) and are expected to enter the mass market in two or three years (i.e. BNAT). The MEEuP differentiates BAT (Best Available Technology) and BNAT (Best Not yet Available Technology), BAT is a technology, leading to minimised environmental impacts, which is already available on the market or at least the technical feasibility has already been demonstrated (expected to be introduced at product level within 1-3 years). BNAT refers to technology, which has the potential to lead to further (environmental) performance improvements, but is still subject to research and development and is rather a future option / trend. The reference term is “best technology” and not “best product” indicating an environmental improvement potential through application of new technical principles, components, or materials. This intention is reflected by the following subtasks that are prescribed by the MEEuP:

- State-of-the-art in applied research at product level
- State-of-the-art at component level
- State-of-the-art of best existing products outside the EU

The assessment of the BAT and BNAT provides input for the identification of the improvement potential in Task 7. Intellectual property, technical feasibility, and availability on market in a strict sense are not judged here as the objective is to illustrate various technically available (or potentially available) options. However, the task 7 will take these issues into account when suggesting possible improvement options applicable to TVs. A comparison of the MEEuP prescribed subtasks (task 6) and the proclaimed objective “technical analysis best available technology” show contradictions in the description of Task 6. The subtasks require identification of “best existing products” as well as “best technologies at product and component level”. We come to the conclusion that the prescribed subtasks have to be modified for the purpose of the EuP Preparatory Study Lot 5. By reflecting the results of the market and trend analysis, the technical analysis of existing products and the definition of base cases, we propose the following structure for Task 6 report:

- State-of-the-art in TV-display technology (6.1)
- State-of-the-art in TV-set making (6.2)
- State-of-the-art in TV power consumption (6.3)

Subtask 6.1 provides an analysis of technical principles (design options), components or materials that have a potential to reduce the environmental impact of TV displays. The main focus of the analysis is put on power consumption. Further aspects are resource efficiency, new functional materials with low life cycle impact, and the reduction of hazardous substances. The analysis reflects current and expected future market developments. On the basis of our research and interviews with industry we conclude that LCD and PDP have the highest market potential, due to their novelty (Flat Panel Display) and considerable maturity of technology. In consequence we assess primarily technical developments concerning LCD-TVs (e.g. backlight units) and PDP-TVs (e.g. panel luminescence efficiency). Other TV display technologies including various RP technologies, slim CRT, SED, and OLED will be analyzed to some extent as well. Following Figure 1 provides an overview on the current developments regarding TV display technology and their market potential by screen size.

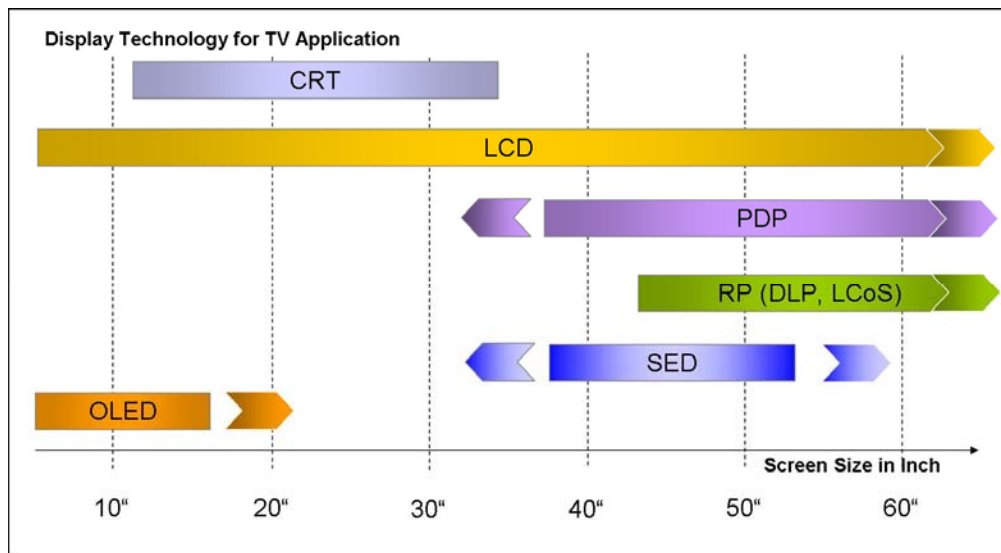


Figure 1: Display technology for TV application in different screen size segments

Subtask 6.2 analyzes state-of-the-art in TV-set making. The analysis will cover best available technology regarding electrical efficiency of the power supply units, miniaturization of electronic components and boards, as well as alternative housing materials, physical design and recycling issues.

Subtask 6.3 provides an overview on most energy efficient products (standard mode and standby mode) in various market segments, thus reflecting best available products in the global market.

The description of technologies presented here is based on ongoing research. New cutting edge technologies are highly guarded secrets and detailed public information is limited. Thus, the

information presented here should be seen as a general overview of potential improvement options rather than a thorough technical analysis.

Note:

Task 6 is based on a literature search as well as contributions from stakeholders. All the registered Lot 5 stakeholders were invited to provide input to this task, and others were also welcome to contribute. Important BATs have been covered to the best of our knowledge. Most of the technical data for this task has been provided directly by the manufacturers/designers or come from other published information. However, the efficiency or other performance levels claimed by them have not been verified independently.

6.1. State-of-the art in TV-display technology

6.1.1. Liquid Crystal Display (LCD) Back-Light Units (BLU)

Today's most prevalent advanced displays, the direct-view liquid crystal display (LCD), do not emit its own light, but rather must be illuminated from behind. The reduction of power consumption is strongly related to the back-light unit (BLU). The most common BLU for LCD-TV today consists of a number of fluorescent lamps (multiple lamp configurations) that span the entire length of the display horizontally in combination with a light reflector. The polarizer on the panel side as well as the BLU driver circuitry has to be included into the system analysis.

The most commonly used lamps in LCD-TVs are Cold Cathode Fluorescent Lamps (CCFL). Advanced fluorescent lamp technologies include External Electrode Fluorescent Lamps (EEFL) and Flat Florescent Lamps (FFL). The future BLU will feature Light Emitting Diodes (LED). Prototypes are available and LCD-TVs with LED-BLU have been the attraction of showcases since 2005. But performance characteristics and manufacturing of LEDs, color mixing technology, and interconnection technology (electronic packaging) are still not matured enough to be commercialized in mass market application for all LCD-TVs.

In addition to the florescent lamp or LED backlight systems, a considerable reduction in power consumption is today already achieved by dynamic scaling (dimming) of the whole backlight unit. A vertically partial dimming through a scaling of single lamps is also possible. LED-BLUs would have the advantage of content specific (vertical and horizontal) area dimming. This kind of BLU technology has a high power saving potential.

The following sub-section describes and assesses technical and environmental aspects of backlight units for LCD-TVs. The analysis covers:

- Fluorescent lamp BLU
- LED-BLU
- Active scaling of BLU
- Efficient polarizer
- Power supply and power conversion efficiency

6.1.1.1. Cold Cathode Fluorescent Lamp (CCFL)

According to manufacturers, CCFL BLUs have according to manufacturer good performance properties; good luminous intensity (defined as $\text{cd}=\text{lm}/\text{sr}$, one lumen of luminous flux per steradian), high luminance density (small form factor and light weight), good color reproduction (70% ~ 72% of NTSC spectrum) and color uniformity, vibration and impact resistance, durability, and excellent blinking characteristics, quick start at low temperature, low heating and long lifetime (20.000 ~ 60.000 hours)¹. CCFL is very mature technology and hence the costs are relatively low. CCFL is a gas discharge lamp and classified as an electronic component. CCFL is a sealed glass tube with electrodes on both ends. The tube is phosphor coated and filled with inert gases (Ar/Ne) and a slight amount of mercury (approx. 4mg Hg per lamp). When a voltage is applied to the electrodes (strike voltage is 1.0KV ~ 2.5KV), the gas is ionized allowing the electrical current to flow. The collision of moving ions inject energy to the mercury atoms, which lets the atoms jump to a higher energy level followed by emitting ultraviolet photons when falling back into their original energy level. This effect is called gas discharge phenomenon. The wavelength or color of the visible light depends on the type of the gas and phosphor (red, green and blue phosphors for producing three band white light)².

During operation, the CCFL generate UVB and UVC radiation. Over time, this can damage important components inside the monitors. The LGP (Light Guide Plate) located behind the TFT (Thin Film Transistor) is primarily made of plastic and reacts quite sensitively. This component is responsible for uniform illumination, brilliance of color and brightness. UV radiation causes the components to turn yellow and, thus, impairs the image quality, brightness, and color values³. CCFL glass manufacturer have developed high UV-blocking glass in order to counter this problem. In the CCFL, ionized gas conducts the electrical current. The impedance of the gas conductor, unlike that of the metal conductor having a linear behavior, decreases as the current increases. Therefore, the CCFL has to be driven by an alternative current (AC) to avoid a potential explosion⁴.

¹ http://www.j-right.com/html/ccfl_lamp.htm. (03/2007)

² Phosphor is the limiting factor for high color gamut. Average CCFL reach just of 70% of NTSC spectrum. LG.Philips however showed at the FPD International 2005 (19th -21st October) in Yokohama a 23" WUXGA LCD with improved NTSC color gamut of 90% due to new phosphor CCFL.

³ Schott Solutions Magazin No 1 / 2006:

http://www.schott.com/magazine/english/download/sol106_09_glasstubing.pdf?PHPSESSID=916 (03/2007)

⁴ Wei-Chung Cheng: Power Minimization in a Backlit TFT-LCD Display by Concurrent Brightness and Contrast Scaling. Paper in the Internet: <http://atrk.usc.edu/~massoud/Papers/cbcs-journal.pdf>. (03/2007).

