The Generation Beyond Print-on-Paper

By
Michael Kleper

Paul and Louise Miller
Distinguished Professor,
School of Print Media

Rochester Institute of
Technology

A Research Monograph of the
Printing Industry Center at RIT

September 2002
No. PICRM-2002-01

R·I·T Printing Industry Center
An Alfred P. Sloan Foundation Center

The Generation Beyond Print-on-Paper

By

Michael Kleper
Paul and Louise Miller Distinguished Professor
School of Print Media

Rochester Institute of Technology

R·I·T Printing Industry Center
An Alfred P. Sloan Foundation Center

A Research Monograph of the
Printing Industry Center at RIT
Rochester, NY
September 2002

With Thanks

The research agenda of the Printing Industry Center at RIT and the publication of research findings are supported by the following organizations:

Rochester Institute of Technology
Alfred P. Sloan Foundation

Adobe Systems Incorporated
Baldwin Technology Company, Inc.
Creo Inc.
RR Donnelley
Heidelberg
hp indigo
IBM Printing Systems
Kodak Polychrome Graphics
MAN Roland Inc.
MeadWestvaco Corporation
NexPress Solutions LLC
NPES
VIGC
Weyerhaeuser
Xeikon America Inc.
Xerox Corporation

Table of Contents

Abstract

The purpose of this paper is to:

- Compare and contrast paper display with on-screen display.
- Examine the state-of-the-art in electronic "paper-like" screen display technology.
- Highlight the screen display technologies that are under development and most likely to affect or replace print.
- Introduce the subject of printed electronics.
- Present comments from leaders in the display technology field.

Today's printing and publishing process involves repurposing content, publishing through multiple channels, and applying XML coding to separate form from content. All of these operations can serve, in one way or another, to disassociate print output from other forms of publishing. The result has been that information that would have been published solely in print is also published, or is exclusively published, for on-screen display. Although on-screen publication, or the presentation of information in some form of digital display, has accounted for a reduction in the relative volume of printing, it must be kept in mind that print-on-paper is *just another form of display.*[1] As such, printers manufacture displays that are composed of one or more layers of ink on a succession of sheets of pulp-based paper. The recognition that *printers are display manufacturers* is of critical importance for three reasons. First, it helps to identify where the competition with print exists. Second, it forces printers to be aware of the incredible advances that are being made in the information display field. And, third, it can lead to the identification of ways in which printers can become part of the new generation of display technologies.

Printing is the foundation of our information infrastructure, carrying the content that fuels innovation, records progress, chronicles history, delivers information, inspires creativity, supports learning, provides entertainment, and creates delight and amusement. Print, as an information technology, has played an important role in every aspect of human advancement, from the Renaissance to the Space Age. Printing remains the third largest manufacturing industry in the United States, employing over 1.2 million people.[2]

Printed paper is not just a surface that holds information; it is an inexpensive, flexible display carrying a persistent message. Virtually all forms of graphic communication and visual media are expressed in some form of information display: a canvas, a wall, a photograph, a computer monitor, a television or movie screen, a PDA or cell phone display, etc. The relative ease by which readers move from reading on paper, to reading on a computer monitor or other electronic panel, and back again, attests both to the similarity of their functions and to the content that they display. Whereas electronic displays can provide highly accurate renditions of paper-based content,[3] the reverse is not true. In addition, electronic displays are characteristically dynamic in nature, supporting animation and video, whereas the content of printed paper is immutable and permanent.[4]

Today, print has been unchained from its traditional paper foundation and been expressed through a variety of electronic channels. Its electronic format or "e-state" makes it suitable for expression in fixed formats, such as CD/DVD-ROM and other Read Only Memory forms; semi-permanent

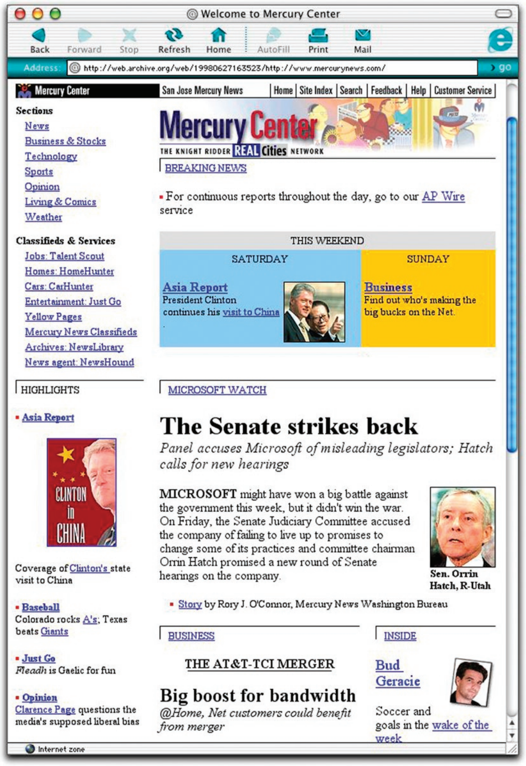


Figure 1. The first newspaper to publish its entire news content and classified ads online was *The San Jose Mercury News* in 1993.[8] The site was initiated as a proprietary service of America Online, and in December of the following year, the newspaper launched its own Web site, Mercury Center (http://www.mercurycenter.com).

forms, where it is kept on storage media; or temporary forms, where it may be displayed on a pay-per-view basis. Books that at one time would have only been produced in print, are published in proprietary and non-proprietary electronic formats for e-book readers, and for display on laptop computers and various forms of hand-held digital devices. The market for all forms of electronic books is expected to reach 26 percent by 2015.[5] Virtually all major newspapers, and a majority of smaller newspapers, have editions that are delivered on the Internet (Figure 1).[6] A survey conducted in 1999 by the Newspaper Association of America found that more than half of web users who sought news online went to newspaper web sites to find it.[7]

Print is losing its market to various forms of digital expression. An increasing proportion of the work of the Government Printing Office (GPO), for example, one of the largest printers and procurers of printed materials in the world, is going electronic. According to Richard G. Leeds, Jr., Manager, Electronic Systems Development Division, U.S. Government Printing Office:

"We are driven by the printed product because that is where our revenues come from, and, actually, as the printed products have gone down and we provide more and more electronic products, basically what happens is the printed product has to cost more to produce the revenue to support these other products. We are in a lot of different areas, and we have been asked by the Supreme Court for a Real Server, RealVideo, RealAudio area, so our RealServer is up, and although print-on demand is not big, we have had different agencies and congressional entities want to have list servers, so we essentially put them up so they can distribute electronically, and although it is kind of like print on-demand, it's not.

"Over the last few years with our on-line products, because we are one of the biggest government on-line sites, where we see it, unfortunately, is not only the hits against our [printed] products, but as our revenue [declines] because the more they get used to using the electronic side, of course they want less and less printing.… Printing has really changed from disseminating ink on paper to disseminating through electronic means."[9]

METHOD

The shift from reading on paper to reading on screen can be documented in a variety of ways. This monograph is based on an in-depth literature search (see Works Cited) and a comprehensive itinerary of on-site visits (see Site Visitations). It is an expansion of an interest expressed in examining the fundamental differences between reading on paper and reading on screen, and follows the on-screen reading experience to its logical result: an inexpensive, flexible, light-weight electronic surrogate for paper.

It has become necessary to promote the importance of print in daily life. The printing industry launched a self-promotion campaign in 2002 entitled "Print: The Original Information Technology™." The print awareness program, sponsored by the Printing Industries of America (PIA) and the Graphic Arts Technical Foundation (GATF), was initiated to "unite an industry and champion the value of print among the general public." The logo (Figure 2) and theme are expected to be carried on truck decals, posters, billboards, bumper stickers, business cards, web pages, etc. The Printing Association of Florida (PAF) in partnership with Avanti CaseHoyt/St. Ives is the first to produce a series of print ads (Figure 3). According to Michael Streibig, PAF's president and CEO, "Together we have the capability to create and convey a positive, consistent image for our industry and to get the message out on a statewide as well as nationwide basis."

The viability of print has been placed in doubt as much by industry observers as by the statistics that have shown steady declines.[10] Perhaps the most influential and controversial voice is that of Dan Okrent, former editor-at-large, and former editor of New Media at Time Inc., and former managing editor of LIFE magazine. Okrent presented a very thought-provoking lecture at the Columbia Graduate School of Journalism entitled, "The Death of Print?" Here is a brief portion of that lecture[11]:

> "So, to the point: **why is print dead?** It's a two part argument, the first part fairly simple but worth some elaboration, the second part as obvious as the morning sun.
>
> "**Part one**, in a phrase, is that we have, I believe, finally learned not to underestimate the march of technological progress…. I don't need to tell you what the average computer can do today, nor do I

Figure 2. The PrintIT logo has been designed to bring attention to the pervasiveness of print. The campaign is described at the Graphic Arts Information Network site, http://www.gain.net. (Courtesy of Printing Industries of America, Inc.)

