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Research article

Liquid Crystal Display: Environment & Technology

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Abstract

Liquid Crystal Display (LCD) technology has rapidly become a significant component of modern electronics. It offers solution to the rising need of low power-consuming, space-saving and better display devices thereby, paving the way for significant economic opportunities. However, the environmental impact of the end of life of the LCD products should be judiciously assessed, so that they do not become a hazard in near future. In this paper an assessment has been done to analyze the environment impact of the LCD technology. The materials used in production, manufacturing, subassemblies and composition itself have been found hazardous in nature. The recycling methods for Cathode Ray Tube (CRT), a predecessor of LCD are well established; however those of LCDs are as yet to be explored in right earnest. Two principle components of LCD i.e. mercury and liquid crystals are very difficult to biodegrade. With the increased application of LCD technology the sizeable aggregation of hazardous components has put up a question mark on the long term use of this technology especially in developing economies. Modern conscious society is keen to know that how much the product is polluting the air and soil during its production or in use or after disposal. The cost of certain design and process change in manufacturing for green product might however be costing substantially in some cases. Thus, conscious review of chemical and functional aspects of LCD with other display technologies can lay the foundation to develop a balanced perspective meeting the twin needs and requirements of economic viability as well as environmental concerns for generations.

Keywords: Liquid crystal display, environment friendly design,

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1. Introduction

Liquid Crystal Display (LCD) has given a new demarcation to the display devices. The liquid crystals are used to display image in thin, light computer. LCD screens are used in most laptop computers as well as in flat panel monitors. It has replaced conventional cathode ray tube (CRT) monitors. The CRTs were preferred for their superior colour presentation by graphics and photography professionals. The constant improvements in LCDs technology have, however, made the performance nearly comparable and the differences less noticeable.

LCD panels are transmissive and could not emit light on their own and therefore require backlights to generate colours on LCD screen. Backlight structure is different in various applications. Edge type backlights are used for notebooks and monitors, whereas, direct types are used for LCD TVs. Light sources used in backlight are also various, which include cold cathode fluorescent lamp (CCFL), external electrode fluorescent lamp (EEFL), hot cathode fluorescent lamp (HCFL), flat fluorescent lamp (FFL) and light emitting diode (LED). CCFLs, employed in backlighting units (BLU) of LCD, have many drawbacks including high power consumption, using mercury to create vapor discharges etc. In tube based technology, CCFLs are usually susceptible to failures. The space occupied by CCFLs also constrains in slimming down the thickness of the LCD panel [1].

LCD monitors are apparently projected as environmental friendly, energy efficient in comparison to lead subjugated CRT models. However, LCD displays fail to reduce the impacts of mercury and arsenic which have serious concerns to environment and human health. Mercury is hazardous and requires special mandatory disposal mechanism in various countries. During manufacturing of LCD panels, the gases such as NF3, SF6 and SiH4 etc, are used, which are hazardous in nature. It is, however, inexpensive for manufacturer to use these gases which produce more emissions. The emphasis should be laid to design the products in such a way that any toxic materials or chemicals for any process should not be used as ingredients and also, it should not leach precarious substances after end-of-life [2], [3].

2. How Does Liquid Crystal Display Operate?

Light, a transverse wave, vibrates in a plane perpendicular to the direction of propagation. Direction of plane of vibration is random for normal light (i.e. un-polarized). When the un-polarized light passes through the polarizer, the plane of vibration of all light waves become perpendicular to the direction of propagation. In LCD, liquid crystal is sandwiched between two crossed polarizer's. When molecules lie perpendicular to the plane of the polarizer, i.e. along the direction of the light ray, polarization does not take place and the crossed polarizer does not allow light to pass and as a result the cell appears black. When the molecules are parallel to the plane of the polarizer, i.e. along the direction of light vibrating plane, polarization takes place[4], [5].

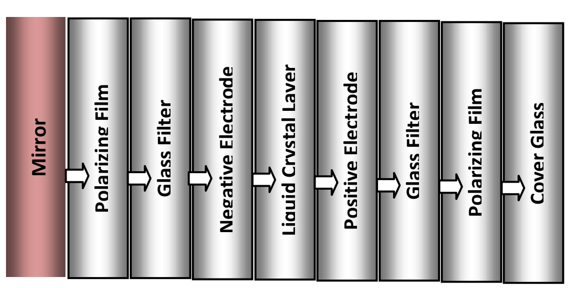

Fig. 1. Working of Liquid Crystal Display

Liquid crystal (LC) exhibits both the properties of liquid and solid states. All the molecules in LC tend to align in the same specific direction, which enables them to flow as a liquid. LC are affected by electrical current and can exist in several distinct phases with varying temperature. LCD technology uses one of such phase, viz. 'nematic phase', where the molecules have no spatial order. Twisted nematics (TN) one of the particular types of nematic phase used in LCD. TN can untwist to varying degrees on application of electric current based on their reaction to electric current the passage of light can be controlled [6].