The power consumption of the CCFL BLU depends on the number of lamps, the dimension and chemical composition of the lamps (illumination efficiency decreases with age due to deteriorating chemical properties of the CCFL), the reflector design as well as the electrical efficiency of the power supply and the driving inverter unit. The dimming (scaling) of the complete CCFL BLU according to actual ambient brightness (sensor-based active brightness control) or the average picture level of the video image is an effective measure to reduce power consumption furthermore.

According to DisplaySearch, there are usually sixteen CCFL in a 32" LCD-TV⁵. The emission (brightness) efficiency of CCFL is about 60 lm/W with improving potential (60 ~ 80 lm/W). A short investigation on CCFL drivers for LCD-TV application indicated that the inverters feature an input voltage range of DC 5 ~ 36V. The CCFL usually runs at DC 12V with a strike voltage of 1400V to 1800V. The working voltage is assumed somewhat lower at 1000V to 1200V with a working current of 5.5 to 7.5 mA. The rated power consumption of a single CCFL depends on the lamp size (BLU size) and design. For the purpose of the study we assume an average 5.5 Watt power consumption per lamp for a 32" LCD-TV.

The electrical efficiency of the power supply for the BLU is an important issue. Multiple power transformation steps (e.g. 220V [AC-DC] → 12V → 1200V [DC-AC]) contribute to the overall power consumption of a LCD-BLU. Losses particularly are related to the power transformation from a low voltage (e.g. 12V) to a high voltage (e.g. 1200V). In this case power transformation efficiency is usually only 50 to 70%. The electrical efficiency of AC and DC inverters on the other hand is usually already over 80%. One manufacturer was addressing the issue of direct power supply for the BLU in order to avoid the low power transformation step and the related losses. This approach would require however a close collaboration of BLU manufacturers, due to the fact that the TV set-maker would design the power supply and drivers for the BLU.

Improvement potential of CCFL BLU results from:

- Higher emission efficiency of the CCFL through design and chemical composition of the lamp (>60 lm/W)
- Higher electrical efficiency of power supply (avoiding of multiple power conversion steps)
- Higher electrical efficiency of the CCFL driver (DC-AC inverter efficiency >80%)
- Dimming of the CCFL to reduce power consumption (active brightness control or image APL control)

⁵ DisplaySearch Presentation on Backlight system Development (Slide 27), in the Internet: http://www.displaysearch.com/free/sid_leds_in_displays_011306.pdf (03/2007)

6.1.1.2. External Electrode Fluorescent Lamp (EEFL)

EEFL differs from CCFL in a way that the electrodes are outside of the lamp. As there are no electrodes within the lamp, no wires pass through the glass tube, eliminating the need for a glass-to-metal seal, which is claimed to reduce gas leakage problems. EEFL also contains less Mercury (<4mg Hg per lamp). The principle gas discharge technology however is the same. The technical properties are defined by the external electrodes. Claimed advantages of the EEFL include high efficiency and brightness, less heat and less deterioration of the phosphors that heat causes, as well as the elimination of the electrode deterioration caused by ion bombardment. These aspects enhance the lifetime of EEFL (>60.000 hours). Illumination stability and brightness efficiency is good (60 ~ 80 lm/W). To avoid negative impedance of common gas charge lamp, EEFL external electrode allows high frequency voltage function via capacitance coupling. The EEFL operates on a lamp voltage of 1.0 ~ 1.2KV and lamp current 3.6mA⁶. Strike voltage is 1.5KV ~ 2.5KV. It is possible to run 10 to 20 EEFL from a single inverter, which reduces design costs.

According to DisplaySearch, a 32" LCD-TV EEFL-BLU consists of 20 lamps⁷. The rated power consumption of a single EEFL is 4 to 6 Watt. One high performance EEFL-BLU reportedly reduced power consumption of a large LCD-TV by 30% in comparison to a previous CCFL system⁸. According to a press statement, LG.Philips LCD America Inc. showed at the CES 2007 (January 2007 in Las Vegas) an EEFL equipped 32" HDTV LCD panel prototype with a power consumption of only 65 Watt. EEFL is a relatively new development in fluorescent lamp technology with some technical and cost advantages. Up to now EEFL is not much prevalent in current LCD-TV products. The DisplaySearch assessment from late 2005 indicated that supply of large size EEFL is limited.

Improvement potential of EEFL BLU results from:

- Lower power consumption than conventional CCFL
- Potential for power reduction through external electrode and easier inverter design
- Electrical efficiency of power supply and lamp driver circuitry (same as CCFL)
- BLU dimming (same as CCFL)
- Lower Mercury content per lamp (but more lamps necessary, ratio not known)

⁶ http://www.wellypower.com.tw/english/product1_15.php?function_page=c (03/2007)

⁷ DisplaySearch Presentation on Backlight system Development (Slide 27), in the Internet: http://www.displaysearch.com/free/sid_leds_in_displays_011306.pdf (03/2007)

⁸ J-B Kim et al (LG.Philips LCD): High Performance EEFL Backlight System for Large-Sized LCD TVs, Conference Paper (Session 26.3) at the SID 2006 Conference (Society of Information Display), 4 - 9 June 2006 San Francisco, CA; in the internet: <http://www.sid.org> (03/2007)

6.1.1.3. Flat Florescent Lamp (FFL)

FFL is a third backlight technology that has entered the market and it is mercury free⁹. The FFL is a thin, flat, rectangular lighting source that has the appearance of being an adaptation of the EEFL. According to Taiwanese Delta-Optoelectronics Inc., the first company that commercialized FFL BLUs, offer FFL backlights longer lifetimes (100.000 hours) and better color reproduction (80% of NTSC spec) and light uniformity compared to the typically round CCFL¹⁰. The FFL is sufficiently thin and large to cover the entire display area. For instance, a 32" LCD-TV which typically require 16 CCFLs will require just one FFL with a FFL-based backlight system. Even for larger sizes, only one FFL will be needed, states Samsung Corning¹¹. But it has to be said that the brightness efficiency is with 30 lm/W lower than that of conventional CCFL.

As for the design, the electrodes are arranged on the back surface of the FFL fixture, phosphors coat the front, while the gas plasma (Xe) occupies the space between. This permits the backlight source to be spread across the entire display area, rather than being located along its edges with distribution by reflectors, as is the case with round fluorescent tubes. According to DisplaySearch, the power consumption is rather high and thus the market potential of FFL will depend on the issue of improved ratio of power consumption to light emission, high productivity and lower costs.

Improvement potential of FFL BLU results from:

- Mercury free and free of UV leakage
- Very cheap converter design

Critical issues concerning FFL:

- Assumed higher power consumption in comparison to CCFL and EEFL
- Moderate brightness efficiency
- Supply limited for larger BLUs (>32")

⁹ FFL is not an entirely new concept, cp: M. Anandan, D. Ketchum (1992): Multiplicity of Discharge Channels for a Flat Fluorescent Lamp to Backlight a Full Color LCD; in IEEE TRANSACTIONS ON ELECTRON DEVICES, VOL. 39. NO. 6, JUNE 1992 1321.

¹⁰ http://www.delta-opto.com.tw/product/product_tech.asp (03/2007)

¹¹ <http://displayblog.wordpress.com/2006/09/01/samsung-corning-ffl-backlights/> (03/2007)

6.1.1.4. Light Emitting Diodes (LED)

LEDs provide many benefits as a backlight source for LCD-TV. According to an older article in the Nikkei Electronics, LED-BLU does offer a wider range of color reproduction (>100 % of NTSC specification) in comparison to CCFL, EEFF, FFL (<80%) and could achieve even better performance than CRT, PDP or SED panels which have limitations due to phosphors they use¹². LED backlights also enhance the contrast ratio due to the option of arbitrarily scaling (dimming) individual display areas. The dimming of the LED backlight is possible with a response time of 100ns¹³. In combination with a LCD panel speed of up to 6ms this is a real advantage because it improves the deep black reproduction and prevents motion blur.

Over the past three years many manufacturers have released mostly very large LCD-TV products which use red, green and blue (RGB) LEDs for the backlight and have achieved good performance. On the downside, RGB LED backlights demand color mixing technology in order to overcome unevenness of luminance. Color mixing has significantly improved with an increased understanding of the design and function of direct backlight concept¹⁴. Today, RGB LED clusters (usually 1x red, 2x green, and 1x blue) are grouped with some space in between in order to facilitate good color mixing and with minimum design for thermal radiation structures. Temperature control is essential in order to avoid color shift, which is another challenge in LED backlight systems. Figure 2 shows the principle design of LED backlight system in comparison to a conventional CCFL backlight.

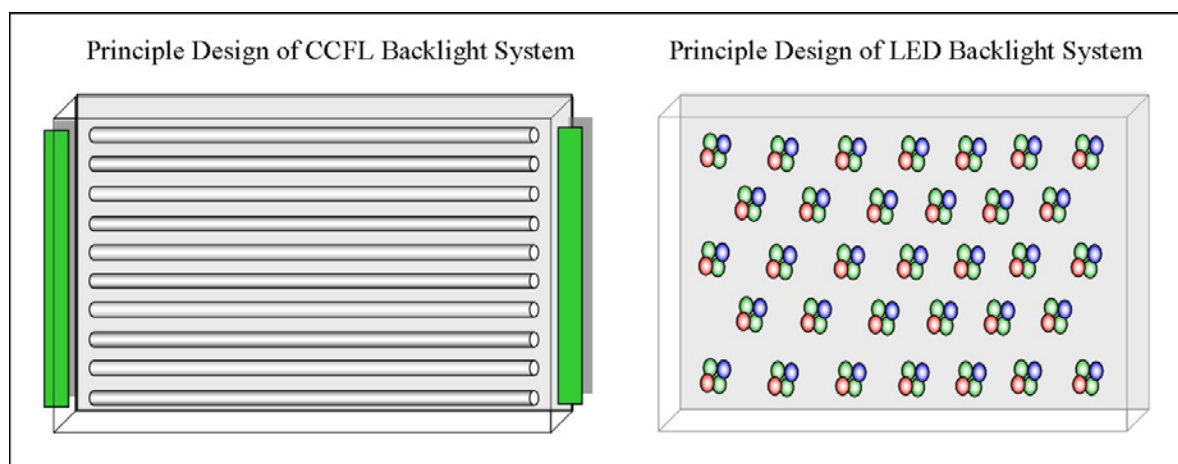


Figure 2: Principle Design of CCFL and LED Backlight System (Source: Samsung)

¹² Nikkei Electronics Asia March 2005 issue: LED Backlights Boost LCD TV color.