Figure 3. This is one of several ads developed by the Printing Association of Florida to promote the value of print in everyday life. (Courtesy of the Printing Association of Florida)

need to tell you similar stories about telephones, or audio equipment, or any other piece of technology. If we imagine it, they will build it.

"So **imagine this** (and if you find it hard to imagine, trust me: I've seen it already, in the development office of a well-established Japanese computer electronics company): Imagine a tablet, maybe half an inch thick, shaped when held one way like an open book or magazine, when turned sideways much like a single page of a newspaper. It weighs six ounces. It's somewhat flexible, which makes it easy to transport. (The truly flexible one, which you'll be able to roll up and put in your pocket, is still a couple of years away, so this one will have to do). Its screen, utterly glare-free, neither flickers nor fades nor grows dull. To move beyond the first screen in whatever it is that you're reading, you run your finger across the top of the tablet LIKE THIS — a physical metaphor for the turning of the page.

"You are sitting on a beach on a Saturday afternoon with this little wonder, and you're reading this week's Time magazine. Then you decide you'd like something a little more, oh, entertaining. You press a series of buttons HERE, and a cellular hookup to a satellite-connected database instantaneously delivers you — well, Evelyn Waugh's Scoop. And when you've had enough of that — click, click — you move on, to the football news, or the office memoranda you didn't finish reading on Friday afternoon, or whatever it is that you want. Click, click again: each download, **coming to you at dazzling speeds,** and a central rights-clearance computer charges your account, much like a telephone account, for what you've read or listened to. The satellite operator keeps a small portion of the income, and the rest goes to the "publisher" — that is, to the agency that either created the material you are reading, or that represents the interests of those who created it. Or imagine this: another message comes to you, from — let's say Coca Cola. It's an advertising message, and you have been paid to read it. You have been targeted by Coca Cola, the marketers from that company have found you on the beach, and for the privilege of getting their message in front of you they have paid the satellite operator a carriage fee. The satellite operator, wanting to guarantee the advertising agency that the impression has been made, credits your master account a few cents. For reading the one-minute message from Coca Cola, you get the first five minutes of tomorrow's electronic newspaper for free. Everyone's happy.

"As I said, **this technology already exists**. It's far too expensive today, and the critical elements of payment systems and copyright protection and royalty accounting have not yet been created. But, I guarantee you that such systems are either in development today or soon will be.

"But, you say, who wants to read a good novel on a computer screen, no matter how clear and snappy and portable it is? Who wants to forgo the tactile engagement with a newspaper or magazine, or even more so the deeper, more gratifying physical connection with a book, and replace it with this potentially alienating form of modern technology?

"Well, that brings me to **part two** of my argument, the part I promised was as obvious as the morning sun. And that is this: last year, Time Inc., spent $1 billion dollars on paper and postage.

"End of argument.

"Or, if you'd like, let me put it this way: you may prefer to ride across town in horse-and-carriage, or across a lake in a wind-powered yacht, but no one makes that carriage or that yacht for you anymore, at least not at a reasonable price. So too with the book: in the future that I am imagining with you tonight, the book becomes an elite item for the very few, an object, a collectible — valuable not for the words on the page, but for the vessel that contains those words. Will it matter to the book-loving litterateurs who stalk Morningside Heights? Probably so,

> though I can't imagine why. Will it matter to the millions who buy a John Grisham paperback and toss it when it's done? Not a chance.
>
> "Nor should it. For we — we who work today by accident in paper and ink; who demand, however sheepishly, that vast forests be cut down to make our paper, for vast sums to be invested in hypermodern printing presses and bindery machines that consume megawatts of environment-befouling energy — we should be happy. For we know — we MUST know — that **the words and pictures and ideas and images and notions and substance that we produce is what matters — and NOT the vessel that they arrive in**."

While Dan Okrent's view of the new media comes from print perspective looking out, Jakob Nielsen, renowned in the field of Internet usability and web design, sees things from the Internet perspective and its affect on old forms of media. Nielsen predicts that most forms of current media will die and be replaced by an integrated web medium by 2008. His argument is based on his observation that existing media are primarily dependent upon their underlying hardware technology, which limits the ways in which the media can be delivered. He observes that:

- Moving images can only be presented on television.
- In-depth stories can only be read in a newspaper.
- Reflective analysis of issues can only be read in a magazine.

It is the technology that does not permit film to be viewed in print, or long articles to be broadcast on television. Nielsen's solution is *integrated media services* delivered over the Internet. This will come about, he reasons, when bandwidth is no longer an issue, when computer monitors and other forms of information display are high resolution, and when web browsers are better designed and support more effective on-line searching. Nielsen says, "This means that around 2008, all computer users will prefer using the Internet over reading printed pages.[12] High-end users may make this switch around 2003. Once the Internet is as pleasant to use as old media, it will win if it provides services that take advantage of the interaction and integration offered by the new media."[13]

Although Nielsen sees an end to old media formats, he sees a "glorious future" for writers, editors, photographers, camera-people, video producers, on-screen talent and actors, and many others who will be needed as interactive media content becomes increasingly important. According to Nielsen, "I am less optimistic about the future for current media *companies* than I am about the future prospects for their *staff*."

Print-on-Paper Will Endure

Although commercial print has experienced a decline, there has been an increase in the amount of printing produced by end-users. As Gene Gable, president of Seybold has said: "…I would also argue that some of what those kinds of shifts are going to do is actually take business away from the commercial printing segment and put it in the hands of the Epsons and the Hewlett-Packards and the companies that are good at home-based printing." This is the popular wisdom, and, in fact, printer manufacturer Hewlett-Packard predicts a 50 percent jump in paper use in the next five years caused by people unable to stop clicking the print icon.[14] A contrary view, however, is held by former Seybold program director, Thad McIlroy, who reasons that people will grow more accustomed to reading on-screen and maintaining documents on their systems, and will not be as inclined to press the print button. "I feel that, when you look at a technology adoption pattern, I think what they're now projecting is a human tendency that's going to be able to work through, particularly as the display devices get better, there's going to be a really significant drop-off in that kind of home printing."[15] Regardless of who is right, the end result is the need for less output from the printing industry.

Although inexpensive computer technology and data storage are readily available, each change in technology is somewhat disruptive of what preceded it. Business analyst Richard Quinn writes that "…every time you introduce a new data-management technology into the mix, you need to go back to everything you've done in the past and make sure you can still find and retrieve it intact….What do we do when we retrieve these records [we've found]? We print them — not because we like to print them, but usually because we have to share them with someone who doesn't have the same version of imaging technology we have. What do they do with the information when they receive it? They either file it in its paper form or re-scan it into their systems — and the cycle begins once again."[16]

THE LIFE CYCLE OF PAPER

The life cycle of paper can, perhaps, be best observed in the practices of public and university libraries, and their policies regarding the storage, replacement, and disposition of printed items in their collections. On an increasing basis, newspapers and magazines are not entering the library system at all. According to Sheila Smokey, Collection Development Librarian at the Rochester Institute of Technology, "At a best guess, over the past five years, I'd say we are buying perhaps 35 to 50 percent less paper serials in favor of electronic alternatives. This will increase annually. We buy very few paper indexes, for instance, since these are better accessed electronically. We've only started our Serials Review for 2003 and already I'm aware of 63 paper titles that will be cancelled in favor of electronic access only. We avoid CD-ROM, if possible, because it limits off-campus access to the product."[17]

Stacks of newspapers and magazines, which are routinely disposed of in favor of microfilm versions, both to save space and provide easier reference, are now being replaced with electronic archives. Not only do library patrons not tolerate the year or more that it typically takes to microfilm serials, but they prefer online access.

And how do libraries dispose of the great bulk of serials that are no longer needed? Some go to back-issue-jobbers who sell to individuals or to libraries missing particular issues that they

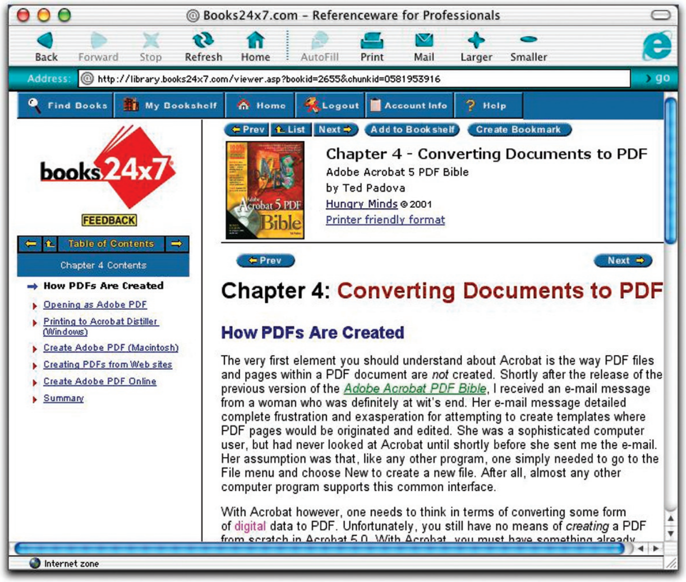


Figure 4. The Books24x7 user interface provides access to the entire contents of each book, with several navigation aids and capabilities to copy/paste and print.