In TN display, the light vibration follows the twist from one polarizer to the other, so that all light passes the cell, without being absorbed, in spite of the polarizer's are crossed. Thus the cell appears to be bright. LC's are sensitive to electric field, which forces to arrange the molecules parallel to the field. The twist is destroyed with the applied voltage across the LC cell, and forces the molecules along the light direction without affecting the polarization of light. All light is now absorbed by the crossed polarizer's and the cell appears black subjected to the electric field. LC display contains a large number of individual picture elements (pixels) and a matrix of squares is created locally to control the state of the twist in their respective area.

The Table 1 and 2 provides the components used in the LCD, their chemical composition and typical weight.

Table 1. Major Constituents of LCD Display

Constituents	**Major Components**
TFT array	• Glass substrates, • Gases, • Sputter Targets, • Photo resist, Developer • Photo Masks
Module assembly	• Backlight unit, light emitting diode, CCFL, brightness enhancing film (BEF), dual brightness enhancing film (DBEF), reflector films, diffuser film, TFT driver ICs, backlight inverter, tab tape, and ACF
Cell assembly sections	• Color Filter, Alignment Layer, Liquid Crystal, Sealant, Spacers, Polarizer's, Viewing Angle Film and TAC.

Table 2. Major Chemicals Used in LCD Display

TFT Contains	**Chemicals used**
Gate electrode and source/drain electrode:	• Refractory metals (Ta, Cr, Mo, W), Ti, Cu, Al, Al alloys, Ta-Mo, Mo-W, Cr-Ni, Ti-Mo, Mo-Al, Ti-Al-Ti, other dual or triple layers
Gate insulator (dielectric)	• SiN, SiO, SiNx, SiO2, SiOxNy, Si3N4, Ta2O5, Al2O3, dual dielectrics
Semiconductor	• a-Si:H
Ohmic contact	• n+ a-Si:H
Passivation layer	• SiN, Polymer overcoat

Conductive electrode	• Indium tin-oxide
Color Filter (Cell assembly) Contains	
Black matrix	• Cr, Ni, black polymer resin, black chrome (Cr/CrO or Cr/CrO2), Fe/FeOx, Mo/MoOx
Color filter colorants	• Dyes or pigments
Photopolymers/binders	• Gelatin, casein, acrylic, polyimide, polyvinyl alcohol, epoxy, melamine, polyester
Overcoat layer	• Transparent acryl resin, polyimide resin or polyurethane resin
Conductive electrode	• Indium tin-oxide

The sealed liquid crystal matrix between two glass plates is connected with polymers in LCD. The composition of LC includes a bicyclohexyl compound (35-50% by weight), a cyclohexyl phenyl compound (15-25% by weight), a bicyclohexyl phenyl compound (20-25% by weight), and a cyclohexyl biphenyl compound 15-20% by weight). A single LC compound does not satisfy the various requirements of the displays, so, compound mixtures are generally used to optimize the physical and chemical properties for specific applications. LC mixtures in a typical LCD usually contain about 10 - 25 compounds, with several thousands of mixtures in use which differ in their chemical properties of alkyl or alkoxy side chains.

The backlight unit (BLU) major constituent of LCD contains hazardous mercury to operate. The BLU has light source, reflector, light guide plate, and diffuser. Several technologies are used in backlight units, e.g. electroluminescent, light emitting diode, and cold cathode fluorescent lamps. The light source is a fluorescent tube because it offers low power consumption and very bright white light. The reflector is usually a polymer film with a thickness of 25 µm coated with Ag or Ag-alloys with a thickness of 150 nm. The polymer film is made of PET (polyethylene terephthalate), and contains UV-ray absorbing agents to prevent UV-ray originating degradation. PET polyester is formed from ethylene glycol (EG) and terephthalic acid (TPA) and they may leach chemicals into the water (such as the potentially toxic material antimony) when stored in hot or warm temperatures.