¹³ Heise online 20.07.2005, in the Internet: <http://www.heise.de/newsticker/meldung/61890> (01/2007)

¹⁴ Robert Scott West et al (Lumileds Lighting): http://www.lumileds.com/solutions/LCD/Luxeon_Direct-SID_2003.pdf (01/2007)

The LED backlight technology is on a fast track. LED and BLU Manufacturer (e.g. Lumileds, Osram Opto Semiconductors, Toyoda Gosei) try to meet the demand of LCD manufacturers by improving the dimension (thickness), lifetime (>50.000 hours), stability (avoid nucleation and growth of dislocations), operation temperature (low) and uniform luminance characteristics (high), and related power consumption of the color LED and LED backlight units. Red, green and blue LEDs are made of a variety of inorganic semiconductor materials such as AlGaAs, AlGaP, AlNiP, AlGaN, InGaN, ZnSe, Al₂O₃, or SiC and manufactured in thin-film semiconductor processes. It is not possible to assess the environmental impacts of LED materials and manufacturing process within the scope of this study. The current costs for LED backlight unit however indicate manufacturing related impact. According to DisplaySearch has the LED backlight unit a cost factor of 2.5 ~ 3.0 in comparison to CCFL¹⁵. LCD-TVs with LED backlights are on average 70% more expensive than conventional CCFL LCD-TVs.

In press releases of LCD-TV manufacturers, it is usually said that LED backlights have lower power consumption. From the currently available LED backlight products it is difficult to draw precise conclusions regarding power consumption. As an example, Osram Opto Semiconductors showed in 2005 a LED backlight unit prototype for an 82" LCD-TV (!). This prototype was only 40 mm deep and featured 1120 LEDs in clusters (1x red, 2x green, and 1x blue) with a lifetime of 50.000 hours. According to Osram OS consumes this prototype 1000 Watt in use with no cooling fan necessary. In January 2006 Samsung presented at the CES showcase in Las Vegas the first 82" LCD-TV with a LED backlight acknowledging lower power consumption¹⁶.

For comparison purposes we have calculated the power consumption of a LED-BLU based 42" and 32" LCD-TV. The calculation was simply done based on the comparison of the screen surface area in relation to the 1000 Watt power consumption of the 82" LCD-TV. Following this calculation scheme the 42" LED-BLU LCD-TV would consume 256 Watt and the 32" TV would consume 148 Watt. In comparison to the average power consumption values for conventional backlight LCD-TV (see calculation in Task 5 report chapter 5.4.1) the 42" would consume slightly more than the average (220W) and the 32" would consume exactly like the average (159W). The latest Samsung LE-40M91B (40" LCD-TV with LED backlight) with exceptional picture quality and a wide spectrum of additional features is specified in the product catalogue with 230 Watt.¹⁷ Assuming

¹⁵ DisplaySearch Presentation on Backlight system Development (Slide 27), in the Internet: http://www.displaysearch.com/free/sid_leds_in_displays_011306.pdf (03/2007)

¹⁶ Samsung press release from 6 January 2006 (SEC).

¹⁷ In an article of the EE Times Asia from 14 March 2007 Mao Yu-Hai, chief scientist at Power Analog Microelectronics (PAM), said: "When using LED backlight, the power consumption can be reduced by 50 percent. In Samsung's 40inch LCD-TV, it consumed 170W. After it changed to LED backlight, it only consumed 100W". http://www.eetasia.com/ART_8800456473_765245_7b2a9ec1200703_no.HTM.

that the backlight consumes 60% ~ 65% of total power consumption this is good performance and shows the potential of LED backlight. In combination with an advanced backlight control for partial area dimming of LED clusters or dimming of single LEDs the improvement potential for power consumption has to be assumed excellent. However, by what percentage this improvement is achievable is difficult to assess. About 34% possible decrease has been reported in an older study conducted in 2003¹⁸. Our assumption would be similar high (>30%), but LED backlight technology for LCD-TV application is not mature yet and commercialization for mass production will take some more time.

Improvement potential of LED BLU results from:

- Potentially low power consumption in combination with active area dimming
- No hazardous substances (Mercury free)
- Potentially longer lifetime

Issues to be solved in LED:

- LED quality, uniform color characteristics, and long-life stability
- LED system integration (e.g. control circuit design, materials of electronic packaging, and thermal management)
- Current high manufacturing and system integration costs

6.1.1.5. Conclusion

BLUs have a significant influence concerning the picture quality, lifetime, and power consumption of LCD-TVs. Today, almost all LCD-TVs feature a CCFL-BLU. CCFL will remain an important backlight technology in the near- to mid-term future due to a good price to performance ratio and limited improvement potential can be expected in the case of CCFL. EEFL and FFL have some technical advantages – EEFL shows better power efficiency and FFL is mercury free. However, our investigation indicates that LED-BLUs have the most promising market and environmental improvement potential in the mid- to long-term future. This assessment is confirmed by market forecasts for backlight units¹⁹. LED technology is not yet mature. It is therefore difficult to assess the actual environmental improvement potential or impact.

Comment: This statement contradicts with the catalogue data from Samsung. Mr. Mao might refer to a different product.

¹⁸ Environmental, Technical and Market Analysis concerning the Eco-design of Television Devices, IPTS, JRC, European Commission, 2003.

¹⁹ Digitimes online news 26 may 2006.

6.1.2. LCD Panel Efficiency

6.1.2.1. High Efficient Polarizer

The technical development in the field of LCD panels is focused on the improvement of light channeling (polarization) and light passing efficiency (transparency) of the functional layers for high and even luminance output. The improvement of the polarization filters, diffusers, glass substrate with TFT and circuitry, the liquid crystal layer, color filters and other alignment and protection layers have direct influence on the power consumption of the LCD-TV. The improvement of the light passing efficiency could result in a smaller dimensioning of the BLU (e.g. reduced number of lamps), which results in lower power consumption of the system. Most of the material and design developments in the field of LCD panels (functional layers) are proprietary technologies (IP). Due to this situation it is very difficult to provide a comprehensive analysis of best available technology (BAT) and not yet best available technology (BNAT) for LCD panels. As an example, we take the important technical aspect of polarization.

The polarizer is the functional link between the backlight (lamp) and the LCD panel. Today, reflective polarizer (e.g. marketed by 3M Electronics) or prismatic films achieve a higher utilization of the lamp's randomly emitted light. Normally S-wave light is absorbed by the polarizer and basically lost. The reflective polarizer of 3M Electronics (Vikuiti™ Dual Brightness Enhancement Film) for example achieves a higher utilization of the lamp emitted light by reflecting the s-wave light and receiving it again after reflected by the BLU. According to 3M, this "recycling of light" increases the light throughput and hence the overall efficiency of BLU by up to 50%. This positive effect can be used for reducing the number of necessary lamps in the BLU and the power consumption accordingly. In a test by 3M, a 37" LCD-TV with a Vikuiti™ DBEF and 12 CCFLs produced brightness equal to the same LCD-TV with regular 16 CCFLs and no DBEF. The DBEF configured system also drew 35 Watts less power to produce the same brightness. In conclusion, the reflective polarizer film of 3M can increase the energy efficiency of LCD-BLU 30% to 50% which relates to a 20% to 30% power reduction of a LCD-TV.

Today, many TV-makers purchase already LCD panels with such high efficient polarizer films from 3M Electronics. However, it is important to understand that such polarizer films are proprietary technologies and are therefore an important cost factor.

6.1.2.2. LCD Panel Manufacturing

If trying to characterize the technical development in the field of LCD panels it could be said that improvement is focused on both enlargement and miniaturization.

Enlargement: The drive for larger screen sizes and higher production yield demands larger glass substrates. The 8th generation in LCD panel manufacturing with glass substrates of 2160 x 2400 mm² started in 2006. Extensive automation in production and the extremely competitive market situation makes LCD panel manufacturing costs and yield a key economical and environmental issue. There is a very simple correlation; improved production yield lowers the environmental footprint. Production yield – highest quality output – in LCD panel manufacturing is closely related to the level of miniaturization in the functional layers of the LCD.

Miniaturization: The drive for higher resolution (Full HD) demands finer color cell structures (red, green and blue filters separated by a black matrix) in order to generate a respectively higher number of pixels in the same space. With increasing number of pixels and corresponding color cells not only the amount of thin film transistors (TFT) will increase but they have to be miniaturized. Miniaturization demands a high degree of precision in manufacturing as well as cleanliness. Most LCD panel manufacturing steps have to be carried out in clean room environment (lithography and wet etching are commonly Class 10 whereas sputtering and plasma enhanced chemical vapor deposition [PECVD] is Class 100 and the rest Class 1000+). A considerable cost and yield factor are the multiple cleaning processes. According to a manufacturer around 80% of defects come from particles on the substrate. Therefore physical and chemical cleaning becomes a key factor for quality improvement. However, extensive cleaning processes are resource and potentially pollution intensive.

Resource conscious improvement of manufacturing yield: In conclusion, from an environmental point of view further development in LCD panel manufacturing should focus on an optimum break even point of yield (output quantity) to resource consumption (input quantity). The authors of the study are limited to this statement. A description of best practice examples or best available technology is not comprehensively possible due to the fast occurring changes from one manufacturing generation to the next, the specifics and complexity of applied LCD manufacturing equipment, as well as the protection of technologies on all levels by intellectual property rights.