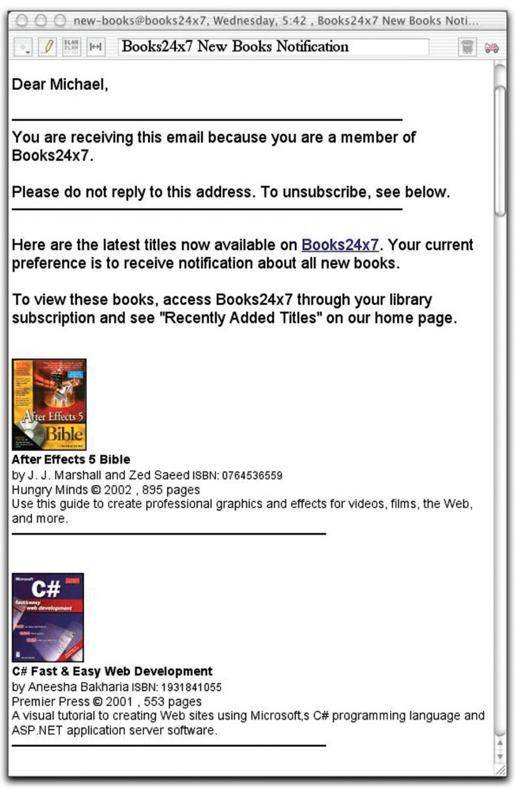


Figure 5. All new additions to the Books24x7 collection of a particular library are sent, via e-mail, to patrons registered to use the service.

bind and maintain, or simply want to have in their collections. In other cases the serials may be given to people or groups in the community, or else recycled. According to Helen Anderson of the University of Rochester Rush Rhees Library, "We withdraw books from the collection usually only if they are absolutely falling apart or if we have many copies and decide to reduce the number in the collection. If the copy being withdrawn is in miserable condition, we generally throw it away and decide whether or not to replace it based on whether we have other copies and whether the subject is still relevant to our collection. Generally we replace print with print when available when it comes to books but this is not written in stone. I suppose we could replace a discarded print item with a microform or electronic version if we saw reason to do so (price, access, etc.)."[18]

A portion of books that would have been purchased in print form are being provided through services such as Books24x7 (Figure 4), netLibrary, ebrary, and others, which offer the entire content of technical books on-line, either by subscription or using some fee structure. As books are added to the collection, patrons are informed through e-mail (Figure 5). In addition, libraries are increasingly, although not in significant numbers, lending e-book readers to their patrons.

The model of the university library in the 21st century is placing a higher value on user spaces, such as group study rooms and instructional development centers, than on the shelving of books. Significant library renovations have been undertaken by leading universities, including Columbia, Cornell, Dartmouth, Dickinson, Emory, Johns Hopkins, Tufts, UCLA, and Yale. In every case the libraries are opting for more computers and fewer printed books.[19]

The transition from reading on paper, to reading on screen, is far from complete. Print on paper will be with us long into the future[20] because it holds many benefits, including:

- It is an effective means of information storage.

- We have a high level of comfort in using it.
- There are, in certain instances, legal requirements for maintaining information on paper.
- We have an effective infrastructure for producing it, copying it, scanning it, filing it, shredding it, and recycling it.
- There are certain printed products, such as packaging, wrapping paper, theater programs, tickets, and other items that not only carry information, but provide a measure of utility as well.
- It can be, and usually is, imaged at a very high resolution.
- It occupies physical space in the real world, which can aid in locating it, and the content that it holds.
- It will not become obsolete as technology advances.
- It does not require a special device to read and use it.

THE CASE FOR PRINTING

What then is the case for printing (Figure 6)? What defines the nature of information that is best expressed in printed form?

- Information of a persistent nature that serves as a continuing reference, i.e., coffee table books.
- Information that will be consumed in environments where electronic viewing is unavailable, undesirable, or inconvenient. i.e. course hand-outs, theatre programs, etc.
- Information that is mission-critical, or is sufficiently important on a personal or business level, that consigning it to system with several potential points of failure, such as storage on a hard drive that can fail, viewing on a system that is dependent upon electricity, accessing through a network connection that can break, etc. is intolerable.

Figure 6. This photo may say it all. This is the table of presentation materials for registered participants at the Society of Information Display, in Boston, May 2002. Despite the fact that this organization is at the forefront of display technologies, and that their members are highly computer literate, and that session presentations were also available on CD-ROM, each presentation was available on paper. Why? Because participants are accustomed to having a paper copy so that they can follow along with the presenter. (Photo by author)

- Information that requires some form of action.
- Information that must be submitted as a part of a transaction, such as bank deposit, or a loan agreement.
- Information that must be handled by those who do not have access to a computer system.[21]
- Information that must be printed to satisfy a legal requirement, such as a mortgage or a death certificate.
- Information that must be carried on one's person, such as a driver's license or medical insurance card.

The Tablet PC

Despite the advantages of print on paper, the use of print on-screen will ultimately grow at the expense of both traditional and end-user printing. One of the several ways in which this is likely to happen involves Microsoft and other companies reinventing the personal computer as an electronic tablet, i.e., a Tablet PC. The Tablet PC provides a form of computer interaction that is, ironically, much like pen and paper, but in a totally electronic realm. The user interacts with a touch-sensitive screen, inputting data, editing it, navigating through various applications, and combining various elements, including rich media forms such as music and video, into new documents and publications. Although in concept the Tablet PC is an entirely new hardware design *(pure tablet),* most PCs that will have tablet capabilities will resemble the familiar clamshell design *(convertible),* with a full keyboard. Microsoft's objective is to have the Windows XP Tablet PC Edition in use in 50 percent of laptops by 2007, although this is a target for the OS, not for Tablet PC hardware volume.[22]

One of the most significant features of the XP Tablet PC software, and what distinguishes it from the standard version of Windows XP, is the consideration of ink as a data type. Ink, which is the handwritten input that either can remain as a graphic representation or be converted into editable characters, achieves the status of a data type having a complete set of properties (such as pressure, angle, time, color, curve fitting, etc.). As such, handwriting, like keyboarded text, can be italicized, bolded, or underlined, or used in other ways similar to standard text, such as re–flowing. The Tablet PC has, then, a screen that simulates *paper* and a data type that simulates *ink.*

There are several iterations of computer devices designed specifically for storing, viewing, and modifying documents and other digital file formats. The Estari, Inc. 2-VU dual screen (Figure 7), mobile computing device, for example, is designed to be held like a book, and store virtually any kind of document and multimedia element for viewing anywhere. Estari CEO Dr. George Crist observes that "this format for printed publications is widely accepted, based on a study of 30 centuries of graphic design and consumer testing."[23] The device connects to other computers and networks through both wired and wireless means, and supports input using an on-screen, wireless, or USB keyboard.

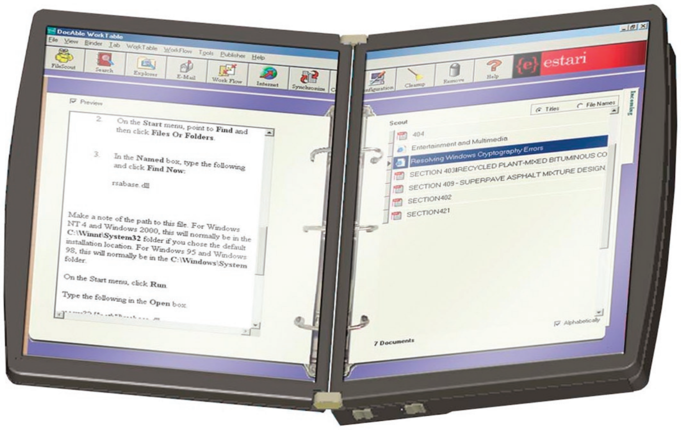


Figure 7. The Estari 2-VU provides two 12- or 15-inch touch-sensitive TFT XGA color panels, a 30GB or higher hard drive, and a DVD drive (and optional DVD/CDRW). (Photo courtesy of Estari, Inc.)