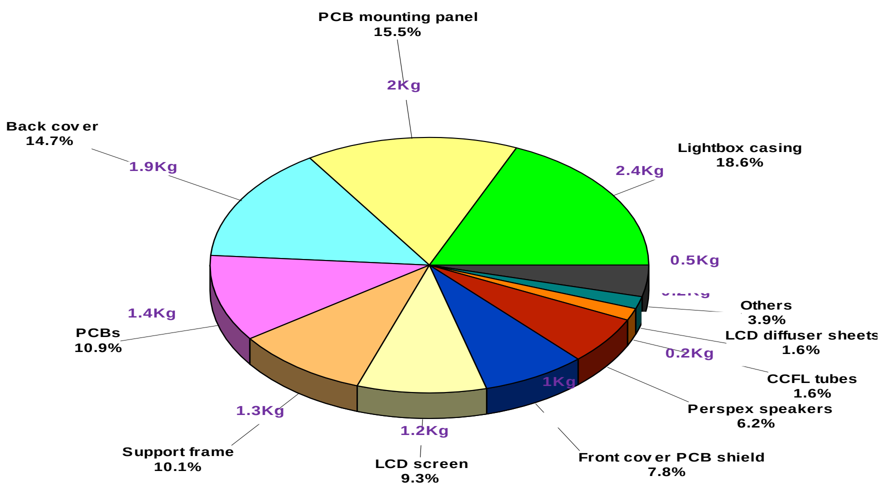

Fig 2 Weight % of key components of the LCD

The Fig. 2 shows the weight percentage distribution of key components of LCD. LCDs are relatively ineffective in terms of power use per display size; because of the vast majority of light that is being produced at the back of the screen is blocked before it reaches the viewer. To start with, the rear polarizer filters out over half of the original un-polarized light. A significant portion of the screen area is covered by the cell structure around the shutters, which removes another portion. After that, each sub-pixel's color filter removes the majority of what is left to leave only the desired color. Finally, to control the color and luminance of a pixel as a whole, the light has to be further absorbed in the shutters.

The backlighting system must be extremely powerful for these multiple transmission. Highly efficient CCFLs also require several hundred watts of power, and maximum of this power would be required to light an entire house. As a result, LCD televisions usages similar overall power compare to a CRT of the same size.

3. LCD Market

a. Global

LCD is becoming the dominant display technology in global scenario, mainly due to their application ability which includes adequate visual quality, low power consumption, and affordable cost. The total sale of LCD globally has reached nearly 245 Mn in 2012. Major consumption is mainly due to sharp growth of black and white displays of conventional mobile phones and PDAs. In addition, LCDs are well suited for mass production with a lot of manufacturers. Furthermore, there are a number of companies that produce LCD manufacturing equipment [11], [12].

Table 3. LCD Manufacturers Global Factsheet

TFT ARRAY	
COMPONENTS	**MAJOR MANUFACTURERS**
Glass Substrates	• Asahi Glass Co. (AGC), AGC Display Glass Yonezawa Co., Ltd. 4-2837-11, Hachimanpara Yonezawa City, Yamagata 992-1128 Japan • Corning, Corning Incorporated , One Riverfront Plaza , Corning, NY 14831 USA • NH Techno Glass (NHT), NH Techno Glass Singapore Pte Ltd (Singapore), Tuas South Ave 8, 32. • Nippon Electro Glass (NEG). Osaka Phone: (81)6-6399-2711Fax: (81)6-6399-2731Tokyo Phone: (81)3-5460-2510Fax: (81)3-5460-2525 • Samsung Corning Precision Glass (SCP) , 22- Yongdu-ri Tangjeong Myeon, Asan – si, Chungcheongnam – do, Korea
GASES	-Do-
Sputter Targets	• Mitsui Mining & Smelting, 19F, Gate City Osaki, West Tower 1-11-1, Osaki SHINAGAWA-KU, TKY 141 -8584 Japan +81-3-54378000 (Phone) • Nikko Materials, and Tosoh. No. 62, You-Lian St., Bade City, Tao-Yuan, Taiwan, R.O.C. Tel +(886) 3 368 2303 Fax +(886) 3 365 2712 • Idemitsu, 163 Penang Road #06-01/05 Winsland House II Singapore 238463 • IZO