The following example of the Toshiba Matsushita Display Technology Co., Ltd (TMD) Ishikawa Plant shows some strategies to reduce global warming potential in LCD panel manufacturing. There is a limiting factor to this example due to the fact that this particular plant does not produce

large LCD panel for TV application. However it is an example that indicates best practice. We present the example in form of the original article which was taken from the JFS²⁰ Newsletter of February 2007. Japan for Sustainability (JFS) is a non-profit communication platform to disseminate environmental information from Japan. Check out website:

Example: LCD plant's efforts to tackle global warming

Towards a Sustainable Japan--Corporation at Work Article Series No.58 An LCD Plant Tackles Global Warming (Toshiba Matsushita Display Technology Co., Ltd.) http://www.tmdisplay.com/tm_dsp/en/index.html

... compared to the final assembly of digital devices and home appliances, the manufacture of LCDs, semiconductors and other electronic device parts consumes massive amounts of energy, and the industry has been called upon to promote in-house global warming measures. As a global corporation that produces digital and electronic devices, social infrastructure, and home appliances, the Toshiba Group is committed to tackling global warming, and is focusing its efforts on its electronic device business because this sector accounts for about 70 percent of the group's total energy consumption (CO2 equivalent), while accounting for only 20 percent of total sales. This article introduces Toshiba Matsushita Display Technology Co. (TMD), part of Toshiba Group's electronic device manufacturing team, focusing on its LCD plant's efforts to tackle global warming. [...] The company enjoys a reputation for its technological excellence in the area of small- and medium-sized mobile displays. [...] TMD incorporated a wide range of anti-global warming initiatives in a new LCD manufacturing line that was installed in its Ishikawa Plant in November 2005 and started operations in April 2006. Compared with conventional manufacturing lines, the new line is expected to achieve a 53 percent reduction in greenhouse gas emissions.

The new line incorporates three types of anti-global warming strategies, including one that was introduced into LCD manufacturing for the first time. The first strategy was to conserve energy in cooling water used in air conditioning. The LCD manufacturing process requires a highly clean environment in order to maintain product quality, and air conditioning is always used to control cleanliness, temperature and humidity in clean rooms. To regulate room temperature, 14-degree C (Celsius) water suffices, but 6-degree C water is needed to regulate humidity. Formerly, 6-degree water was used to regulate both room temperature and humidity, but the new line uses two systems with different water temperatures: 6-degree water for controlling humidity and 14-degree C water for controlling temperature to increase cooling efficiency with less energy input. Ishikawa Prefecture where the plant is located has severe winters, and another way the company attempts to reduce total energy consumption is to use cold air from outside to cool down the air conditioning coolant water from December to March.

Another strategy was to build a "ballroom" type clean room, and to make effective use of under-floor air-conditioning/recirculation passages. [...] Conventional manufacturing lines consume a huge amount of energy because they consist of many small clean rooms for individual work processes. The new line improved space efficiency by eliminating room partitions and completing the manufacturing process in a single clean room. They also aimed to reduce power consumption by cleaning not the entire room but only individual pieces of manufacturing equipment and the transfer system that moves the substrate boards between machines. Ordinary clean rooms are two-storied: the second floor is used for production and the first floor for the passage of dirty air pulled down from the ceiling to the floor by the air conditioning system. The new line attempts to also use the first floor for production. If this idea can be realized, they

²⁰ <http://www.japanfs.org/>

can substantially reduce clean room floor space, allowing for further reductions in electricity consumption by air-conditioners, etc.

Ballroom-type clean rooms have been adopted at some semi-conductor plants. However, it was thought difficult to do so in LCD plants, because LCD manufacture uses substrate boards larger than those used for semiconductors. The unprecedented production design of these clean rooms, which incorporated less space for air recirculation passages, was the largest challenge in building the new line. [...] The team completed a new clean room design that occupies about 44 percent less floor space compared with conventional designs by incorporating many innovations such as the installation of a cleaning unit on each piece of equipment, a system to control airflow during the transferring and loading of substrate boards, and cleanliness adjustment mechanisms for each process. As a result, the new design successfully reduced the use of building materials and cleaning units, minimizing initial construction cost as well as reducing the amount of energy consumed.

The third strategy was to reduce Perfluorocarbon (PFC) gas emissions. PFC gas, a kind of chlorofluorocarbon, has a greenhouse effect that is thousands to tens of thousands times greater than carbon's. PFC gasses, including CF₄, SF₆ and NF₃, are indispensable in manufacturing LCDs. However, the resulting exhaust gas is resistant to decomposition with water. This gas was emitted directly to the surrounding environment. In the new TMD line, PFC gas emissions were reduced by 90-95 percent by introducing cutting-edge equipment that renders PFC gas harmless by burning and decomposing the gas before adding water to it. TMD also decided to replace NF₃ gas with a type of fluorine that does not have greenhouse effect, and equipped the new line with Japan's first fluorine gas generator. The use of fluorine was known to reduce environmental impacts, but practical use of fluorine on a massive scale, as in mass production of LCDs, has been difficult due to constraints on the pressure and concentration of the fluorine in the process of putting it into a gas cylinder. TMD [...] employed a method [...] that applies electrolysis to fluorinated acid to generate the fluorine. [...] The LCD industry set a worldwide goal to reduce PFC gas emissions to the year 2000's level by 2010. As LCD production is expected to experience a 3- to 5-fold increase by 2010, this target value appears extremely ambitious.

[...] According to preliminary calculations, the new line incorporating all these innovations will reduce greenhouse gas emissions to 28,258 tons of CO₂ equivalent annually, while a comparable conventional line would emit 60,082 tons annually. This achievement is imminent. The engineers who participated in launch of the new line are striving to solve issues in order to achieve further reduction of greenhouse gasses.

Written by Eriko Saijo

Japan for Sustainability (JFS) Newsletter No 58 of February 2007

<http://www.japanfs.org>

6.1.3. Back-Light Engines for Rear Projection Displays

There are currently different optoelectronic technologies for micro-display rear projection TVs in the market. The most commonly used technologies are branded under the names DLP™, 3LCD™, and LCOS. Rear projection TVs work on the principle of projecting a full-color image from a smaller screen through a projection lens on a larger display screen. The image is created by a set of optics and electronics that illuminates and projects red, green and blue (RGB) light onto the smaller screen. All of these projection systems are currently using Ultra High Pressure (UHP) lamp as a light source. The UHP lamps contain mercury and are said to have a limited lifetime, making replacement a necessity. Power consumption of RP-TVs is mostly related to the UHP lamps. The power consumption in conjunction with the optoelectronic system is difficult to assess due to the variety of technology adaptation. The main systems are shortly introduced followed by an analysis of the backlight engines.

6.1.3.1. DLP System

DLP (Digital Light Processing) is the name for the optical system that uses DMD. DMD (Digital Micro-mirror Device) is a display technology where hundreds of thousands of carefully positioned micro-mirrors are arranged on a semiconductor substrate. Each mirror corresponds to a pixel and projects an image by reflecting the light from the source. 1-chip and 3-chip systems are available. DLP™ (Digital Light Processing) and DMD™ (Digital Micro-mirror Device) are trademarks of Texas Instruments Incorporated. For more information: <http://www.dlp.com>

6.1.3.2. 3LCD System

3LCD is the most widely used projection technology system. 3LCD technology employs three small high-temperature polysilicon active matrix liquid crystal displays (HTPS LCDs), hence the name 3LCD. In principle white light is divided into red, green, and blue using two dichroic mirrors, which are special mirrors that transmit light with a certain wavelength. Each color is then passed through a dedicated HTPS LCD, before being combined with the other colors in a prism. The prism is formed by combining four triangular poles to create one rectangular solid. High precision is required in the processing and adhesion of poles to avoid dark lines and double images caused by misaligned dichroic surfaces. The image is then ready to be projected via a lens onto the larger front screen. For more information: <http://www.3lcd.com>

6.1.3.3. LCoS System

LCoS (Liquid Crystal on Silicon) is a reflective LCD display panel with a high open area ratio. Since the wiring area and switching elements are under the reflection layer, it doesn't require a black matrix area, so images are seamless. 1-chip and 3-chip systems are available. 3-chip LCoS rear-projection TVs achieve high performance by utilizing the high resolution characteristics of this element avoiding a color wheel. 1-chip LCoS systems use a sequential optical drive system with a rotation prism mechanism that divides the light into red, green, and blue and projects the picture. LCoS is a reflective technology. Instead of a backlight, light from a projection lamp strikes the liquid crystal cells from the front, hits a mirrored pane behind them then bounces back out toward the screen. JVC calls its own LCoS technology D-ILA or in HD models HD-ILA. Sony's version of LCoS is dubbed SXRD for Silicon X-tal Reflective Display.

6.1.3.4. Ultra High Pressure (UHP) Lamps

UHP lamps are currently used for RP-TVs. Philips developed the high pressure mercury type UHP lamps. The UHP lamp was designed with the ability to maintain small arc gaps by virtue of the fact that its mercury fill operated at pressures over 200 bar as compared to operating pressures prevailing at the time in the vicinity of 50 bar. UHP lamps can reach lifetimes of more than 10.000 burning hours²¹ enabled by the regenerative chemical cycle using a patented halogen filling. Adding a certain amount of oxygen and halogen to the lamp atmosphere prevents the tungsten evaporated from the lamp electrodes to condense on the wall, as in the colder regions the tungsten atoms react chemically to form oxyhalide molecules²². The need by the projection industry for more light on the screen for its imaging products and the requirements to illuminate ever smaller imaging apertures is not as yet satisfied. There is a demand for lamps that go beyond the performance limits of current UHP lamps in terms of total light output, efficacy, arc gap size and color. Dr. Holger Moench, Principal Scientist at Philips, said in an online interview: "We (Philips) are the innovators and we still innovate, year after year, new lamps. We started with a 100 Watt lamp of this size (holds a larger lamp) and now operate at more than 200 Watt that size (holds a smaller lamp), so miniaturization is one research issue aiming at portable projectors. Another thing is that we extend the lifetime up to 20.000 hours making consumer products realistic²³."

