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Technical background and design options to raise energy efficiency and reduce the environmental impact of TVs

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1 Introduction and overview of design options

Many design options have been identified to increase energy efficiency and to reduce the environmental impact of TVs

The environmental impact of TVs is mainly caused by their electricity consumption during operation time. Because the current worldwide development is tending towards LCD (Liquid Crystal Display) TVs, further design options usually refer to this type of television sets. Several technical design options for increasing energy efficiency of LCD TVs already exist. Most of them are well known and their positive effect on electricity consumption is beyond question. While many of those technical design options have been implemented in most recent LCD TVs, a systematic and worldwide approach to create a super-efficient appliance is still missing.

Cost is one reason. The purchase price of an extremely energy efficient TV can be too high to be offset by future electricity cost savings. Nevertheless, all energy saving design options - independent of costs - are presented here, as costs are relative and can possibly be lowered in the future through economies of scale.

The main measures to improve the energy efficiency of LCD TVs are targeting the following issues:

- More efficient backlight sources
- Improved combinations of optical films
- Increased panel transmittance
- Efficient power supply units
- Power management schemes

2 Basic design options

The following table with focus on LCDs presents an overview of the most important technical design options as well as estimations of savings and price effects.

Table 1: Efficiency improvement options in LCD TVs

Components	Expected improvement options	Cost / Effect on efficiency / Availability
Backlight Source	CCFL (Cold cathode fluorescent lamp) to LED (Light Emitting Diode)	Cost increase, but adopted anyway by manufacturers due to improved picture quality and the possibility to built thinner displays
	High LED efficacy	Short term: Technical barrier in thermal management of LEDs and displays as well as cost increase by adoption of higher efficiency LEDs Long term: Higher efficiency and overall cost reduction for manufacturers
Optical films	Optimized combination of films, Multi-function film, e.g. prism + diffuser (micro-lens film)	Higher efficiency, but trade-offs in material cost and complexity of the manufacturing process
	Reflective polarizer	Cost increase, frequently proprietary technology by only few manufacturers
LCD Panel	Improvement in panel transmittance by optimizing pixel design and functional layers (polarizers, colour filters, data lines)	Frequently proprietary technology by only few manufacturers, R&D investment required but development is driven by total cost reduction of the manufacturing process
Power management	Backlight dimming in relation to picture content, i.e. black colours	Cost increase. The saving effect varies depending on the respective backlight structure, input images, and image processing algorithm
	Backlight dimming in relation to ambient light, i.e., Auto Brightness Control (ABC)	Cost increase. The saving effect varies with manufacturer default settings and ambient light levels
Other	Power Supply Unit (PSU) Efficiency	Minor trade-off between cost and efficiency. Therefore this option is already implemented in most TVs
	Colour gamut (by colour filter or light source)	Trade off with efficiency

Source: Further developed, based on LBNL (2013A)

Technical efficiency options which also lead to improvements of other product characteristics desired by consumers are more likely to be adopted on their own without additional policy intervention compared to options which predominantly 'only' improve efficiency. For example, LED backlighting leads to thinner and lighter TVs as well as to an improved picture quality. High efficiency LCD panels require less optical films or backlight lamps what leads to a reduction of overall costs (LBNL 2013A). This sensitivity regarding incremental costs is primarily due to the smaller additional electricity costs saving potential per unit compared to other appliances. The following sections discuss the most relevant specific technological design options for LCD TV efficiency improvement.

2.1 Backlight Source

LEDs have already superseded CCFLs as the dominant LCD TV backlights on most markets worldwide. LED-LCD TVs are typically more efficient than CCFL-LCD TVs because LED efficacy (e.g., 50-70 lm/W in 2010) is higher than CCFL efficacy (e.g., 30-50 lm/W). Additionally, LEDs have much better dimming capabilities compared to CCFLs. Even based on 2010 data for ENERGY STAR qualified TVs, on average LED-LCD TVs were 20 to 30 % more efficient than similar CCFL-LCD TVs (LBNL 2013A). As TV manufacturers receive additional benefits from LED backlighting, such as better colour reproduction capability, a mercury free display, and thinner/lighter panels resulting also in reduced logistics costs, a large transition from CCFL to LED backlight is taking place even under a 'business as usual' assumption.

2.2 LED Efficacy

The LED backlight efficiency will improve as a result of research and development with focus on higher LED efficacy (expressed as lumens per watt or lm/W), optimized LED structures, and an improved LED thermal management. Higher LED efficacy results in less LEDs needed to illuminate a LCD TV and therefore material cost reductions are also possible for manufacturers. The average LED efficacy for TVs in 2010 was 50-70 lm/W and is expected to increase to more than 150 lm/W in the near future. Driven by this efficiency improvement, the average number of LED packages used for a 32-inch LCD TV is expected to decrease by 42 % in 2012, compared to 2010 (LBNL 2013A).