Photoresist	• AZ Electronic Materials, Taiwan Co., Ltd. 5th Floor No. 96 ChienKuo North Road Section 1. Taipei 104 • Dongjin Semichem Co Ltd. 472-2, Gajwa-Dong, Seo-Gu. INCHEON404250. South Korea. KOR. • Tokya Ohka Kogyo (TOK), 150 Nakamaruko Nakahara-ku, Nakahara-ku, Kawasaki-shi, Japan
Developer **Photo Masks**	• Fujifilm Electronic Materials, FUJIFILM Electronic Materials U.S.A., Inc. 80 Circuit Drive North Kingstown, Rhode Island 02852 • JSR, 22F, Shiodome Sumitomo Bldg. 1-9-2, Higashi-shinbashi MINATO-KU, TKY 105-8640, Japan +81-3-62183500 (Phone) • LG Chem Power Inc , 1857 Technology Drive , Troy, Michigan 48083 , Tel 248-307-1800 • Toyo Ink Manufacturing, Toyo Ink SC Holdings Co. Ltd 3-13, Kyobashi 2-chome, Chuo-ku, Tokyo, 104 8377 Japan Phone : +81-3-3272-5731
MODULE ASSEMBLY	
Backlight Unit (Blu) **CCFL (Cold Cathode Fluorescent Lamp)**	• Radiant and Coretronic, 11 Li Hsing Rd., Hsinchu Science park Chu-Nan, 350, Taiwan • Taesan and Heesung , Pyung-Taik City, South Korea.AUO, 189, Hwaya Rd. Kueishan, Taoyuan 33383, Taiwan • CMO, 59-1 Sanjia, Rende District, Tainan City 71702 TEL: +886-6-2663000.2665000, Taiwan
Backlight Inverter **Light Emitting Diode (LED)**	• Darfon, 167, Shan-Ying Road, Gueishan, Taoyuan, 33341 Taiwan. • Foxconn, No.2,2nd Donghuan Road,10th Yousong Industrial District,Longhua,Baoan,Shenzhen City,Guangdong Province,China • Logah, 7 Pezzullo St Johnston, RI, 02919, U.S.A , Tel: +1 (401)-780-5084 • Sharp, P.O.Box 17115 Dubai , Jebel Ali Free Zone, United Arab Emirates. • TAIYO YUDEN (U.S.A.) INC., Chicago (Sales Headquarters & Midwest Regional Sales) Office [components, CD-R] 10 North Martingale Road, Suite 575, Schaumburg,IL 60173 U.S.A. Phone:630-237-2405
Brightness Enhancement Film (Bef)	• MNTech, 1113-6 Namchon-ri, Oksan-myeon, Cheongwon-gun, Chungcheongbuk-do Korea. Phone: 82-43-7101317. • E-Fun, 136 N. Grand Ave, #148, , West Covina, CA 91791, USA • Mitsubishi Rayon , 5441 Avenida Encinas, Suite B Carlsbad, CA 92008. T. 760.929.0001 • Reflexite, European Conversion Center (ECC) Unit 5, Cleaboy Business Park Old Kilmeaden Road Waterford, Ireland • LGE, Twin Towers, 20 Yeouido-dong, Yeongdeungpo-gu, Seoul 150-721, KOREA Tel: +82 (0)2 3777 1114. • Kodak, Eastman Kodak Company 343 State St. Rochester, NY 14650. • General Electric, 42°50’0″N, 73°52’32″W, GE Global Research, 1 Research Circle, Niskayuna, NY 12309 • LGS, No. 8-2-293/82/A/796/B, Road No.36, Jubilee Hills, Hyderabad - 500033
Dual Brightness Enhancement Film (Dbef) and Diffuser Films	• 3M proprietary technology, 3M Corporate Headquarters 3M Center St. Paul, 55144-1000