²¹ Consumer tests indicate 5000 – 8000 hours as more realistic. DLP TV Review in the internet: <http://www.dlptvreview.com/dlptvreviews/projection-lamp-replacement.html> (03/2007)

²² Pavel Pekarski et al: UHP Lamps for Projection Systems, Philips Research Laboratories, Aachen, Germany

²³ <http://www.research.philips.com/profile/people/researchers/uhp.html>

Environmental performance of UHP lamps are defined by power consumption and containing hazardous substances. Sony is utilizing a 120W UHP lamp (Model XL-5200) in the current LCoS-based (SXRD) 60" RR-TV (KDS-60A2000) which consumes according to catalogue value 210 Watt. Sony also provides a power saving option of this product reducing the luminescence output. Samsung also utilizes a 120W UHP lamp in the current 61" DLP-based RP-TV (SP61L6HX) with TV-set power consumption of 166 Watt. In the specification a lamp life of 8000 hours is given²⁴. According to a product safety data sheet for a UHP lamp of Philips Lighting is the mercury content 0.01 – 0.023grams²⁵.

Issues related to UHP lamps:

- Improvement lifetime
- Miniaturization and lower mercury content
- Fair power consumption

6.1.3.5. Laser-based light sources for RP-TVs

Another controversial development in the field of RP-TV is the so called laser-projection TV. Their advocates claim a long lifetime (50.000 hours) and increased energy efficiency by using two-thirds less power than traditional RP-TV²⁶. The Australian chipmaker Arasor International and America-based Novalux showcased first laser-projection TV prototypes based on a Mitsubishi RP-TV in Australia (2006) and at the 2007 Consumer Electronics Show (CES). There are currently legal and financial business disputes connected to the development and application of this technology. It is therefore out of the scope of this study to investigate the technical potential of this controversial technology. In conclusion, laser-based light sources for RP-TVs are not yet available technology.

²⁴ <http://www.samsung.com/au/products/tv/rearprojectiontv/images/SP61L6H.pdf> (03/2007)

²⁵ http://www.hp.com/hpinfo/globalcitizenship/environment/pdf/L1709A_PSDS.pdf (03/2007)

²⁶ http://en.wikipedia.org/wiki/Laser_TV (03/2007)

6.1.4. Plasma Display Panel (PDP)

PDP is a self-emissive display which generates ultraviolet radiation through a gas discharge and excites phosphor to convert this radiation into visible light. Therefore each plasma cell (pixel) has a controlled light emission depending on the required brightness of the image. As a result, the power consumption increases with a brighter image (high average picture level²⁷) and decreases with a darker image (low average picture level). Improving the panel's luminescence efficiency is an important measure for reducing power consumption and only achievable through further PDP technology development.

6.1.4.1. Advanced PDP luminescence efficiency

The Advanced PDP Development Center Corporation (APDC), a joint venture of the three Japanese PDP manufacturers Pioneer, Panasonic, and Hitachi, aims to develop plasma display panels with cell pitch of 0.1mm and average luminescence efficiency of 3 lm/W that corresponds to 0.3mm cell pitch and 10 lm/W. Current PDP-TV cell pitch is 0.3mm and up to 2 lm/W²⁸. For example APDC predicts that power consumption can be decreased to less than 70W with a 42" PDP when luminescence efficiency of 10 lm/W is materialized. APDC has demonstrated luminous efficiency of 5,7 lm/W at the CEBIT 2007 in Hannover, Germany (see Figure 3).

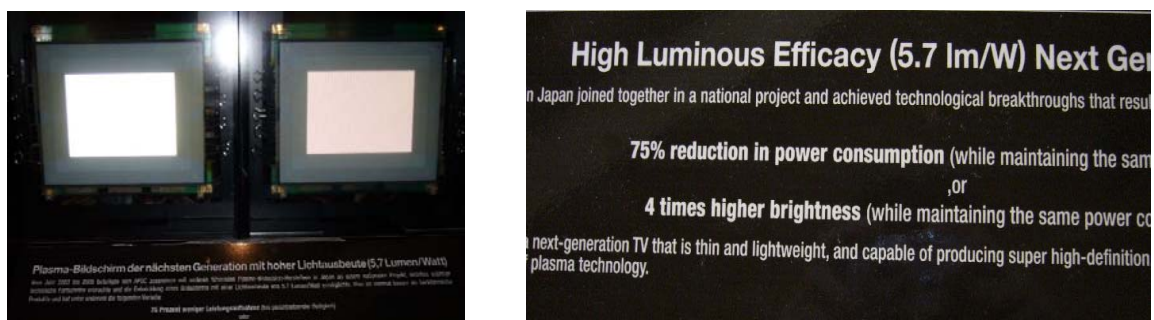


Figure 3: High luminous efficacy PDP at the CEBIT 2007

²⁷ Average Picture Level (APL) is the average luma (Y) level of the video input signal during active scanning time integrated over a frame period; defined as a percentage of the range between reference black and reference white level (Definition following draft version of revised IEC 62087 (2007-03-19)).

²⁸ Advanced PDP Development Center Corporation (APDC) was established in July 2003 to co-develop basic technology for advanced PDPs in league with five PDP companies: <http://www.advanced-pdp.jp/fpd/english.html#1> (02/2007)

The two Korean PDP manufacturers LG Electronics and Samsung SDI follow similar technology strategies to improve luminous efficiency. In the year 2005 SDI introduced the HEXA cell structure with a 30µm fine barrier rib that achieved a higher efficiency as a conventional panel design²⁹. The Pioneer Corporation has announced on 9 January 2007 the launch of breakthrough new plasma display technology including a Crystal Emissive Layer that the company believes will change the competitive landscape in the flat-screen television market. The new technology premieres a completely re-engineered infrastructure, including a new panel, filter, electronics and drive sequence. Pioneer's exclusive Crystal Emissive Layer is sandwiched between the plasma glass and the individual light cells. This advanced layer helps conduct energy more efficiently so that each cell can be charged and discharged three times faster than before. This technology enables Pioneer displays to emit more light and it also increases contrast. Finally, the Crystal Emissive layer improves luminance efficiency by 22 percent compared to previous models by lowering power consumption. Pioneer is the first in the industry to include Crystal Emissive layer technology.³⁰

From various discussions with major PDP manufacturers the following strategies regarding technological measures in conjunction with energy efficiency improvement can be drawn:

- Improvement of panel design and applied materials
- Improvement of drive sequence
- Improvement of drive voltage

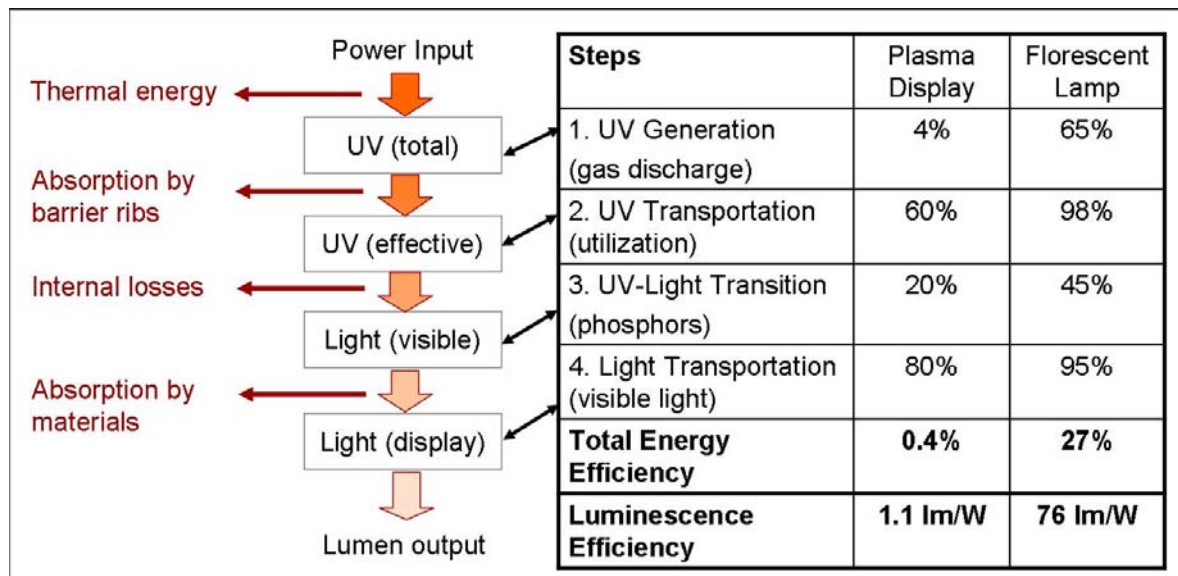


Figure 4: PDP luminescence efficiency analysis (Source: JEITA 2004)³¹

²⁹ Displaybank (2005): FPD International 2005, LCD and PDP Panel Company Trends (by Luke Koo)

³⁰ http://www.pioneerelectronics.com/pna/v3/pg/enhanced/article/0,,2076_310069717_283578751,00.html

³¹ http://it.jeita.or.jp/infosys/jeitakouza/kyouzai/waseda/05w_pdp_1.pdf (03/2007)

Figure 4 above shows an analysis of technical processes and resulting factors which determine the luminescence efficiency of PDP. The material was provided by industry with reference to a JEITA seminar on PDP from year 2003. The relatively low efficiency indicates already improvement strategies. According to major PDP manufacturers the general approaches to panel redesign are:

1. For better UV generation
 - a. improved gas composition
 - b. development of new MgO material for high secondary electron emission
2. For better UV transportation
 - a. development of new cell structures for better UV irradiation
3. For better UV-visible light transition
 - a. phosphor development and selection
 - b. better processing of phosphor
4. For better light transportation
 - a. improvement of aperture ratio
 - b. ultra fine barrier rib formation under 50 μ m
 - c. improved transparency
5. Improved driving scheme
 - a. Improved electrodes control method
 - b. New drive chip
6. Energy recovery circuitry for plasma panel
7. Lower drive voltage
 - a. reduction of driver power consumption by lower voltage, currently 80 ~ 200 V, active power control

The actual energy saving potential of these measures can not exactly be assessed. It will depend individually from the generation and utilization of higher luminescence efficiency (deriving from new technological solutions) as well as the connected power management trade-offs (deriving from set-making [cp. task 6.2]). The energy saving potential will also depend on the power measurement test procedure. As explained before, energy consumption of PDP is directly related to the dynamic change of the average picture level (APL). A dynamic power measurement procedure, which is drafted for the revised edition of IEC 62087, will provide the best base for measuring the “on (average) mode” power consumption of the PDP. The power consumption data that we have received from manufacturers for their latest PDP-TV products (BAT) indicate the magnitude of energy consumption improvement over the past years.