2.3 Optical Films

By improving the amount of light that can pass through the optical films without negatively affecting the essential functionality of the films (i.e. light uniformity of the panel), the amount of needed backlight and therefore electricity consumption of LCD TVs can be reduced. Generally, a typical LCD backlight requires a reflective polarizer, prism film(s), diffuser(s), and a light guide panel (LGP) or diffuser plate. For this purpose, optical films have been combined as stacks of layers in many different ways in order to reduce material costs as well as to increase efficiency. Especially advanced reflective polarizers are considered as an option for additional efficiency improvements in optical films, resulting in 20 to 30 % efficiency improvement in LCD TVs (Fraunhofer IZM 2007, LBNL 2013A).

2.4 High Panel Transmittance

The average transmittance of LCD TV panels currently available on the market is between 5 and 6 %, and the highest achievable panel transmittance in 2013 was between 6 and 7 % (LBNL 2013A). If panel transmittance can be improved, the same target luminance of display panels can be achieved at reduced costs by using less expensive (and less transmissive) optical films and/or by using fewer backlight LEDs. Therefore, manufacturers have a strong intrinsic incentive to improve panel transmittance. One example of this recent technology trend in panel efficiency improvement is the development of low-voltage driven panels. Low-voltage driven LC materials would allow manufacturers to use narrower low-resistance data lines, i.e., high cell aperture ratio, than can currently be used. Aluminium (Al) is now being used for data lines and could be replaced with copper (Cu). Depending on development of the LC cell structure, the average panel transmittance is expected to increase to 7 to 10 % until 2015 (LBNL 2013A).

2.5 Power Management

2.5.1 Backlight Dimming

Since an LCD is a non-emissive display type, blocking the polarized light through adjusting the LC orientation for the respective pixels is the method to show dark parts (e.g. the colour 'black') of the picture. In this case, in conventional displays the LCD backlight is still activated and - without other additional saving measures - consumes an unchanged amount of energy. Dimming the backlight behind the dark parts of the screen consequently reduces this unnecessary electricity consumption and improves at the same time the reproduction of the colour black.

The simplest dimming option is to dim the whole backlight by a universal factor in each frame, which is called zero-dimensional (0D or 'complete' / 'global') dimming. This option can be applied to all types of backlights. Backlight dimming in relation to the ambient light conditions, i.e., auto-brightness control (ABC), can be a part of this method. Currently, most low-end products include either no dimming option at all or only a 0D dimming. More advanced dimming methods are usually still limited to middle class and high-end products.

One advanced option is to dim parts of the backlight area depending on the specific characteristics of the input image, either by one-dimensional (1D, partial or line dimming) or by two-dimensional (2D or local dimming) dimming. For 2D dimming, LED-direct backlights are required, in order to regulate every pixel separately. While local dimming of LED-direct backlights will be more effective in reducing relative power consumption than partial dimming of LED-edge backlights, current LED-edge backlight displays are basically more efficient than those with LED-direct backlights because of the less complex structure and the smaller number of required LEDs.

In addition, due to the more cost-efficient production, LED-edge backlights are expected to dominate the LCD TV market for the next years. As the effect of dimming methods varies depending on input images, dimming algorithms, and backlight structures, the actual effectiveness of different dimming systems may vary significantly (LNBL 2013A).

2.5.2 Auto Brightness Control (ABC)

In general, the energy consumption of LCDs is proportional to their luminance. An integrated ABC system enables a TV to adjust its brightness level automatically in accordance to the requirements of the actual room ambient light levels. Although, the effect of ABC varies between different manufacturers and their respective technical approaches, the average on-mode power consumption can be reduced by 22 % with activated ABC compared to the operation with ABC function disabled. The reported range of overall savings is between 4 and 36 % (LBNL 2013A, based on ENERGY STAR 2011a, ICF 2011).

2.5.3 Occupancy Sensors

Additionally to ABC, occupancy sensors can help save further energy by preventing TVs from being left on when people leave the room or fall asleep (LBNL 2013A). However, the actual energy saving potential of this option is highly user dependent and therefore hard to predict.

2.6 Basic design options: Summary

Many of the presented basic design options to improve energy efficiency of LCD TVs can and therefore will be cost-effectively integrated in all types of new LCD TVs in the near future even in a ‘business as usual’ scenario. Other not directly cost-effective design option will be integrated anyway due to their outstanding capability to improve significantly the attractiveness of TVs for consumers, e.g. by allowing better picture quality or even thinner displays. However, some of the efficiency options will not be applied in the near future without policy intervention. Especially for low-cost small and/or entry-level TVs it is very unlikely that e.g. reflective polarizers and advanced dimming technologies, which could reduce the electricity consumption of LCD TVs by 20 to 40 %, will be adopted (LBNL 2013A).