Reflector Films	• Toray Industries, Inc. Nihonbashi Mitsui Tower, 1-1, Nihonbashi-Muromachi 2-chome, Chuo-ku, Tokyo 103-8666, Japan: Tel: +81-3-3245-5111. • Teijin DuPont, P.T. Indonesia Teijin DuPont Films Jl. M.H. Thamrin, Kel. Panunggangan,Kotamadya-Tangerang 15001, Indonesia, Tel: +62-21-5312-2115 • 3M • Keiwa, Keiwa Inc. 3F-15, No.38, Taiyuan St., Jhubei City,Hsinchu • Tsujiden, 4-8-3, Takaidohigashi, Suginami-ku, Tokyo, JAPAN • SKC Inc., 863 Valley View Road , Eighty Four, PA 15330 U.S.A. , Telephone: 724-941-9701 • Kimoto, KIMOTO TECH INC, 601 Canal Street, PO Box 1783, Cedartown, Georgia 30125 USA, Phone: +86-24-2452 0220
Light Guide Plate (LGP)	• Wooyoung, 371 Daemyung-ri Daegot-myun Kimpo-si Kyunggi – do Korea • Radiant, 1, Central 6th Rd., K. E. P. Z., Kaohsiung City, Taiwan , +886-78216151 • Coretronic, No.11, Li-Hsing Road, Science Park Hsinchu, , 300 Taiwan. • Pontex, No. 23-6, Lung Hsing Lane Feng Hsing Road, Sec. 2, Tan Tzu Hsiang, Taichung Hsien, Taiwan R.O.C. • Kenmos, Nan-Ke 1st Rd., Tainan, Tainan, Taiwan. Zip/Postal : 741; Telephone : 886-6-5057799; • JinMinShang, Taiwan • GLT, Enplas, Taiwan • Zeon, 311 E. Chicago St., Suite 520Milwaukee Wisconsin 53202Ph : +1-414-475-6472Fax: +1-414-431-6380
Driver IC	• Samsung, 105 Challenger Rd. Ridgefield Park, NJ 07660-0511. • Novatek, OAO NOVATEK 22 A, Pobedy street, Tarko-Sale, Yamalo-Nenets Autonomous District, 629850, Russia. • Himax, No.26, Zih Lian Road, Sinshih District TAINAN, 741. Taiwan • NEC, 7-1, Shiba 5-chome, Minato-ku, Tokyo 108-8001 • Oki , Oki Data Americas, Inc. 2000 Bishops Gate Blvd. Mt. Laurel, NJ 08054-4620 1-800-OKIDATA (1-800-654-3282) • MagnaChip,1,Hyangjeong-Dong,Heungdeok-Gu CHEONGJU, 361728. South Korea +1-800-4831140 (Phone) +1-800-2535177
TAB (Tape Automated Bonding)	• Hitachi Cable , 61 Alexandra Terrace, #05-05 Harbour Link, Singapore 119936. • Mitsui Kinzoku, 48 Kamome-cho, Naka-ku, Yokohama-shi, Kanagawa 231-0813, Japan, TEL : +81-45-625-5902 • Shindo, (between 7th Ave & Broadway) New York, NY 10018.
ACF (Anisotropic Conductive Film)	• Hitachi Chemical, St.Luke's Tower, 8-1 Akashi-Cho, Chuo-Ku, Tokyo 104-0044, Japan, Phone:81-3-3543-3700 • Sony Chemical Information Devices (SCID), 7-1, Konan 1-chome, Minato-ku, Tokyo,
CELL ASSEMBLY SECTIONS	
Color Filter (Cf) **Liquid Crystal (Lc)** **Alignment Layer Or Orientation Layer**	• JSR, JSR Micro N.V. Technologielaan 8, B-3001 Leuven Belgium • Nissan Chemical, 3-7-1, Kanda Nishiki-cho, Chiyoda-ku. Tokyo 101-0054, Japan. • Chisso, Tsukamoto Daichiba Bldg., 2-3-1, Fujimi, Chuo-ku, Chiba city, 260-0015 Japan

Sealant	• Mitsui Chemical, Shiodome City Center, 5-2, Higashi-Shimbashi 1-chome, Minato-ku, Tokyo 105-7117
Spacers	• Kyoritsu Chemical, 37-11 Den-enchofu 5 Chome Ohta-ku Tokyo 145-0071 Japan • Nippon Kayaku , Tokyo Fujimi Bldg. 1-11-2, Fujimi CHIYODA-KU, TKY 102-8172 • Sekisui Chemical , Calle 21E, No.524 Civac, Cuernavaca, Morelos, Mexico

b. INDIA

India is amongst the fastest growing markets for LCD technology in the Asia Pacific. India's contribution to total LCD devices sale in the Asia Pacific region has grown to 18% in 2010 and could reach to 39% in 2014. A study reports that 9.9 Mn units of LCD TV in particular have been sold during 2012. The CRT shipments are expected to 20.3 Mn by 2015 in comparison to 4.8 Mn in 2012. TV demand will continue to grow in India, as 120 million households still require access to television. Exponential future growth is imminent for LCD TV and other display devices in India due to declining prices, increasing availability of LCD technology and increased domestic production [13], [14].