The data in the following Table 1 indicates the improvement potential in power consumption for the three main PDP screen size segments over the past two years. The power consumption values are best available products in the year 2005, 2006 and 2007. The values for the 2005 and 2006 products are taken from catalogue. They are slightly rounded due to the fact that it is unknown if there were even better performing products at that time. It was not possible to determine the test procedures for these data. We assume however that the values are not rated power consumption values but average on-mode values. The 2007 data have been received from EICTA member and have been tested based on JEITA standard.

Table 1: Power consumption of PDP Best Available Product in 2005, 2006 and 2007

PDP power consumption	37-inch	42-inch	50-inch
2005	300 W	330 W	430 W
2006	240 W	260 W	330 W
2007	191 W	204 W	257 W

The power consumption values in Table 1 indicate a considerable improvement for PDP. However, it is still not possible to determine exactly how much improvement is related to technological measures on the one hand and how much improvement might be related to the measurements procedure. We advise to make comprehensive measurements of TVs (all display technologies) as a first option with the new dynamic video signal under the revised IEC 62087 test standard or – as a second option – with the static 4-bar video signal (former JEITA standard which is integrated into the revised IEC 62087).

In order to indicate the power consumption improvement potential related to the increase of luminous efficiency we discussed the issue with leading PDP manufacturers and asked them to provide an estimate. We like to thank Hitachi, Panasonic and Pioneer for providing an estimate of the improvement potential of PDP. According to this estimate, the average on-mode power consumption of a current (HD-ready) 42" PDP-TV with a luminous efficiency of 1.8 lm/W is approximately 200 Watt. The three Japanese manufacturers expressed their opinion that luminous efficiency for HD-ready PDP could be technically increase to a level of 3 lm/W or (at an absolute maximum) to 5 lm/W by the year 2010. According to Figure 5 could a 42" HD-ready PDP-TV in standard mode (at APL 40%) consume approximately 150W with 3 lm/W technology and only 110 Watt with 5 lm/W technology. The power consumption of the receiver is dropping respectively with the improvement of the luminous efficiency. Further improvement potential derives from improved driver, power supply efficiency and power management. For general approaches see Task 6.2 on set-making.

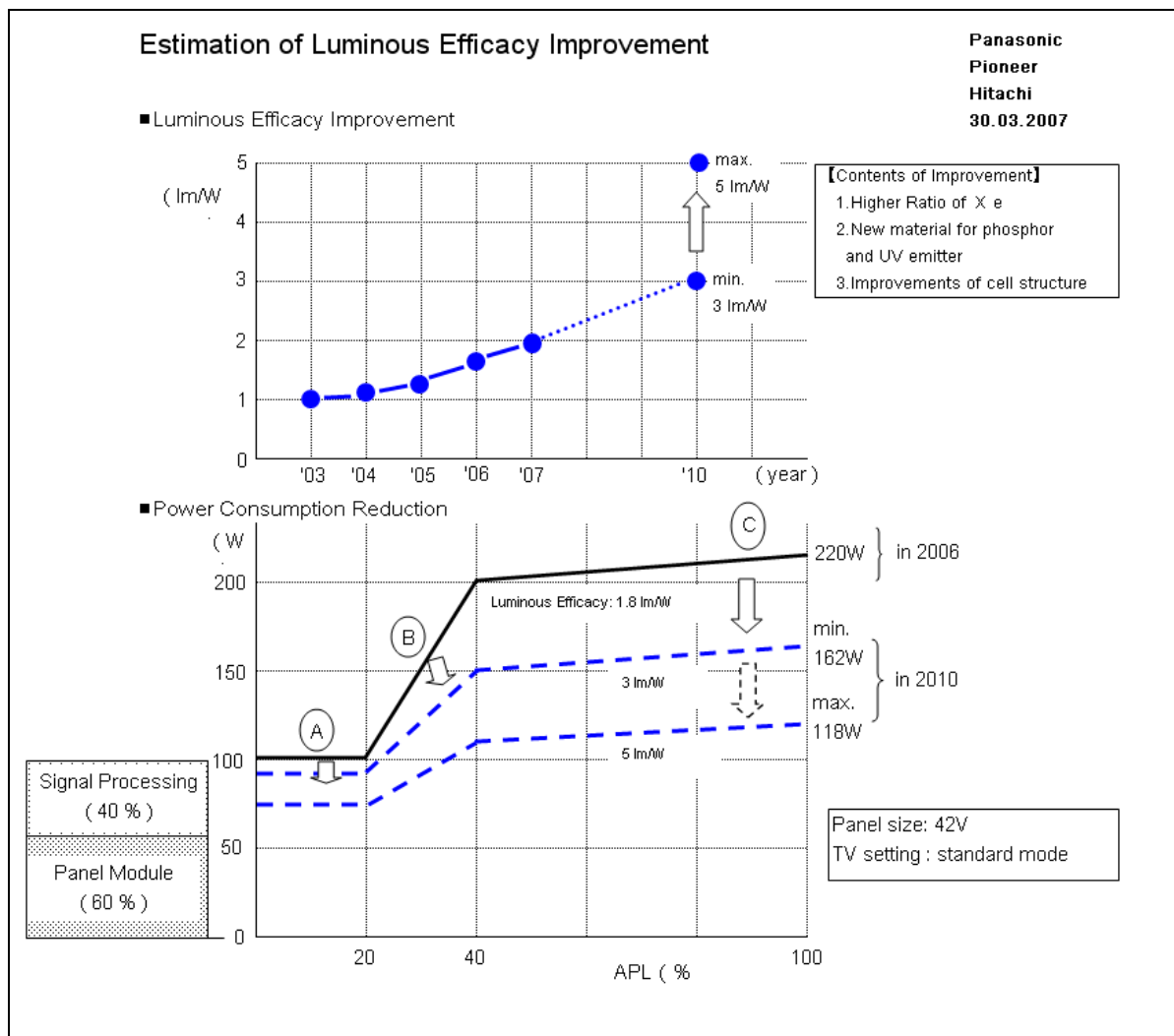


Figure 5: Estimation of luminous efficacy improvement for 42'' PDP

Following the stakeholder meeting on May 3rd 2007 a review of the provided data were suggested by the two Korean manufacturers LG Electronics and Samsung. Both companies stated their opinion that the provided assumptions on the improvement potential of luminous efficiency and related power consumption are to high. As a more realistic figure LG Electronics suggested 2 to 3 lm/W for HD-ready PDP-TV and considerably lower efficiency of full HD products. Furthermore, it was indicated that the integration of digital tuners, HDD as well as the enhancement of picture quality will result in increasing power consumption on the receiver side.

In conclusion, the improvement of luminescence efficiency still has the best potential for reducing the overall power consumption of PDP-TVs. However, the improvement estimates provided by Japanese PDP manufacturers have been critically reviewed. The PDP manufacturers agreed that it seems feasible that HD-ready TVs could achieve a luminous efficiency of up to 3 lm/W by the year 2010. It was also clearly stated that full HD TVs could not achieve 3 lm/W by the year 2010 due to

the fine cell structure that is required. The novelty of the full HD PDP technology makes it difficult to estimate the improvement potential. At the present moment full HD products would require considerably more power than similar HD-ready products.

6.1.4.2. Lead free PDP

In November 2006 the Panasonic Corporation of North America announced that they achieved a proprietary lead-free plasma display panel. Lead in PDP is current exempted from the RoHS Directive 2002/95/EC (see Task 1). Lead-oxide glass is used in the dielectric layer, electrodes, glass sealant and other structural elements, primarily because of its capability to stabilize production yield and quality. According to the press release Panasonic has eliminated all of the roughly 70 grams of lead used in a 37" PDP³².

³² Online News of Green Supply Line from 27 November 2006: <http://www.greensupplyline.com> (11/2006)

6.1.5. Slim Cathode Ray Tube (CRT)

CRT is the most mature TV-display technology with no significant improvement potential. One recent development by mainly Korean TV-maker are so called "slim CRTs," which have significantly lower depths than conventional CRTs. One 32-inch slim CRT, for example has a depth of about 35cm, as compared to a conventional 32-inch tube's depth of 50cm. This is a reduction of about 30 percent, and it puts it into a size category that is competitive with a microdisplay RP-TV of similar screen size, at a significantly lower price.³³ The reduction in CRT depth requires a commensurate increase in deflection angle, which in turn requires higher deflection currents to swing the electron beam over the wider angle. Higher currents cause greater heat buildup in deflection coils and their driving electronics. Traditional CRT deflection amplifiers are analog class AB amplifiers, but another innovation is the use of Class D amplification, which employs pulse width modulation rather than traditional analog amplification. Class D amplification significantly increases efficiency and reduces heat buildup in the amplifier circuitry.