Tablet PC screens will ultimately have a resolution and quality indistinguishable from print on paper. Microsoft's Dick Brass, predicts that by 2005, 250 million people will routinely read books and newspapers on some variety of digital reading device, and by 2019, 90 percent of all books will be published in digital form. Whether these "optimistic" predictions occur or not, it is highly likely that the display of content that was formerly carried exclusively, or primarily, on paper, increasingly will be formatted for on-screen delivery and use, where the limitations of print do not exist, and:

- The use of color does not carry a premium price.
- Rich media elements, such as animation and full-motion video with sound can be included.
- Hyperlinks can be added to connect users with related information and services.
- Wireless and high-speed connectivity will provide instant delivery and updating of news and information of interest to the reader.
- Young readers, who have grown up using personal computers and other digital devices for education and entertainment, will increasingly expect their information and data services are delivered through digital means.

The success of the Tablet PC is predicated on several factors, not the least of which is whether or not people want it. Although handwriting may be more natural than the use of a keyboard, the handwriting recognition accuracy of most systems has traditionally been mediocre at best. Apple, which led the way with its Newton products in the early 1990s, introduced the Inkwell handwriting recognition technology with Mac OS X version 10.2 (code-named Jaguar), at the Macworld exposition on July 17, 2002. A benefit of Inkwell over a Tablet PC is that it can be used with any digitizing pad that is connected to any Macintosh running Jaguar, and supports handwriting input in any application. In his keynote address, which is typically full of live demonstrations, Steve Jobs, uncharacteristically decided not to show it. Nor did Apple VP Phil Schiller at Seybold San Francisco on September 10, 2002.

Reading on Screen vs. Reading on Paper

The presentation of information *on-screen* as opposed to *on paper* carries with it a variety of inherently different characteristics. The first is that a computer screen is emissive, with light emanating from behind a glass surface, whereas paper is reflective, using the light in its immediate environment. Further distinctions are that:

- A computer screen requires a power source; paper does not.
- A computer screen can display more colors than can be printed on paper.
- A computer screen can display animation and video; paper cannot.
- A computer screen is often stationery; paper is not.
- A computer screen can display different pages, multiple pages, and pages in a variety of sizes; marks on paper are fixed.
- A computer screen can display any of the tens-to-hundreds of thousands of pages of documents stored on its attached computer hard drive whereas paper attains considerable bulk and weight as its volume increases.[24]
- Information on a computer screen is dynamic and changeable; information on paper is not.
- Images displayed on a computer screen do not deteriorate whereas continued handling of paper leads to noticeable wear and image degradation.

Numerous studies have been conducted to investigate how reading on-screen, primarily the reading of web pages, can be improved to better represent the experience of reading print. Jakob Nielsen, a recognized expert in this area, along with his research partner, John Morkes, found that web page readers tend to scan rather than to read, and that their preference is for text that is short and concise. These preferences, however, may deal more with the purpose for which readers used the Internet…that is, to locate specific information quickly. The correspondence between a web browser page and a printed page is not 1:1, and many computer monitors are landscape- rather than portrait-oriented, further exaggerating the difference.[25]

THE CASE FOR ON-SCREEN READING

Displays have traditionally served as windows for information. We read information on-screen which has a high relevance, and fulfills an immediate need. If it meets neither criteria, yet has usefulness, is it consigned to storage, either in memory or to media, or to print. Print at this point in the information cycle is totally under the control of the end-user. It will materialize from a laser or inkjet printer, and remain unread until the reader finds a use for it…and hopefully when that time comes, the user will be able to locate the printed document.

The distribution of information on-screen eliminates the time and expense of full-color printing, a process that even in its fastest digital production cycle cannot compete. In addition, the gap between the generation of information, and its packaging in a printed form, is growing rapidly. According to a Gartner Group prediction, for the typical enterprise, the amount of unstructured information doubles every three months.[26] While it took 50 years, between

1900 and 1950,[27] for information to double, Richard Saul Wurman observes that "the information supply available to us doubles every five years," and that "there has been more information produced in the last 30 years than during the previous 5000."[28]

The primary means by which people deal with the glut of information is through a computer interface of some kind. Today, virtually all information is generated and processed through computers, whether it is intended for viewing on-screen or on-paper. The reading on-screen experience is increasing significantly due to computer networking and the unprecedented impact of the Internet. According to a report from The United States Commerce Department released in April 1998, the amount of traffic on the Internet doubles every 100 days.[29] Print is simply not the appropriate medium to deliver such vast amounts of information…it cannot keep pace with the volume nor provide the means to efficiently store and retrieve its contents.

Computer Display Technology

With a strong case made for on-screen reading, it is appropriate to address the current state of computer display technology. First of all, how good does a display have to be? Although most computer monitors display 72 to 90 ppi, experts say that at a normal viewing distance of 18”, a user requires at least 200 ppi in order that they do not see the pixel structure of the display surface. If pixels can be seen, then the user is located too close to the monitor. 200 ppi is approximately equivalent to printed output at 700 dpi.[30] As viewing distance increases, the need for pixel density decreases. For example, at a viewing distance of four feet, 75 ppi is sufficient. The makers of e-paper maintain that a resolution of 300 dpi is sufficient, and that the human eye cannot differentiate resolution beyond that.[31]

At the Society for Information Display (SID) conference, the world’s premiere display technology event, in May, 2002, there were two tracks offered that dealt with “electronic paper.” This unprecedented interest in display systems that compete with, or replace, paper, legitimizes the view that print on paper is becoming less of an effective means for information display, and that there are emerging technologies that provide viable alternatives.

Today’s flat panel displays (FPD), mainly constructed using liquid crystals, are more than adequate substitutes for paper. The viewing angle of paper is 180 degrees, while the viewing angle of the best flat panel display is about 170 degrees. Although the reflectivity rate, a measure of sunlight readability, of paper is 100 percent, and the highest reflectivity of available LCDs is 70 percent, that amount is more than double what it was only four years prior, which shows significant progress.[32] In some respects LCDs are superior to paper. For example, the average contrast ratio of paper is 40:1,[33] whereas flat panels exhibit contrast ratios as high as 350:1. Flat panel displays, which are the window of a connected computer system, can also provide capabilities well beyond the mere emulation of paper, such as:

- Display pages, or selected page content, at any size (i.e. zoom), and in some cases, change the font to suit the reader’s preference.
- Store thousands of documents, or entire books, and retrieve any page or citation, almost instantly.
- Display multiple pages side-by-side, or open multiple document windows simultaneously.
- Control and maintain color management settings.[34]
- Support the manual or dynamic extraction of text and graphics for use in derivative documents.
- Generate text-to-speech output to read aloud what is displayed on-screen.
- Provide in-context definitions of unfamiliar terms.
- Search a text for specific content or context.
- Generate a summary of lengthy texts.
- Provide links to hypertext references or to web pages.
- Offer language translation (with the proper software).

- Display multimedia components such as animation, sound, and video.

LCD: THE PREEMINENT ELECTRONIC DISPLAY TECHNOLOGY

The prominent role of the Cathode Ray Tube, or CRT,[35] is being usurped by the LCD, or liquid crystal display. LCD display technology has been applied to a wide range of products, from watch and calculator displays, to large format computer monitors and television screens.

The liquid crystal phase of matter, discovered by Friedrich Reinitzer, an Austrian botanist in 1888, results when cholesteryl benzoate is heated. At one temperature the solid appears murky, whereas at a higher temperature it appears clear. He found that in the liquid crystalline state, in which materials exhibit a rod-like molecular structure, they have a tendency to align along a common axis. This is in contrast to the liquid stage in which there is no discernible order. In the 1960s it was discovered that the transmission of light through charged liquid crystals could be controlled, and in 1971 the first commercial LCD was introduced.[36]

LCDs are constructed of two sheets of glass containing a layer of liquid crystal material. The bottom sheet of glass is coated with a layer of transparent oxide film, usually indium tin oxide (ITO), which is electrically conductive, and is used to pattern the electrodes. The pattern of electrodes is used to provide the location where electric charges will be applied. In simple terms, the charges stimulate the liquid crystal particles to change alignment, and serve as minute shutters that block or allow light to be emitted. Several additional layers are applied to form a glass sandwich sealed with epoxy on all sides, with the exception of one corner. The open corner is used to infuse the liquid crystal material under vacuum and then sealed.

The fabrication of LCD panels, for laptop computers, monitors, televisions, and other applications, can be viewed in terms of the manufacturing generations, which are differentiated by the size of the mother glass substrates that have been, or are being, used. Each successive generation has presented a larger substrate size, therefore yielding either larger panels per substrate, or more panels per substrate. The second-generation substrate, for example, yields one 15-inch panel, which can be used for a laptop or computer monitor screen. The third-generation substrate size of 550- x 670-mm, can yield four 15-inch screens, and the fourth-generation substrate size of 680- x 880-mm can produce six 15-inch screens.