Soruce: ELCINA; India, Toshiba; Japan

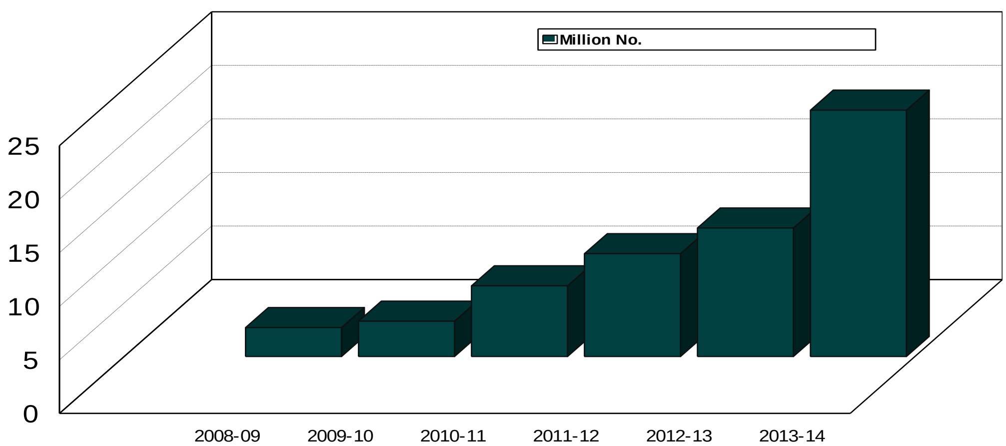

Fig.3: Indian LCD Market Growth Path

Fig. 3 shows the Growth Plan of Indian LCD Market. Samsung, Sony, and LG are the major players in the segment with a market share of 61 percent during 2011. In 2010, these companies held a combined market share of 81 percent [12], [13], [14]. Other companies like Videocon, Toshiba, and Panasonic are quickly gaining ground in this segment. Some other major companies in this segment are:

- Haier, New Delhi
- TCL, Andheri East, Mumbai
- Weston, Naraina Industrial Area Phase-New Delhi
- Oscar, Noida (U.P.)
- Salora, Okhla Industrial Area Phase-New Delhi
- T Series, New Delhi

- Philips, DLF Phase - 3, Gurgaon
- Beltek, Noida (U.P.)

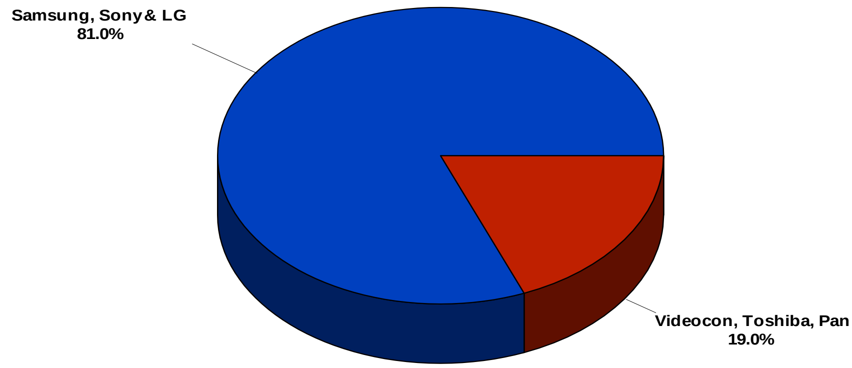

Fig 4 Indian LCD display Market Share

Fig. 4 shows the current Indian market distribution of companies in LCD display devices. The growth drivers for increased display market:

- Strong local demand for electronic products, especially mass consumption items such as mobile phones, personal computers, and consumer electronics.
- Rising labor costs in western countries and now also in Asia.
- Shorter time to market and lower manufacturing cost benefit offered by electronics manufacturing sector (EMS) companies due to scale of production and specialization in manufacturing.

Presently, major manufacturers, Sony and Panasonic are making LCD devices in country like Thailand and then shipping them to India as Special Free Trade Agreement with Thailand on duty. China, South Korea, Taiwan are the other countries supplying the finished products to India.

4. Environmental Concerns of LCD

a. Loss of Light Energy

The working of liquid crystal display (LCD) is lacking energy efficient principle. It polarizes light and thereafter filters light energy in every stage. Due to filtering white light from a background source, allowing only the colors needed to produce the image on the screen to pass through and be visible the process in LCD is highly power consuming. These processes filter out major portion of the light energy. It is estimated only 10-20% of the light energy of the background source is used in actual display. Comparing other displays, this is considered to be most inefficient [15].

b. Hazardous Chemical

The backlight major constituent of LCD contains hazardous mercury to operate. The backlight unit has a polymer film reflector, made of PET (polyethylene terephthalate), which is formed from ethylene glycol (EG) and terephthalic acid (TPA). These are potentially toxic to leach to soil and water in tropical condition after the end-of-life of the LCD displays. Various other chemicals used to improve the display quality and response time are hazardous to the environment. Liquid crystal itself is made up of dioxins and furans, which could be potentially dangerous to emit toxic gases under high thermal conditions. After their usable life, LCD is considered to be very difficult to biodegrade and hazardous to water and soil. Thus the chemical used for the key performance of the LCD is not environment sound for the tropical country like India.

c. HAZARDOUS GASES

LCD display cannot be considered as green product. Various hazardous gasses are used in manufacturing the products. Some of the gases and chemicals used for manufacturing process of LCD, indicated in Table 5, are potentially dangerous. The TFT-LCD manufacturing processes utilize significant amount of gases for thin-film deposition and etching. These include silane, phosphine, ammonia, and hydrogen for polycrystalline silicon and silicon nitride thin film deposition in a plasma-enhanced chemical vapor deposition (PECVD) reaction chamber. In addition, nitrogen trifluoride or fluorine is used in the PECVD chamber cleaning. Chlorine and sulfur hexafluoride are used in the dry etching of thin film. The hazards of these gases can be classified as pyrophoric, flammable and oxidizing gases.

