

OLED

An Emerging Display Technology



Organic Light Emitting Diode (OLED)

Source: Fortuno Doro Technology Corp.

Erik C. Astheimer
Research Analyst
(914) 921-5168

OLED – A Primer

On May 23rd-28th, 2004, the “Society for Information Display” will hold its 2nd annual conference in Seattle, Washington. In advance of the conference, we wanted to provide you with a brief primer on the current display technology market as well as highlight the emerging technology of Organic Light Emitting Diodes (OLEDs). OLEDs, which are considered by many to be a viable technology next to liquid crystal display (LCD), has been gaining interest due to its unique characteristics versus other competing technologies. While commercialization of the technology is still approximately 3-5 years away, there are some OLED displays that are being manufactured and incorporated into small consumer electronic products such as cellular telephones and digital cameras. The market potential for OLED material producers and LCD manufacturers will increase further as the limitations are addressed and the proliferation of products involving these types of displays expand.

While OLEDs will not displace LCDs in the near future, the current research and commercialization trends are increasing. We highlight one publicly traded pure-play OLED company in this report; Universal Display Corporation (PANL – \$10.51 – NASDAQ).

Liquid Crystal Display

Liquid crystal display technology currently dominates the flat panel display (FPD) market in terms of investment, revenues, and mind-share. As we highlighted in our January 23rd, 2004 report “LCD – Bright Opportunities”, the FPD industry is poised for dynamic growth due to the increased penetration of notebook PC’s and liquid crystal display monitors in the PC market as well as the growing popularity of LCD-TVs in the consumer market. The worldwide FPD market is roughly \$40B with a 23% CAGR through 2006. In particular, the LCD market, which represents approximately 75% of the FPD industry, is projected to grow at 26% to about \$52B by the year 2006. LCD technology functions through the use of pixels composed of liquid crystals that have the ability to polarize light in the presence of an electronic field. Compared with conventional cathode ray tubes (CRTs), LCD’s consume less electricity, generate less heat, and have a better contrast ratio – even when compared to plasma display panels.

Display Technologies – What are they?

Today, there are many different types of display technologies in the marketplace, each with their own unique characteristics to address specific applications. Below is a sample list of popular approaches used in display systems:

- **Cathode Ray Tubes (CRT)** – The technology used in most televisions and computer display screens. A CRT works by moving an electron beam back and forth across the back of the screen.
- **Field Emission Displays (FED)** – FED is a flat cathode ray tube that uses a matrix-addressed cold-cathode to produce light from a cathodoluminescent phosphor screen. The technical feasibility of the FED has been demonstrated and various companies and institutions are in the process of developing cost effective prototypes; however, constraints still exist.
- **Organic Light Emitting Diodes (OLED)** – Unlike LCDs, which require backlighting, OLED displays are emissive devices that give off light rather than modulating transmitted light or reflected light. OLEDs possess unique characteristics which will be discussed later in this report.
- **Plasma Display Panels (PDP)** – Technology that operates by controlling discharges from ionized gases. Plasma displays are becoming an alternative to LCD as they can be easily manufactured in a large format. Compared to conventional CRT displays, plasma displays are about one-tenth the thickness--around 4", and one-sixth the weight.
- **Light Emitting Diodes (LED)** – An LED is an electronic device that lights up when electricity is passed through it. LEDs have been around for decades and are used in everything from car dashboards, to large indoor/outdoor display systems, to portable electronics as indicator lamps.
- **Liquid Crystal Displays (LCD)** – Quickly becoming the dominant display technology in the FPD market. Function through the use of pixels composed of liquid crystals that have the ability to polarize light in the presence of an electronic field. The core advantage to LCD is the usefulness, relatively low power consumption, and high contrast.

Overview – Organic Light Emitting Diodes (OLEDs)

Eastman Kodak developed the first OLED in the late 1980s, and since then, scientists have been making the necessary strides to overcome limitations of the technology, positioning OLED to become commercially available over the next 3-5 years. OLEDs are currently produced in small quantities for initial applications in OLED displays found in a wide variety of portable consumer electronics (ideal for cellular phones and portable electronics, car audio systems, and potentially handheld TV's and notebook PC's). One of the most alluring characteristics of the technology is the ability for it to be manufactured on plastic, thereby opening up the possibility for a flexible OLED display that could lead to many disruptive display applications. DisplaySearch estimates the OLED shipments to grow significantly from \$263 million to \$3.5 billion by 2008. In 2002, approximately 3.5 million passive matrix OLED sub-displays were sold, and over 10 million sold were sold in 2003.

OLEDs are extremely thin layers of organic material applied to a substrate of glass or plastic. When the material is stimulated by an electrical charge, light is emitted. In defining a simple OLED structure in a more scientific way, it is constructed using two electrodes separated by a conductive organic layer; when these electrons collide within the organic layer, photons are emitted. OLED technology is solid-state, uses lower voltages than plasma, and can be manufactured more thinly than active matrix LCD's.