On May 24, 2002, LG Philips started production on the first fifth-generation fabrication production line in Kumi, Korea, using a mother glass substrate of 1000- x 1200-mm for the production of 15-inch and 18.1-inch desktop monitors, 15-inch laptop computer screens, and larger LCD TVs.[37] This substrate size, of more than one meter square, can produce up to fifteen 15-inch LCD panels, or any combination of other sizes. At full capacity, this one plant will produce over 60,000 full size sheets per month.

LCDs have several advantages over CRT displays: they are lighter, more energy efficient,[38] and more compact. In addition, the absence of the CRT flicker can reduce eye strain.[39] However, *some* forms of LCD also have many disadvantages: a restricted viewing angle, an insufficient (or at least lower) contrast ratio, and an inadequate (or at least slower) response rate for displaying animation and video. The characteristics of the various types of displays in common use are shown in Table 1.

LCDs and most other displays, use one of two methods to activate each of the pixels constructed within the display: passive or active addressing. In a passive display, the transparent electrodes are patterned in rows and columns perpendicular to one another, above and below the liquid crystal layer. A charge at the intersection of a row and column causes the liquid crystal molecules at the pixel site to align parallel to the electric field and become opaque. Due to the slow response rate of passive displays, more than one pixel can be on simultaneously, since the liquid crystals return to their non-excited states slowly.

In an active matrix display, which is typically used in computer monitors and television screens, the pixel addressing is initiated from behind the layer of liquid crystal film. The

Display Type	Viewing Angle	Contrast Ratio	Response Speed	Brightness	Power Consumption	Life
PMLCD (passive matrix liquid crystal display)	49-100 degrees	40:1	300ms	70-90	45 watts	60K hours
AMLCD (active matrix liquid crystal display)	>140 degrees	140:1	25ms	70-90	50 watts	60K hours
CRT (cathode ray tube)	>190 degrees	300:1	n/a	220-270	180 watts	years

Table 1. The Characteristics of Computer Displays in Common Use[40]

front of the screen is coated with a uniform layer of electrode material, while the back has a patterned coating. The patterned coating, called TFT, or thin film transistor, creates a switch behind each pixel that can be addressed faster and more accurately than the passive method. In addition, the active matrix has higher contrast and a greater viewing angle. The TFT and its associated gate and source lines are not highly transparent and therefore require a significantly brighter backlight.

Color is achieved by segmenting each pixel into subpixel components, each with its own filter: one each for red, green, and blue (RGB).[41] The filters selectively pass or absorb light. It is the combination of the three subpixels, illuminated to various intensities, which form the full color for each individual pixel.

In 1999 there was an oversupply in the field of flat panel displays, and in its pre-eminent form, the LCD display. The result was two-fold. First prices of the displays fell (even more than the typical price drop of 10 to 20 percent which has been common for more than fifteen years). Second, a portion of the oversupply, which was originally manufactured as displays for laptops, was diverted to create the market for LCD computer displays for desktop systems. This trend has created a growing demand for flat panel displays to replace CRTs both as displays in desktop computer systems and as televisions.

According to DisplaySearch, the leading display market research and consulting firm in the world, the market for flat panel displays (FPD) which are used in notebook PCs, Tablet PCs, LCD monitors, LCD TVs, mobile phones, PDAs, and digital and video cameras will increase by 39 percent in 2002 and 42 percent in 2003. These significant increases represent an acceleration by manufacturers in their glass input and yield ramps, which are likely, according to DisplaySearch, to lead to an over-supply situation. It was an oversupply of notebook displays that created the market for LCD monitors, which has helped to cause an erosion of the CRT monitor market.[42]

CREATING THE FUTURE

The 1999 Industrial Design Excellence Award from the Industrial Designers Society of America was presented to Robert Steinbugler for a design concept of the newspaper of the future. Steinbugler, an IBM designer, created a prototype newspaper, actually an *eNewspaper,* composed of loose plastic pages bound to a strip of aluminum and attached to a rigid pad containing control buttons. The spine and pad contained a dataport to receive the current issue, memory to hold it, and a battery to power the e-paper pages.

Figure 8. The IBM eNewspaper has a form factor similar in size and shape to a standard newspaper. (Photo courtesy of the IBM Strategic Design Group)

Figure 9. The electronic newspaper of the future will lie flat as well as bend, and will be resistant to most environmental hazards, although spilling hot coffee on it would not be a good thing. (Photo courtesy of the IBM Strategic Design Group)

The eNewspaper connects to a data source using a modem or network connection and searches for news of interest to the reader. The news is “delivered” to memory, or to a 300 MB microdrive, and the first 16 pages are displayed immediately on the dual-sided flexible media. After the reader finishes reading the first 16-page “section,” he or she presses a control button to load another section. The device is designed to reflect the way in which paper newspapers are read, folded, and carried; and how readers clip, save, and send news articles of interest.

Among IBM’s objectives for creating the prototype were to:

- Design a format that closely resembles what people are familiar with, but enhances that experience with more efficient electronic features.
- Provide the electronic means to cut, paste, store, and send articles and other content. At the same time the page format of the device would allow a user to copy or fax pages using conventional copiers and fax machines.
- Provide an environmentally responsible news distribution system that eliminates paper.

Although designed years before its availability, the first version of the IBM electronic newspaper pages were designed to use E Ink, which was then a “future technology.” IBM recognized the suitability of the media and became an early investor in the company. The second version of the eNewspaper was designed to utilize OLED (Organic Light Emitting Diode) display technology (Figures 8, 9, 10, 11).

The use of OLED as a portable, high-resolution display, has also been incorporated in a prototype reader developed by Universal Display Corporation (Figure 12).[43] The reader consists of a small cylinder which contains a single sheet of OLED wound around its core. The OLED is driven by active matrix circuitry, and imaged through internal memory that receives content through wireless technology.

Figure 10. Flexible pages will compose a section of the IBM eNewspaper. These pages are reimageable to display successive sections comprising one or more issues of the newspaper. (Photo courtesy of the IBM Strategic Design Group)

Figure 11. The flexible "enewspaper" backplane contains a touch-sensitive control panel used to manipulate its content. (Photo courtesy of the IBM Strategic Design Group)

The technologies that will enable "futuristic" devices, such as the IBM eNewspaper and the UDC Pen, consist both of new display technologies and new methods for producing the electronics, memory, batteries, and other components to drive them. The leading "new" display technologies that present the most potent challenge to ink-on-paper are Gyricon Media, E Ink, and OLED. All of these technologies are characterized by their innate capabilities to be made in thin, flexible forms; to exhibit a display that is "paper-like"; to be manufactured at prices much lower than current technologies; and to be manufactured in a roll-to-roll process with either in-line or off-line fabrication into finished electronic goods or devices.

The electronics that drive displays, referred to as the "backplanes," can now be manufactured by printing the electronics on plastic. This method, which earned its three inventors the Nobel Prize in Chemistry in 2000, opens an entirely new age in electronic component fabrication…one that is certain to reduce the cost, size, and weight of electronic devices while cutting the development and manufacturing time. It is certain to influence the creation of new sorts of electronic devices that will greatly influence all aspects of society.

Figure 12. This is an artist's mock-up of a portable pen-sized communication device that can receive information from the Internet and other sources. (Image courtesy of Universal Display Corporation)

Paper-like Electronic Displays

GYRICON MEDIA

Gryicon, from the Greek for "rotating image," is the name that Nickolas Sheridon, a physicist at Xerox Palo Alto Research Center (PARC) gave to his electronic paper in 1975. The project was begun with the intent to develop an inexpensive yet high-resolution display that could be used in place of the CRT monitor used on the Xerox Alto computer.[44] The Alto monitor was among its most expensive components, and Xerox wanted to reduce the $32,000 list price of the computer system. Sheridon recognized that the monitors available in the early 1970s had poor contrast, and were, in fact, a major focus of ergonomic and safety concern.[45] According to Sheridon, "I thought, I guess, that instead of replacing paper with the monitor, it might be smarter to replace the monitor with paper."[46] His first working prototype made using glass balls consisted of the Xerox "X", imaged somewhat crudely on a single sheet of the material. In 1977, seeing no practical value in his work, Xerox took Sheridon off of the project, and stopped all e-paper development. Sheridon nonetheless patented his Twisting Ball Panel Display in 1978. Sheridon resumed development in 1991, when his patents were on the verge of expiration, and when scientific discoveries in the field of electrically conducting plastic offered, what he believed, was the missing element for totally flexible electronic paper. He worked on a series of new patents with colleagues Ed Richley and Joseph Crowley covering Gyricon sphere manufacture, Gyricon sheets, and a variety of devices for imaging the material including a printer, stylus, and wand (Figure 13).