Pulmonary irritant with toxic NF_3 gas is used in the manufacturing flat panel displays to clean the chamber. The gas reacted with fluorine and deposited solid on reactor walls to form gaseous byproducts such as silicon tetrafluoride in chemical vapor deposition chamber. Nitrogen trifluoride is a significant greenhouse warming gas with a Greenhouse Warming Potential (GWP) >10,000 as compared to carbon dioxide. It could damage liver and kidneys. With the growth of LCD displays in last decade, the consumption of NF_3 has also increased from 55 Million US$ in 2006 to 99 Million US$ in 2010 [16], [17]. Highly toxic fluorine gas with extreme oxidation and corrosion potentials is also used in chemical vapor deposition chamber cleaning. Silane or silicon tetrahydride (SiH_4) used in TFT-LCD manufacturing is also potentially hazardous chemical. SiH_4 is used for deposition of interconnects or masking etc. Exposure of SiH_4 gas above 5 ppm in blood could create spontaneous flammability. The consumption of SiH4 is also growing rapidly with LCD growth. The consumption of SiH_4 during 2006 was ~55 Million US$, which was enhanced to 78 Million US$ during 2010.

A highly toxic and pyrophoric liquefied compressed gas and phosphine (PH_3) are primarily used as a phosphorus dopant at N-type semiconductor in the TFT LCD manufacturing industry. Acute exposures to phosphine may attack cardiovascular and respiratory systems causing peripheral vascular collapse, cardiac arrest and failure, and pulmonary edema. Ammonia (NH_3) used to grow a silicon nitride layer in the TFT-LCD device is also toxic and corrosive. Chlorine (Cl_2) another oxidizing gas used for etching in TFT-LCD industry is hazardous. [16].

d. MERCURY ACCUMULATION IN END-OF-LIFE PRODUCTS

LCD display is growing in India exponentially. Each unit requires one back lighting CCFL unit, which contains hazardous mercury. It could be estimated that CCFL of different sizes contain nearly 3.5 to 13 mg of mercury per lamp. If we consider the LCD display already reached 9.9 Mn in 2012 and would grow to 20.3 Mn by 2015. The huge mercury used in the LCD product and in turn substantial accumulation of mercury in the end-of-life products would create potential hazards to the environment. The Fig.5 is showing the growth of LCD displays in India and the subsequent mercury accumulation in the LCD display.

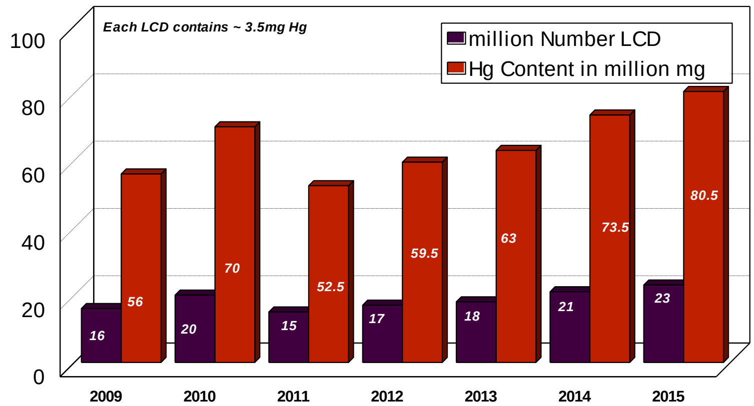

Fig. 5 Growth of LCD Panels and year wise mercury accumulated

5. Comparison of LCD with CRT Displays

The images in LCD screen are inferior in quality than that of in CRT screen. The color uniformity, image sharpness and viewing angle are all lacking and also fast moving images appear blurred because the crystals could not response quickly enough like CRT. Though, recent technology up-gradation has tried to sort out some of the issues, however, due to inferior basic technology LCD could never beat the image quality of a CRT.

LCD is mainly preferred due to its lighter weight and occupies lesser space. For a portable device, like lap tops, mobile phones etc. LCD could be very handy, whereas, CRT could not provide any solution. The shelf life of LCD would be typically 5000-7000 hours, whereas CRT tube can retain more than 15,000 hours of life. In a life time, at least, one should use two LCD display comparing to CRT display. The end-of-life LCDs thus would be more in number than CRT displays. This would burden more in electron waste stream, which is alarmingly increasing in our society.