Product examples: A new ultra slim 21" CRT-TV was introduced by LG Electronics with a deflection angle of 120 degree³⁴. Concerning power consumption limited information are available. For example the rated power consumption of the Samsung WS-32Z429T Slim Fit HD Ready CRT-TV is 160 Watt.³⁵ According to LG Electronics slim CRT-TVs are highly price competitive up to 32-inch TV market and expected to enter developing markets in Asia, the Middle East and Eastern Europe.

Improvement potential of slim CRT results from:

- Material weight reduction from smaller form factor
- Potentially lower power consumption due to Class D amplification

³³ Randy Hoffner article from 12.07.2005: http://www.tvtechnology.com/features/Tech-Corner/f_randy.shtml (02/2007)

³⁴ <http://www.gizmosinsight.com/2007/03/08/LG-brings-the-world-slimmest-CRT-TV.html> (03/2007)

³⁵ <http://www.sdsdigital.co.uk/Samsung-WS-32Z409T-Slim-Fit-HD-Ready-CRT-Television-pr-737.html>

6.1.6. Surface-conduction Electron-emitter Display (SED)

FED (field emissive display) is the effort to create a flat panel display based on the CRT principle. There are several companies in Japan, Korea, and the USA which hold patents in FED technology. SED (Surface-conduction Electron-emitter Display) a formerly joint development of Canon and Toshiba seems to be the most promising FED technology with commercial potential³⁶.

SED is a flat panel display technology that uses surface conduction electron emitters for every individual display pixel. The surface conduction electron emitter emits electrons that excite a phosphor coating on the display panel, the same basic concept found in traditional cathode ray tube (CRT) televisions. This means that SED can combine the slim form factor of LCDs with the high contrast ratios, refresh rates and overall better picture quality of CRTs³⁷. The surface conduction electron emitter apparatus consists of a thin slit across which electrons tunnel when excited by moderate voltages (tens of volts). When the electrons cross electric poles across the thin slit, some are scattered at the receiving pole and are accelerated toward the display surface by a large voltage gradient (tens of kV) between the display panel and the surface conduction electron emitter apparatus.

The SED technology has been developed by Canon since 1987³⁸. Although market introduction was announced continuously since 2005, the promising SED technology seems still not to be mature enough for mass TV manufacturing. According to a January 2007 press statement from Canon: “SED television sets are to be introduced in Japan in the fourth quarter of this year (2007) as originally scheduled, although Canon will reassess its future mass-production plans for SED panels”. SED panel prototypes (50” and 36”) have been showcased in the past with very good picture properties, small form factor, and low power consumption. These properties were observed during a visit of SED Inc. in June 2006³⁹. SED Inc. however did not provide technical specifications and power consumption data for the SED-TV prototypes at the present state of development.

³⁶ Canon Inc. and Toshiba Corporation announced an agreement by which Canon will purchase from Toshiba all of Toshiba's outstanding shares of SED Inc., which was jointly established by both companies. On completion of the purchase, SED Inc. will become a wholly owned subsidiary of Canon, effective January 29, 2007. Canon Press Release: <http://www.canon.com/press/2007/sed2007jan12.html> (02/2007)

³⁷ <http://www.sed-fernseher.eu/what-means-sed-tv> (03/2007)

³⁸ Ibid.

³⁹ During a demonstration at SED Corporation in Japan the author observed power consumption for a 36 Inch SED prototype panel in a range of 80 to 120 Watts while replaying a high definition video.

Improvement potential of SED results from:

- Potentially very low power consumption
- Good form and weight factor
- No known hazardous substances (except lead in glass frits)

Limiting factors:

- High yield technology/processes for mass-manufacturing seems not mature yet
- Highly competitive market situation (product costs/price pressure)

6.1.7. Organic Light Emitting Diodes (OLED)

OLED was first discovered by Kodak in 1987. Three years later, a research group at Cambridge University, UK, observed similar properties in conjugated polymers, consisting of long carbon chains with alternating single and double or triple bonds. Meanwhile, oligomers and dendrimers are also utilized as OLED materials⁴⁰. OLEDs are self-emissive, highly efficient displays with good optical properties. The OLED electrically excites fluorescent organic compounds to emit light, and performs voltage driving or current driving on a number of organic luminescent cells so as to display images. It has a structure in which a luminescent layer made of an organic compound is put between an anode and a cathode. The OLED for TV application is an active matrix-type, featuring two thin film transistors (TFTs). An OLED has advantages that visibility is high by self color development, an all-solid display superior in impact resistance is provided different from a liquid crystal display, a speed of response is high, little influence of a temperature change is exerted, and a visual field angle is large. In recent years, use as a light emitting device in an image display apparatus has been noticed. The OLED devices may be driven by low voltage direct current (DC), and have short microsecond response times. OLED devices have wide viewing angles and excellent contrast ratios because of their self-luminescence.⁴¹

However, for mid and large screen applications with long life time (in the case of television displays it is an average of 60.000 hours) technology development is reported to be problematic. Material deterioration and stability are two key issues in that respect. Even though the red and green LEDs have shown long lifetimes of 10,000 to 40,000 hours, the blue component suffered high failure rates after about 3,000 to 5,000 hours. With the current R&D focus on a refinement in

⁴⁰ German Flat Panel Display Forum (2004): European Technology Flat Panel Displays, 4th Edition.

⁴¹ Technical discription from: <http://www.electronics-manufacturers.com/info/monitors-and-displays/flat-panel-monitor.html>

material composition and manufacturing technology for blue LED, this limitation should be overcome soon. Another issue is sealing of the OLED. Without some way to seal the display in a waterproof outer covering the matrix can easily be damaged. These issues add to still high costs of the manufacturing processes⁴². Against that background market research institutions such as MEKO concluded that OLED-TVs will not appear in the market soon.

Somewhat surprising are recent developments indicating that OLED technology is likely to be introduced for small size TVs (under 27 inches). At the “2007 International CES”, the trade show of the Consumer Electronics Association on January 8-11 in Las Vegas, OLED prototypes were exhibited. A press statement at the JCN Newswire showed Sony a 27-inch OLED-TV with Full HD panel and an 11 Inch OLED-TV with wide-SVGA panel. The statement reads: “The prospect of mass production of the panels for smaller size OLED-TVs is close to being cleared, and development on the panel for middle / larger-sized is currently under development”⁴³. According to media report connected to the 2007 International CES it is assumed that Sony will mass produce small OLED-TVs by 2008⁴⁴. Seiko Epson developed with a 40-inch the so far largest full-colored OLED display with the help of conventional ink printing⁴⁵. Although these prototypes and press statements do not allow us to revise the previous conclusion that OLED-TVs are not “around the corner”, it indicates once again the dynamics of the TV display market.

Improvement potential of OLED-TVs results from:

- Potentially very low power consumption
- Potentially low weight and small factor
- Potentially efficient manufacturing processes

Limiting factors:

- High yield technology/processes for mass-manufacturing unclear
- Highly competitive market situation (product costs/price pressure)

⁴² Information on the prospect of OLED technology for television display application derives from talks with individual companies.

⁴³ http://www.japancorp.net/Article.Asp?Art_ID=13958 (03/2007)

⁴⁴ [http://www.golem.de/showhigh2.php?file=/0701/49819.html&wort\[\]=OLED](http://www.golem.de/showhigh2.php?file=/0701/49819.html&wort[]=OLED) (03/2007)

⁴⁵ <http://www.oled-display.net/amoled-oledtv.htm> (03/2007)

6.2. State-of-the art in TV-set making

6.2.1. Power Supply Efficiency

Most TVs feature an internal power supply unit (PSU) as the display or backlight – the main source of power consumption – requires up to couple of hundred Watts for operation. But also video signal processing, display driver, audio components and interfaces need in sum a considerable amount of energy. Power consumption however is not only related to the power draw of single components. The amount of required voltage levels and power conversion steps contribute significantly to the total power consumption due to conversion losses. An efficient PSU and improved power management can save a high amount of energy. The PSU has to be compliant with IEC 1000-3-2 Class D standard and therefore need an active Power Factor Correction (PFC) to limit the variation of the input voltage in front of the main PSU.

6.2.1.1. Reference Design for PSU η +80% and <1W Standby

As an example, On Semiconductor published in March 2006 the reference design documentation (TND316/D) for a built-in and tested GreenPoint™ solution for a 200W LCD-TV power supply with following specifications:

- Universal input voltage; $90V_{ac}$ to $265 V_{ac}$, 47 – 63 Hz
- Main power supply output voltage; 24V/6A, 12V/3A, 30V/1A
- Standby power supply output voltage; 5V/2A, $P_{in} < 1W$ when the consumption on the 5V is <80mA.
- PFC compliant with IEC 1000-3-2

According to the reference design performance summary the power supply efficiency for 230 V_{ac} is η 80% at 20% load and η 90% at 80% load. The standby power consumption for 230 Vac (U_{in}) and P_{load} 300mW is given with 800mW and for P_{load} 400mW is 900mW. Regarding the architecture selected for this reference design On Semiconductor makes the statement that “this reference design allows design optimization so that the desired performance is achieved without increasing the component costs and circuit complexity too much”⁴⁶. In conclusion, the reference design demonstrates a high efficient PSU solution and low standby.

⁴⁶ On Semiconductor TND316/D (reference design documentation package), page 9, March, 2006 – Rev 0.