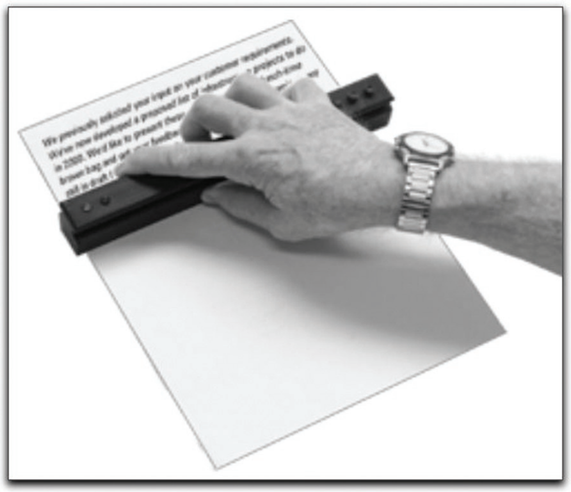


Figure 13. The Gyricon wand, shown in prototype form, would hold the digital contents of several volumes of information. Content would be formed on a blank Gyricon sheet by running the wand down its surface. (Courtesy of Gyricon Media)

The Gyricon material is composed of a thin, flexible, transparent silicone rubber sheet (Figure 14) in which millions of minute plastic spheres[47] are embedded (Figure 15). The spheres are *bichromal,* that is, black on one half,

Figure 14. Nick Sheridon, inventor of Gyricon electronic paper holds one end, and Fereshteh Lesani holds the other, of the first roll of material produced in cooperation with 3M. (Courtesy of Gyricon Media)

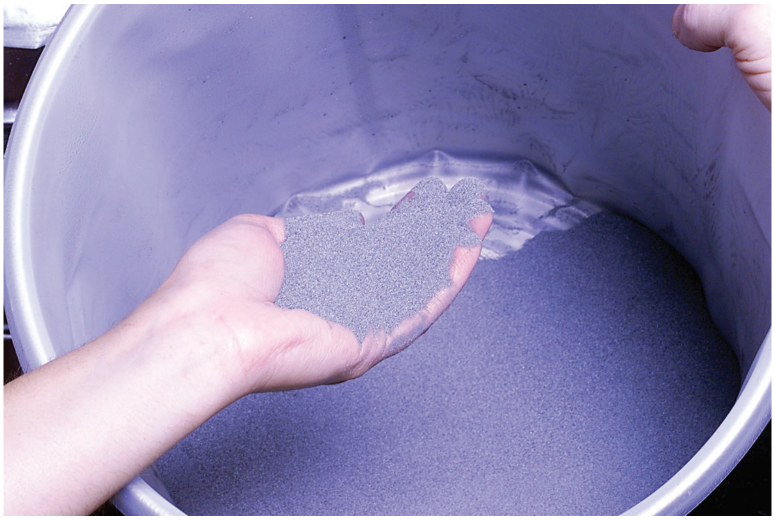


Figure 15. The minute Gyricon beads are as small as grains of sand, yet can be controlled independently to form high resolution images. (Courtesy of Gyricon Media)

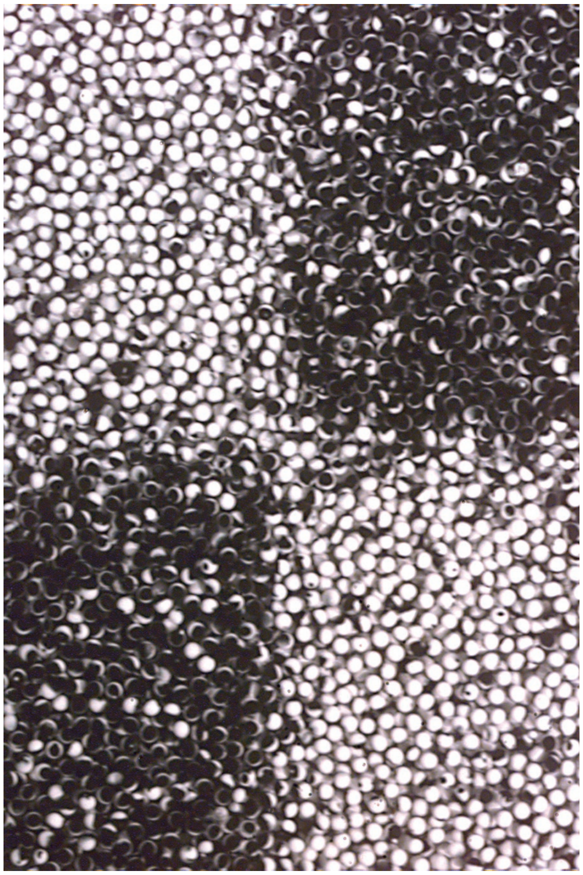


Figure 16. A close-up view of the bichromal Gyricon beads shows how the black hemisphere creates an image, while the white hemisphere creates the "paper" background. (Courtesy of Gyricon Media)

and white on the other. The black half carries a very small static electric charge, while the white half is electrically neutral. The spheres are free to rotate in their surrounding fluid, and to react to the presence of an electrical charge. The application of an electrical charge will either attract or repel the black hemisphere, and cause the spheres to rotate, placing one of their sides close to the surface. The black side up will result in the formation of an image, while the white side will produce the background (Figure 16). The material can be applied to a printed circuit backplane to precisely control the formation of image-producing "pixels."

The Gyricon material is *bistable* meaning that once an image has been formed it no longer requires power to maintain it. This attribute contributes to the low power requirements of the material, a characteristic that has earned it the "zero power display" description. A page requires only microwatts to image and can remain in its imaged state almost indefinitely, even if it is rolled up and stored in that manner.

Gyricon also exhibits the characteristic of being extendable. Matt Howard of Gyricon Media explains:

> "Extendable means the display can be folded up, rolled, and minimized when you're not using it, and then it can be expanded and maximized. The display can be maximized when you want to use it. This could have significant implications to things like Palm devices, where you can hide the display when you don't want to see all the information, or when you don't want to, or need to, see all the information….You can take that a step further. With electric paper, because it's low power and requires zero power to maintain an image, you can physically remove the electric paper from the driving electronics and from the power source that you use to put an image on it, and use several sheets of the material like you use paper on a desktop or in 3-D space. It means you have an infinitely large display area that can be broken up and manipulated in 3-D. It allows you to use electronic documents more like you use paper documents."[48]

In addition to its use as the faceplate for a passive- or active- matrix display, Gyricon material can be imaged in a specially built "printer." It can be used as paper would be used, fed through the device sheet by sheet to produce "printed" pages (Figure 17). Unlike paper, the material could re-imaged an infinite number of times. In addition, like paper, the image could be faxed or scanned, and recaptured in a digital format. Another proposed imaging method is with the use of a optical scanner wand that would be wiped across a Gyricon sheet to create an image. The wand could hold thousands of pages, and a single sheet of Gyricon could be used to view them all.

Sheridon envisions a Gyricon electronic newspaper as consisting of a lightweight briefcase-size cylinder, in which a sheet of Gyricon is wound around a spring-loaded rod held within its center. As the page is pulled out of a slit in the cylinder it would pass over a printer-head, and be imaged with news that was downloaded from the Internet through a wireless connection. To read a new page, the user would retract the page, just as a window shade is rolled-up, select a new page by pressing a button on the cylinder, and then pull out the sheet of Gyricon again. This process would be repeated to read any or all of the pages in one or more issues of the newspaper (or magazine, report, or any document for that matter). Interestingly, among Gyricon's many investors is Gannett, which owns 110 daily newspapers.[49]

The first commercial application for Gyricon Media will be in signage. Traditionally, retail signage is either printed and produced in the retail store, or in a central location, and then shipped to stores in the chain. The sign production system can be complicated since some items may not be sold in all stores, or pricing may vary based on location. Timing is crucial since pricing events are time-driven, and must correspond to concurrent advertising appearing in the newspaper, radio, television, and on the Internet. Sale pricing must also respond to competitive situations existing between rival stores, and special market situations caused by fads, fashion trends, inventory surpluses, weather, natural and man-made disasters, general economic conditions, and other factors. The retail signage business is huge and represents a "$14 billion opportunity," according to Xerox spokesman Bill McKee.[50]