Source: Sanyo



Source: Samsung

The Benefits of OLED:

OLEDs are possibly a more attractive alternative to LCD technology due to the following unique characteristics:

- **Thinner, lighter** – approximately 1.5 millimeters thick
- **Brighter** – OLEDs have a higher resolution, sharper contrast, and a larger lumination range. OLED is also a light emitting technology that requires no backlight like an LCD
- **Wider viewing angle** – viewing area – up to 180 degrees. LCDs have viewing angles of 160 degrees or less
- **Low power consumption** – OLEDs operate at fairly low voltages - can be battery driven. Depending on the technology, required voltage can range between 1-20 volts. Requires approximately half the power consumption of an LCD as liquid crystal displays always have their backlights on.
- **Flexibility** – can be fabricated on plastic substrates, opening up possibility for flexible displays

Limitations and Opportunity:

With every emerging technology, constraints arise creating roadblocks to commercialization. For OLEDs, much of the technical hurdles relate to lifetime (durability) issues, the extreme sensitivity to moisture, and limitations with the color blue. Since the technology revolves around the use of intricate pixels that tend to degrade over time, this leads to a loss in brightness and possible shifts in color. OLED producers are also looking for ways to increase the size of the viewable area, as the current technology is only suited for smaller applications. Lastly, one of the impediments to the commercialization of OLEDs is addressing the high manufacturing costs associated with production. OLED producers could ultimately benefit from lower capital investment costs stemming from the possible and relatively easy conversion into existing LCD manufacturing facilities.

Conclusion

As OLED display technology matures, it will be better able to improve upon certain existing limitations of LCD and other flat panel display technologies including: high power consumption, costly manufacturing, limited viewing angles, and poor contrast ratios. While LCD penetration into major display applications is expected to be robust for the next decade, a small and increasing portion of flat panel display growth could come from OLEDs. When this occurs, materials' producers and flat panel display manufacturers addressing the market today will be the prime beneficiaries. After the 2nd Annual "Society for Information Display Conference", we will share new opportunities in the worldwide display market as well as highlight key advancements in the field that will drive growth and unlock value of existing participants.

Corporate Participants in advancement of OLED Technology:

The current market consists of just select number of pure-play companies, large multi-national players, and a plethora of private companies. Existing LCD manufacturers are also positioned to partake in the possible commercialization of organic light emitting diodes.

Table 1: Notable OLED Participants (Public and Private)

OLED Materials/Technologies

	<u>Country</u>	<u>Price</u>	<u>Ticker</u>	<u>Comment</u>
Universal Display Corp.	United States	\$10.51	PANL	Involved in R&D of Phosphorescent OLEDs and transparent and flexible organic light emitting devices
Eastman Kodak	United States	\$25.53	EK	Large holder of intellectual property for OLED devices utilizing small-molecule materials
Dow Chemical	United States	\$37.40	DOW	Manufacturing Lumination light emitting polymers (LEPs)
Sumitomo Chemical	Japan	505 JPY	4005 JP	Japanese chemical company focusing on next generation display materials
Toyo Ink Mfg. Co.	Japan	464 JPY	4634 JP	Produces printing ink, equipment and image processing systems. Engaged in OLED research
Sieko Epson Corp.	Japan	3,880 JPY	6724 JP	Involved in research and commercialization of OLED materials

FPD Manufacturers (Potential Adopters of OLED)

	<u>Country</u>	<u>Price</u>	<u>Ticker</u>	<u>Comment</u>
Samsung Electronics	Korea	12,800 KWN	000830 KS	Leading display manufacturer / in evaluation agreements for OLED materials
Sony	Japan	3,900 JPY	6758 JP	Flat panel display manufacturer. In a joint development agreement with Universal Display
Sanyo Electric	Japan	433 JPY	6764 JP	Partnership with Kodak in small molecule OLED Research
AU Optronics	Taiwan	\$20.88	AUO	Produces TFT-LCD and plasma display panels. Recently fabricated an AMOLED using PANL's technology.
Chi Mei Optoelectronics	Taiwan	66 TWD	3009 TT	Manufacturers and markets TFT-LCD monitors and color filters.
Hannstar Display	Taiwan	18 TWD	6116 TT	One of Taiwan's top three producers of TFT-LCD and plasma display panels.
ChungHwa Picture	Taiwan	23 TWD	2475 TT	Manufacturers display components used in flat panel, projection, and plasma display devices
Tohoku Pioneer	Japan	2,300 JPY	6827 JP	Use passive OLEDs in exterior sub-displays for mobile phones
White Electronics Designs	United States	\$6.58	WEDC	Manufacturers FPD for commercial and military aircrafts -- also provides semiconductor products for comm. industry.

Notable Private Companies/Subsidiaries

	<u>Country</u>	<u>Price</u>	<u>Ticker</u>	<u>Comment</u>
Cambridge Display Technology	England	NA	PRIVATE	Holds fundamental intellectual property for polymer-based OLED devices
Covion Organic Semiconductor	Germany	NA	PRIVATE	JV between Aventis Research and Avecia; focus on polymer light emitting diodes
RiT Display	Taiwan	NA	PRIVATE	Manufacturers and markets organic light emitting diodes (OLED).
Lite Array, Inc.	China	NA	PRIVATE	Pre-produces inorganic and organic solid state flat panel displays.
Indemitsu Kosan Co.	Japan	NA	Not Traded	Engaged in the R&D and commercialization of OLED technology
LG Philips	Korea	NA	Not Traded	A JV between the Cathode Ray Tube (CRT) businesses of LG Electronics and Royal Philips Electronics.