6.2.1.2. Miniaturization and System Integration

Particular for medium and large flat panel display TV a high amount of power is required. Thermal management is an issue due to the small form factor of flat panel TVs. The utilization of fans is limited because they are audible. Large heat sinks made of aluminum or copper are expensive and add weight to the whole structure. A further aspect is electromagnetic interference (EMI). As the trend TV design incorporates more electronic components in order to improve functionality. High level of system integration becomes necessary. Higher system integration aiming on a reduction of board surface area and number of electronic components in conjunction with lower voltage and more efficient (low loss) power conversion is the key to improvement.

6.2.2. Housing Materials and Chassis Design

Eco-design measures regarding the housing and chassis of TVs are mostly material related. But also a reduced number of parts (e.g. screws), the methods for fastening components and easiness of assembly and disassembly are good measures to improve the eco-efficiency of a TV-set. In terms of housing and chassis materials there are following trends:

- Utilization of high-value plastics (e.g. PC/ABS which uses phosphorus flame retardants)⁴⁷
- Utilization of recycled plastics (e.g. PC/ABS which is readily recyclable)
- Utilization of renewable materials (bio-plastics and bio-paint)
- Use of chlorine and bromine-free flame retardants (today already mostly phosphor based).
- Substitution of multi-layered or painted plastics
- Substitution of chromium-based protective coatings



Halogen-free PE housing and bio-painted stand
(Eco-Products 2006, Tokyo, Japan)



Chromium-free back side and screws
(Eco-Products 2006, Tokyo, Japan)

Figure 6: Examples of BAT in housing materials

6.2.2.1. Trend towards bio-plastics

Research is under way to develop plastics that use plants (bio) as feedstock. Engineering versions of these bio-plastics are hybrids of oil- and plant-based feedstock preserve property benefits of existing polymers such as PBT or nylon in order to maintain stiffness, durability and other

⁴⁷ Stakeholder commentary added. Dr. David Harrison of Bayer Material Science (25 April 2007): "A change relates to your inclusion of ABS as a high value plastic. Unfortunately, phosphorus flame retardants cannot be used with ABS, and instead brominated flame retardants are usually used. For this reason, we would propose using PC/ABS blend (polycarbonate/ABS) as an example of a high value plastic which uses phosphorus flame retardants and is readily recyclable."

properties needed for technical applications, and actually provide some improvements, particularly in surface finish. Bio-plastics for consumer electronics are usually based on modified polylactic acid (PLA) or corn starch. An example for TV application is not known. However, bio-plastics have a considerable improvement potential as the following example of Fujitsu shows. According to a recent article at the design news for mechanical and design engineers, one metric ton of bio-plastics generates between 0.8 and 3.2 fewer metric tons of carbon dioxide than one metric ton of petroleum-based plastics⁴⁸.

Fujitsu Push Bioplastics

Design News: [http://designnews.com/article/CA6426809.html?nid=2334&rid=\(03/2007\)](http://designnews.com/article/CA6426809.html?nid=2334&rid=(03/2007))

One of the leading players is Fujitsu, which is using a PLA hybrid developed by Toray Industries to make the housing for its FMV-BIBLO notebook PC series Introduced two years ago. The Toray material, called Ecodear, is aimed at fibers, textiles, molded parts and films. Fujitsu and Toray first attacked the problem in 2002 with a pure PLA. The material, however, lacked adequate flame retardance and was not moldable because of its low temperature resistance. They decided to combine PLA (50 percent) with a proprietary amorphous oil-based plastic to achieve the required properties. Toray is now bringing on line a \$9-million plant in South Korea to produce PLA. Annual capacity is 5,000 metric tons a year. Korean packaging converter Saehan is a 10 percent investor. Packaging in South Korea is now being rapidly converted to biodegradable PLA, a trend still in its nascent stage in the United States. Toray is also developing nano additives to use in PLA film. One interesting note: until recently PLA was only used because it is biodegradable. The Fujitsu hybrid material is not biodegradable. In fact, Fujitsu does not want the notebooks placed in landfills, where toxic metals could cause pollution. The goal is to increase recycling of the plastic components. Just recently, Fujitsu announced another turn. The company is now developing with French chemical producer Arkema a bioplastic based on castor oil that provides more flexibility than can be achieved with corn-derived plastics. The goal is to expand use of bioplastics in notebook computers. Castor oil is used because it is a source of nylon (polyamide) 11. A Fujitsu spokesman commented: "By weakening the interaction of the chain molecule in PA-11 and relaxing the stereoregularity of their organization, the resulting new material has sufficient flexibility to withstand repeated bending without causing the whitening that often occurs when such materials are strained." Prototypes of PC cover components consist of 60-80 percent of the new bioplastic, an unparalleled achievement to date. High-density fillers are added to increase strength. Fujitsu's goal is to use the materials for notebook covers, and other applications requiring high impact resistance. Fujitsu also hopes to begin using the material in mobile phone covers too. The new material cuts carbon dioxide emissions 42 percent compared to oil-based nylon 6/6, according to Thomas Grimaud, Arkema's technical polymers business manager.

⁴⁸ Doug Smock, Design News 3/22/2007 6:38:00 AM: Toyota, Sony, Fujitsu Push Bioplastics; in the Internet: [http://designnews.com/article/CA6426809.html?nid=2334&rid=\(03/2007\)](http://designnews.com/article/CA6426809.html?nid=2334&rid=(03/2007))

6.3. State-of-the art in TV power consumption

6.3.1. Standard On-Mode Power Consumption

BAT for on-mode power consumption is difficult to determine due to the variety of benchmark criteria and measurement methods (standards) that could be applied. The on-mode power consumption is directly related to the pictures brightness and quality (e.g. color gamut, motion blur, contrast). Furthermore increase integrated features such as additional tuners, picture improvement, and video recording technologies the power consumption. The differences in power consumption measurement standards also contribute to the resulting values. The rated power consumption does not reflect real use. Therefore standard on-mode power consumption as it is newly defined by IEC 62087 applies much better. But at this moment there are only few comparable BAT values available. Table 2 provides a compilation of best available TVs with a distinction by technology and screen size as well as values from different sources for comparison. As a reference value we use the average power consumption per segment based on 2006 HD-ready TV catalogue values.

Table 2: Best available products regarding power consumption

Technology	Size	26/27"	32/33"	36/37"	42/43"	50/52"
CRT-TV	Average CRT	100 W	130 W			
EcoTopTen 2006 (DE)		84 W	94 W	xx	xx	xx
MPT Testing 2006 (UK)		xx	xx	xx	xx	xx
METI TopRunner 2006 (JP)		xx	xx	xx	xx	xx
EICTA Member 2007 (EU)		xx	78 W	xx	xx	xx
Company Catalogue 2006 (EU)		65 W	100 W	xx	xx	xx
LCD-TV	Average LCD	120 W	150 W	180 W	220 W	275 W
EcoTopTen 2006 (DE)		70 W	85W/ 124W	159 W	xx	xx
MPT Testing 2006 (UK)		xx	112 W	xx	xx	xx
METI TopRunner 2006 (JP)		105 W	104 W	160 W	246 W	322 W
EICTA Member 2007 (EU)		104 W	109 W	168 W	203 W	280 W
Company Catalogue 2006 (EU)		70 W	85 W	100 W	140 W	230 W
PDP-TV	Average PDP			250 W	330 W	410 W
EcoTopTen 2006 (DE)		xx	xx	xx	240 W	xx
MPT Testing 2006 (UK)		xx	xx	xx	285 W	xx
METI TopRunner 2006 (JP)		xx	xx	270 W	288 W	343 W
EICTA Member 2007 (EU)		xx	xx	191 W	204 W	281 W
Company Catalogue 2006 (EU)		xx	xx	241 W	251 W	257 W
RP-TV	Average RP				175 W	190 W
EcoTopTen 2006 (DE)		xx	xx	xx	xx	xx
MPT Testing 2006 (UK)		xx	xx	xx	xx	173 W
METI TopRunner 2006 (JP)		xx	xx	xx	xx	xx
EICTA Member 2007 (EU)		xx	xx	xx	xx	xx
Company Catalogue 2006 (EU)		xx	xx	xx	175 W	175 W

6.3.2. Standby Mode Power Consumption

6.3.2.1. Passive Standby

BAT regarding low standby power under 1 Watt are in the market already. Existing products from brand name manufacturers show that passive standby functions (timer, remote control, soft switch and network activation) can be accomplished with less than 1 Watt. According to our own compilation of power consumption data for 274 HD-ready TVs from product catalogues of the year 2006, over 30% of the devices had 1W standby power or less. Panasonic is currently promoting 300mW standby power for their 2006 products⁴⁹. Philips aims to lower standby below 200mW in televisions by 2008⁵⁰. A passive standby of 100mW for TVs was reported for the CRT-TV prototype that has been designed in the German “Green TV project” in the late 1990s. Mr. Siderius of SenterNovem confirmed this information at the stakeholder meeting on 3 May 2007 in Brussels.

6.3.2.2. Active Standby low

BAT regarding active standby low was provided by Loewe AG (Germany) in a statement form 27 April 2007 addressed to the authors of this report. According to this statement has Loewe AG achieved a power consumption in standby-active-low of only about 1,8 Watt in spite of the additional functions and the integrated Sat-Receiver, DVB-Tuner and Hard Disk Recorder. Loewe confirmed that a further reduction would be technically possible although: “from the actual point of view a value of 0,7 Watt (meaning < 1 Watt) is hard to reach with a high development expenditure and with a reduction of function for the user. A value of < 1 Watt means also a concept revision but can be reached within a period of 2 years a BNAT.

6.3.2.3. Active Standby high

BAT for active standby high can not be provided due to uncertainties regarding the functional spectrum which is covered by this mode. Stakeholder comments however indicated that channel, program and software updates require approximately 20 Watts.

⁴⁹ This information was given at a meeting with Panasonic on March 19th 2007.

⁵⁰ Philips Sustainability Report 2006, page 19.