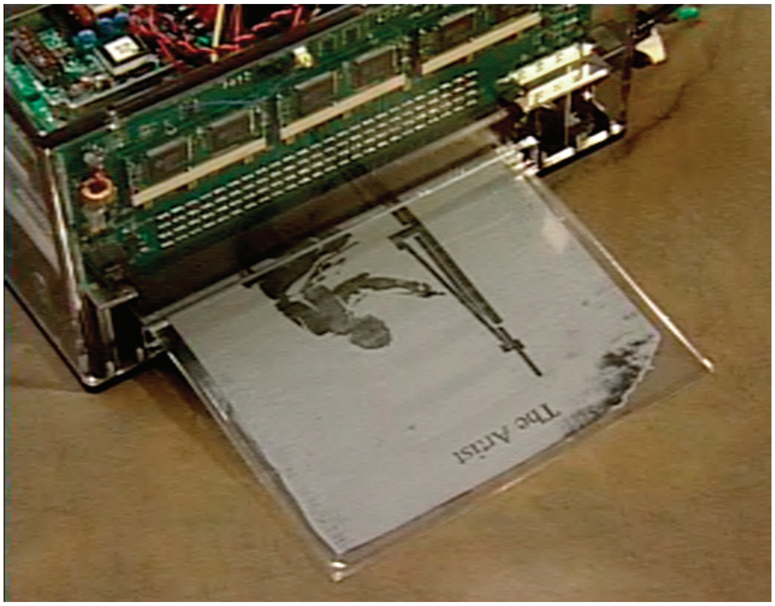


Figure 17. Here a sheet of Gyricon material exits a specially designed printer built as a proof of concept. It is believed that the imaging head of the printer will one day be small enough to fit in a purse or pocket. (Courtesy of Gyricon Media)

The need for electronic signage systems in retail stores is significant, because dealing with signage is time-consuming, and takes sales representatives away from their main responsibility, which is selling. Add to that the fact that in many circumstances the retailer is short-handed, and doesn't have the staff to properly change prices, hang promotional messages, and synchronize new prices with the cash register system. If done improperly, customers either are frustrated when they arrive and cannot find sale merchandise, or are charged the wrong amount when they check-out. Retailers may lose sales because items are not repriced, or may lose money when a non-sale item remains in the system with its sale price.[51]

Gyricon Media's first major test of its 11- x 14-inch SmartPaper signage system was at Macy's East in Bridgewater, NJ in their children's department. The installation was managed by Array/Thomson Leeds, a leading provider of P.O.P. (point of purchase) retail products. Fifteen low-power[52] SmartPaper based signs were installed on a six month trial period in

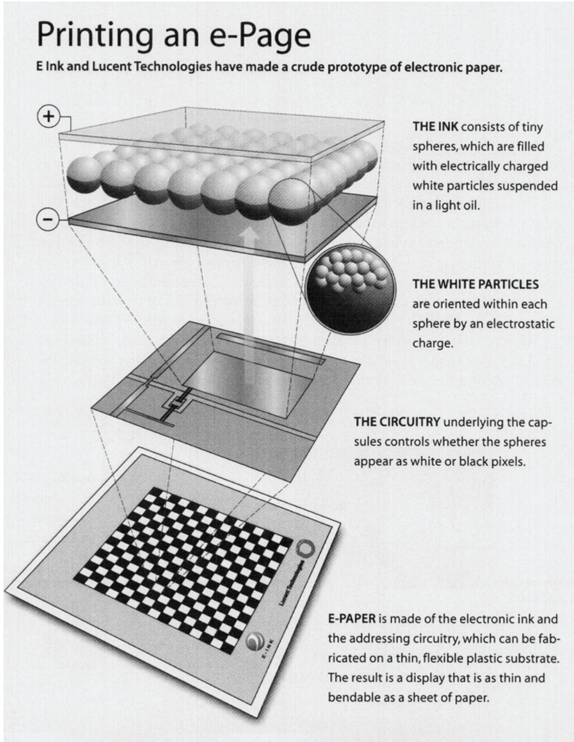


Figure 18. The E Ink imaging technology employs microencapsulated particles, about 100 microns wide, suspended in a light oil which has been dyed to produce the image. Approximately 100,000 capsules would fit in one square inch. The capsules are switchable and respond to electric charges causing them to appear either black (dark dye) or white (white pigment). After the capsules have been charged, they retain their orientation with little or no additional power. (Illustration courtesy of E Ink)

Figure 19. A prototype for a smart card containing an E Ink display. (Photo by author)

the new children's department, Kidz Zone. The content of each sign, i.e., its product name and price, was composed from data generated automatically by Macy's inventory database and sent wirelessly to each individual sign's network address.[53] According to Gyricon Media's interim CEO, Bob Sprague, "Our strategy is to first take SmartPaper to the retail signage market, which fits very well with our technology." Sprague estimates that up to one million Gyricon signs will be manufactured in 2003.[54] Sprague also sees other uses for e-paper, such as construction maps, wallpaper, maps, and even clothing, such as Army camouflage.[55]

E INK

Paper remains the leading format for newspapers, magazines, and other forms of mainstream print media. While its use is not going to diminish appreciably, it remains a target for a number of display technologies offering a paper-like look, but providing additional benefits, such as unlimited re-imaging.[56] E Ink, a company spun out of the MIT Media Lab and incorporated in Cambridge, MA in August, 1997,[57] manufactures an electronic paper-like substrate that uses the same materials found in paper (Figure 18). The black image-forming component contains the same dyes used to make ink dark, and the white background-forming component contains titanium dioxide, used to whiten paper.[58]

As a display technology, E Ink compares favorably to LCD technology. According to Russ Wilcox, vice president and general manager of E Ink, "It's five times brighter, it uses 99 percent less power, it's more portable, has a bigger screen, and longer battery life. It's thinner and lighter, has a higher resolution, and gives workers more freedom. And it gives IT a new tool at their disposal."[59] It also offers opportunities for applications, such as smart card production, never possible prior to the introduction of E Ink technology (Figure 19).

Having perfected the microencapsulation process, E Ink announced an agreement with Lucent Technologies in September 2000 to develop a flexible plastic printed TFT backplane that could be used to address the activation of the pixels residing on the active matrix.

Lucent successfully completed that project, which was conducted on a contract basis. The result was a lightweight 5-inch prototype powered by 256 organic transistors requiring little energy and retaining the capability to display an image even when flexed or rolled up (Figure 20).

The conventional process for creating an active matrix backplane for a display is with the use of a silicon circuit that is made using photolithography. To make a backplane for the plastic-based E Ink material, silicon could not be used, because it requires high temperatures which would melt the plastic. John Rogers, Director of Condensed Matter Physics Research at Bell Laboratories at Lucent Technologies, developed a microcontact printing system that is analogous to rubber stamping, but with ultra-high resolution. The process begins by etching the circuit onto a master stamp used as a die to create several reusable plastic stamps. To "print" a circuit, the stamp is "inked" with a sulfur-containing organic compound which is pressed onto a mylar sheet coated with gold. The transferred organic ink serves as a mask, protecting the unexposed gold, which is etched from the surface. The organic ink is then removed, and a carbon-based semiconductor is adhered to the gold circuit. The result is a transistor array identical to the pattern etched on the master stamp.

Using this system, the backplane circuitry is printed onto mylar plastic which is combined with the E Ink plastic layer to form the display. According to Dr. Rogers, each transistor that has been printed on the backplane serves "as a voltage controlled switch [that] controls the color of the electronic ink pixels. When the particles are at the front of the display (Figure 21), the pixel appears white; when they are at the back, the pixel takes on the color of the dyed fluid in which the pigments are suspended — black in this case."[60]

Joseph Jacobson, who led the development of electronic ink research at MIT, and who, along with MIT undergraduates J. D. Albert and Barrett Comiskey joined Russell J. Wilcox to create the company, said this about the work at Lucent: "I think this is extraordinarily significant. The real dream has been to have

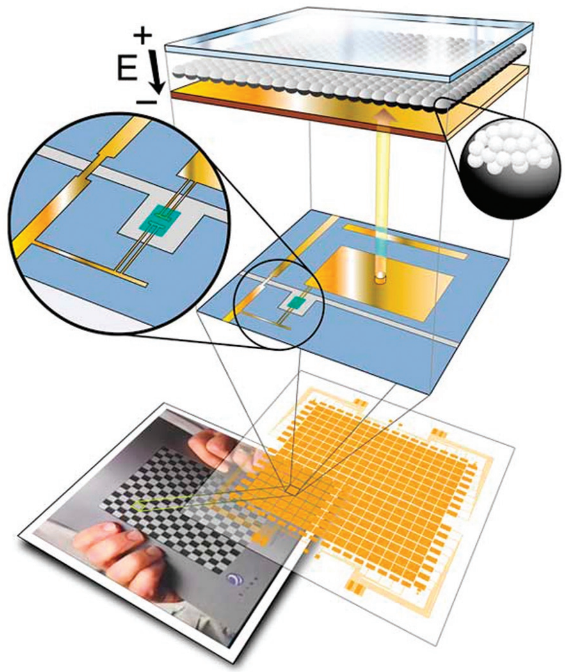


Figure 20. Lucent Technologies developed a flexible plastic display backplane made of mylar for the E Ink material. The precise application of electrical current through the backplane results in the proper reorientation of the E Ink particles. (Illustration ©2000, Lucent Technologies)

Figure 21. A jar containing the E Ink particles. Close examination shows that the particles have separated from the light oil carrier. (Photo by author)