Moreover, the size of an LCD monitor can affect its resolution, and aspect ratio. Larger monitors are more expensive. The transistors used to make active matrix displays have a high failure rate. Bigger monitors have more transistors that could often go defective due to fluctuation of power, tropical condition etc. These LCD could not be easily repairable due to non-availability of the desired transistor. The consumers would pay price and purchase new LCD.

Table 4. LCD Vs CRT Display Technology

Technological Features	CRT	LCD
Type	Emissive	Passive: Transmissive or Passive: Reflective or Passive: Transflective
Working Principle	Electrons generated through thermionic emission are accelerated by high voltage at a cathode with a sweep by magnets into a focused beam which strikes a phosphor screen	Liquid crystal light gates control transmission of a backlight through polarised light filters OR Liquid crystal light gates control reflection of ambient light through polarised light filters OR A mixture of both
Application	Traditional TV, Traditional computer monitor	Digital watches and calculators, mobile phone, laptop and computer displays, TVs up to 42",

Brightness	100 cd/m^2 Wider colour gamut, reflect more room light causing blacks to look gray and vivid colors to appear dull	400-600 cd/m^2 High peak intensity for bright images, best for brightly light environments
Contrast (incl. dynamic range)	1000:1 (Black: 0.01 cd/m^2)	100-600:1 (black: 0.7 cd.m^2)
Field of view	180°	140-150°
Colour gamut	wide (65-70% NTSC)	Wide (65-75% NTSC)
Motion perception	1-3ms	16ms
Lifetime	CRT last 10-20 thousand hours.	LCD can be used 30-50 thousand hours before it reaches half-brightness.
Power Consumption	-	LCD monitor uses approximately one-third of the power of a similar sized CRT.
Image Quality	CRT pixel is less distinguished.	Each LCD pixel is clearly separated from its neighboring pixels.
Distortion	Exhibit geometrical distortion due to curved screen and electron beam scanning over some distance.	Direct pixel mapping gives more precise imaging.
Image Retention	Develop image retention or "burn-in", which causes phosphors degradation	Backlight ages uniformly, image retention will not take place.
Ruggedness	Vacuum envelope of CRT picture tubes is relatively fragile.	LCDs are more resistant to shake, shock and vibration.

Life-cycle energy impact comparison between CRT and LCD has been studied. The global warming impacts for the CRT are greatest during operation, as greater electric power is used. CRT contributes 66% to the overall life-cycle global warming impacts during operating stage. Moreover, the CO emission from used electricity generated contributes 65% to the total life-cycle global warming impacts. LCD has, however, more relative burdens on the environment than CRT. The global warming impacts, displayed by life-cycle stage for the CRT and LCD are greatest in case of LCD manufacturing, due to use of sulfur hexafluoride & CO_2. Global warming impacts for these chemicals are approximately 66% and 27% respectively [18].

Conclusion

The LCD display would completely replace CRT displays in coming few years. Design, manufacturing process and chemical used in LCD displays however raised significant concerns related to the immediate environmental hazards. The chemical composition, design process, manufacturing material used in LCD manufacturing needs to be relooked to find more environmental friendly solution. It is apparent from the present study on LCD display technology and comparison with predecessor CRT technology that the replacement would not be an environmental friendly one.

There are considerable impacts on global warming, water eutrophication in case of LCD. Manufacturing stages of each monitor type, the LCD has more relative burden on the environment than does the CRT. It was established that the back light assembly, CCFL, liquid crystals (i.e. the basic component) required for functioning of the displays are toxic in nature. Moreover, it requires to improve the recycling efficiency and its process enough environment-friendly after end-of-life so that recycling mechanism could be economical viable and easier.

The manufactured life for LCDs (~45,000 hours) much greater than the effective life (~13,547 hours). Effective life of LCDs are not being used as long as they can physically be (less than a third as long) [19]. Self life of the LCD displays is much lesser than that its contemporary displays, e.g. CRT displays. The consumer, therefore, needs to replace at least two LCD during usable life of CRT display. The manufacturing of the two devices would consume more energy and source materials, and thereby putting burden to the carbon foot print. It is always appreciable to accept newer technology once the product is superior in performance, consumed lesser energy during manufacturing as well as in operation and also creating lesser problem during disposal of the device after their usable life.

This study might help industry to focus on improved technological display. Recent development of Organic Light Emitting Diode displays, reflective bi-stable display technologies, micro displays could be alternatives to the LCD technologies. The manufacturing are seriously considering to replace LCD technology with a products having more sustainable life cycle, manufacturing process, which fulfils the WEEE directive of the European commission and requirements of developing economies.

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