3 Further design options

3.1 Further design options for LCD TVs

3.1.1 Three dimensional (3D) displays

The current LCD-based types of three dimensional (3D) displays use static filtering through polarised glasses, polarised screen filters or they use active shuttering through glasses to produce the sequential left and right eye images required for 3D viewing. Polarised imaging introduces a luminance loss of around 40 % of the basic pre-polarisation display luminance, whereas shuttered glasses lose approximately 60 % of the display luminance. Thus, to reproduce 3D experience for consumers, both technological approaches require displays to be operated at much higher brightness levels compared to normal 2D viewing conditions in order to compensate brightness losses from filters or shutters. Consequently, the screens require a significant additional amount of energy compared to 2D TVs or to 2D operation mode. Although the additional energy consumption in 3D mode may differ between different 3D technologies and manufacturers and there is no standardised test method for 3D modes to date, the increase is assumed to be about 30 to 40 % compared to 2D mode operation. Thereby, display luminance is by far the major driver compared to other factors. Other aspects, such as e.g. the additional processing power required for converting basic video data into 3D data amount to less than 1 % of the extra energy consumption of the display (EC 2013A).

Regarding the actual viewing time allocated by the consumer to 3D content for the purposes of energy and regulation metrics, there is some uncertainty. Generally, the growth of 3D content and the use of 3D enabled TVs have been much slower than originally projected. Although new TVs are gradually more and more equipped with 3D capability, most of these units are still and primarily used for 2D viewing. Consequently, as long as being only an “on-demand” add-on function, the negative effects on energy consumption of TVs is limited. However, this may change in the future, especially as soon as new 3D display technologies, which do not require viewing glasses, will be more fully developed and available (EC 2013A). Therefore, new test standards are intended to address this issue more in detail in the future.

3.1.2 Internet-connected televisions

TVs are becoming more and more networked products, offering consumers increasingly the opportunity to browse the Internet, to check email or social networking sites as well as to watch TV programmes and supplemental content directly via the Internet. In order to provide these additional functions, televisions require new or enhanced hardware. According to estimations by LBNL (2011A) the energy consumption of such ‘smart’ or ‘networked’ TVs is assumed be about 10 % higher in the drive circuit compared to conventional TVs. This is however heavily depending on the average picture level (APL) of web content, the power management in networked standby mode and the potential trend to even larger or wider screens e.g. for picture-in-picture viewing.

Consequently, the use of low-power system on a chip (SoC) configurations, better power management schemes and the presentation of web content with the same APL as normal TV broadcast material are appropriate and already existing design options to tackle these efficiency issues.

The global market for networked TVs is expected to grow from 44 million units sold worldwide in 2010 to 123 million units or rather 43 % of the global television market in 2014 (EC 2013A). Hence, in order to encourage manufacturers to use low power hardware and advanced power management schemes, it is most important that specific requirements for the energy consumption of these connected TVs will be included in upcoming energy regulations.

3.2 Alternative Flat Panel Display Technologies

3.2.1 Organic Light Emitting Diodes (OLED)

Organic Light Emitting Diode (OLED) displays represent a promising and fast emerging flat screen technology, which is an emissive technology[1] similar to plasma but which uses LEDs instead of fluorescent lights in each pixel. Currently, OLED TVs can predominantly be found as large screens in the premium product market segment, but this is expected to change as the technology matures (CLASP 2011A). OLED displays offer a very fast frame rate capability, which can match or surpass the frame rates of PDP (High frame rates are required for 3D displays and any display required to resolve high definition fast moving images). Global shipments of OLED TVs are expected to reach 2.7 million units in 2015 compared to 260 million LED-LCD televisions. Based on industry information, OLED displays are expected to become price competitive with LED edge lit LCD by 2016 at the earliest (EC 2013A).

3.2.2 Field Effect / Surface-conduction Electron-emitter Displays

The so-called ‘Field Effect Displays’ and the very similar ‘Surface-conduction Electron-emitter Displays (SED)’ represent other potential flat screen TV display technologies. These technologies operate essentially on the same principle as traditional cathode ray tube TVs, but instead of a central electron gun, each pixel effectively has its own dedicated solid-state electron emitter in order to generate the picture. ‘Field Effect’ and ‘Surface-conduction Electron-emitter Displays (SED)’ are basically considered as well suited to create large low energy displays (CLASP 2011A). However, a final product still has to be developed into a marketable commodity and at the same time other alternatives (especially OLED) already have entered the market. Therefore, a future market introduction is still possible within the next few years, although not very likely considering the prevailing market conditions.

[1] No backlight source is required as the light is directly emitted by each pixel

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