Source: Company reports, Stock Prices as of May 19, 2004

Universal Display Corporation (PANL – \$10.51 – NASD)

Based in Ewing, New Jersey, Universal Display Corporation is a development stage company focused on the research and commercialization of organic light emitting diode (OLED) technologies for use in a variety of flat panel display and other applications. The company is focused on licensing its proprietary technologies and materials to leading display manufacturers. The current focus of the company has been in the research and development of Phosphorescent OLED (PHOLED) as well as proprietary technologies such as transparent and flexible organic light emitting diodes. PANL's phosphorescence technology offers up to four times the power efficiency of normal fluorescence.

For 2003, the company generated \$6.5 million in revenues and posted a loss of \$18.4 million or a loss of \$0.82 a share. We expect the company to have sufficient cash to execute its business plan, while operating at a loss for the foreseeable future. Universal Display Corporation currently trades at 23X TEV/2004 sales and 14X TEV/2005 sales.

- **Pure-Play Focused on OLED Technology** – PANL has a strong patent portfolio, positioning the company to grow revenues and capture market share as OLED displays gain commercial acceptance.
- **Key Selling and License Agreements** – Universal Display is currently selling their proprietary OLED materials to Tohoku Pioneer. It has also established a cross-licensing agreement with Dupont Display, and has entered into key technology development and evaluation agreements with Sony Corporation, Samsung, AU Optronics, and Toyota Industries.
- **Sufficient Cash** – The company completed a \$30 million secondary offering in the first quarter of 2004 (2.5M shares at \$12.00) giving the company increased flexibility. We believe the company has a large enough cash reserve to assist in becoming profitable. 1Q04 cash burn was \$1.9 million vs. \$2.3 million a year ago.
- **Transitional Period** – As OLED technology matures and the applications utilizing the technology expands, we believe PANL will be better able to transition from a development stage company into a normal operating company.
- **Technology Leadership** – Through internal development efforts and their relationships with the University of Southern California, Princeton University, and Motorola, Universal Display has an extensive portfolio of patents (over 500) related to their PHOLED and other OLED technologies and materials.
- **Display Industry Poised for Continued Growth** – The worldwide FPD market is roughly \$40B and is expected to grow 18% a year to \$72 billion in 2007. As a sub-sector, we expect the OLED market to grow from \$263 million to \$3.2 billion over that same time period.

Industry Reports:

January 23rd, 2004 “LCD – Bright Opportunities” authored by Katherine Ahn

IMPORTANT DISCLOSURE

I, Erik Astheimer, the Research Analyst who prepared this report, hereby certify that the views expressed in this report accurately reflect my personal views about the subject companies and their securities. I have not been, and will not be receiving direct or indirect compensation for expressing the specific recommendation or view in this report.

Erik Astheimer (914) 921-5168

© Gabelli & Company, Inc. 2004

ONE CORPORATE CENTER RYE, NY 10580 GABELLI & COMPANY, INC. TEL (914) 921-3700 FAX (914) 921-5098

Gabelli & Company, Inc. (“we or “us”) attempts to provide timely, value-added insights into companies or industry dynamics for institutional investors. We do not have any formal ratings system for our research reports, and we do not undertake to “upgrade” or “downgrade” ratings after publishing a report. We generally write reports on securities that we believe to be undervalued and do not issue any “sell” ratings. Thus, virtually all of our reports containing recommendations would be considered “buy” ratings.

We prepared this report as a matter of general information. We do not intend for this report to be a complete description of any security or company and it is not an offer or solicitation to buy or sell any security. All facts and statistics are from sources we believe to be reliable, but we do not guarantee their accuracy. We do not undertake to advise you of changes in our opinion or information. Unless otherwise noted, all stock prices reflect the closing price on the business day immediately prior to the date of this report. We do not use “price targets” predicting future stock performance. We do refer to “private market value” or PMV, which is the price that we believe an informed buyer would pay to acquire 100% of a company. There is no assurance that there are any willing buyers of a company at this price and we do not intend to suggest that any acquisition is likely. Additional information is available on request.

In the last 12 months we have provided investment banking services as a syndicate or selling group member of underwritten offering to approximately none of the companies that were the subjects of our research reports (all of which would be considered “buy” ratings). Our affiliates beneficially own on behalf of their investment advisory clients or otherwise less than 1% of common stock of all the companies mentioned in this report. Because the portfolio managers at our affiliates make individual investment decisions with respect to the client accounts they manage, these accounts may have transactions inconsistent with the recommendations in this report. These portfolio managers may know the substance of our research reports prior to their publication as a result of joint participation in research meetings or otherwise. The analyst who wrote this report may receive commissions from customers’ transactions in the securities mentioned in this report.