Figure 22. The first commercial use of E Ink technology was in May 1999 in the J.C. Penney Athletic Link department in their Marlborough, MA store. The content of the sign could be changed by the store manager through a wireless link. The three month trial was part of a field experiment involving over 30 retailers. Results of the trials led to the development of the second-generation sign product: Ink-In-Motion. (Photo courtesy of E Ink)

Figure 23. E Ink Ink-In-Motion signage provides attention-getting animation at point of purchase locations. The signs are thin, light, and require little power, running for as long as a year on two AA batteries. (Photo by author)

electronic newspapers or electronic books that are manufactured in the way that you would manufacture a regular book…. This is the first time that anybody has manufactured all of the elements — meaning both the electronics and the display itself — by printing."[61]

E Ink[62] was the first to experiment with in-store dynamic electronic signage (Figure 22). Their first commercial venture is to produce electronic signage in retail stores (Figure 23). According to E Ink CEO Jim Iuliano, "Our express purpose is not to go head-to-head with liquid crystal [LCD]. I want to go where liquid crystal can't go."[63] The E Ink Ink-In-Motion™ battery-powered sign system uses predefined content which is repeatedly cycled with animation, a flashing background, or changing message, to attract shoppers at point of purchase locations. E Ink estimates that their material can be refreshed at the rate of from one to ten changes per second, which makes it unsuitable for video applications.

The simplest signage designs use a direct-drive backplane, with the signage component contents designed into the circuitry. This design does not require thin film transistors (TFTs) on the backplane, which saves money, however, the content of the sign, other than making it flash or animate, cannot be changed.

E Ink has partnered with both Toppan in Japan, a world leader in color filter arrays for flat panel displays, and Royal Philips Electronics of Sunnyvale, CA, a leading supplier of displays for the mobile market, to develop display systems that can be incorporated into third-party products, such as mobile phones, PDAs, e-book readers, and other digital devices (Figure 24). The result has been the development of several display modules, including the world's first high resolution, active-matrix color display using electronic ink (Figure 25).

The initial display products that will be produced by Philips will be manufactured using conventional glass transistor backplanes, with the flexible E Ink material laminated on their surface (Figure 26). Although the displays themselves will not be flexible, the displays will be less than half as thick, and weigh less than half as much, as displays produced using

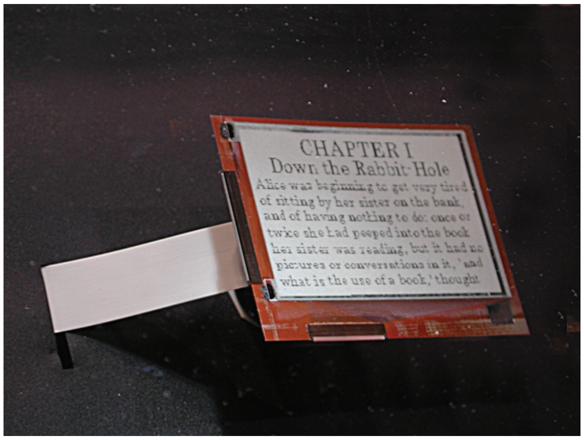


Figure 24. An example of the thin, light-weight E Ink display that will be used in cell phones and similar-sized devices. (Photo by author)

Figure 25. The first high-resolution, active-matrix color display made with electronic ink measures 5 inches diagonally, with a resolution of 320 x RGB x 234 (80 ppi). It is constructed of components from each of its co-developers: the electronic ink layer from E Ink, the color filter arrays from TOPPAN Printing, Ltd., and the active matrix backplane from Philips. The display was announced on July 1, 2002. (Photo courtesy of E Ink)

Figure 26. The display that Philips exhibited at the Society for Information Display meeting in May 2002. (Photo by author)

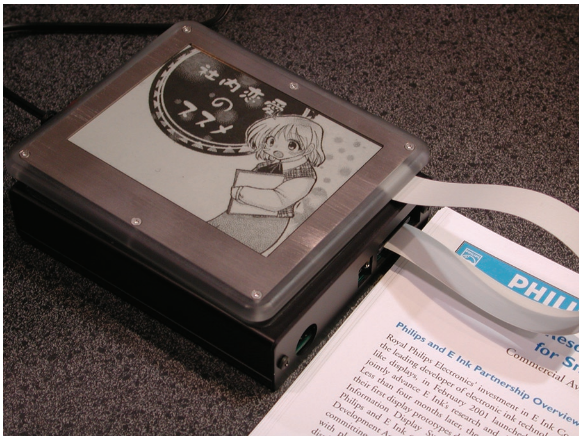


Figure 27. An example of the display that will be among the first to be marketed by Philips. (Photo by author)

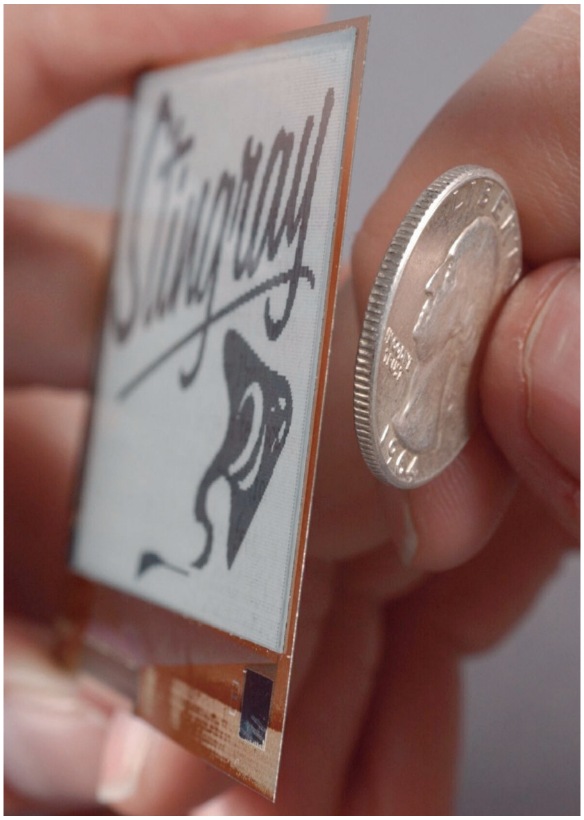


Figure 28. E Ink's prototype display, expected to be in wide distribution by 2004-2005, is the world's thinnest active matrix display with a thickness of 0.3 mm. (Photo courtesy of E Ink Inc.)

other technologies (Figure 27). In June 2002, E Ink demonstrated a prototype of the world's thinnest active matrix display, at 0.3 mm, or approximately half the thickness of a credit card (Figure 28). E Ink's paper-like electronic ink was coated onto a plastic face sheet which was then mated to a rigid steel foil transistor backplane. The card-size display has 80 ppi, and a resolution of 100- x 80-pixels. It is expected to be used for SmartCards and cell phone displays. The generation of displays that will follow will feature completely flexible designs.

By 2005, E Ink plans to produce flexible RadioPaper which will implant a radio frequency ID tag in the material that will automatically receive the latest edition of a particular newspaper or magazine. According to Darren Bischoff, marketing manager at E Ink, "The ultimate dream of E Ink is RadioPaper, a dynamic high-resolution electronic display that combines a paper-like reading experience with the ability to access information anytime, anywhere. This RadioPaper will be thin and flexible just like organic paper and could be used to create an electronic book or newspaper with real pages that can be leafed through, thumbed over and read on the beach."[64]

OLED

Organic Light Emitting Diodes, or OLED, represents a technology with one of the strongest prospects for materially changing the information display industry as we know it. Unlike LCDs, which are used in a wide variety of applications, OLED does not require a backlight or an external light source, which results in less bulk, less weight, and overall less thickness. Thin and light are significant features because they affect the price and performance of the devices into which they are manufactured. A further advantage of the display thinness is an extended viewing angle (of 160 degrees) which is a deficiency of most LCD screens (Figure 29).

Another significant benefit of OLED is the lower power requirements. Without the need to power a backlight or external light source, battery life can be extended considerably (Figure 30). Despite the lower power consumption, the solid state nature of the technology makes the displays highly responsive, with switching speeds of 100 to 1000 times faster than those of LCDs (Figure 31). In addition, OLEDs have another advantage over LCDs in that much of the light produced to back-illuminate an LCD screen is absorbed or filtered out by the LCD itself, whereas an OLED is considerably more energy efficient.

OLEDs are related to LEDs (Light-emitting diodes). These are very familiar devices, used most commonly as indicator lights. They too are emissive, relatively thin, and viewing angle independent. Inorganic LEDs, which were developed in the late 1950s, are based on semiconductors, such as Gallium Arsenide, Gallium Phosphide, and Gallium Nitride. Prior to the introduction of liquid crystal displays, LEDs were commonly used in calculators, and are still used in large advertising signs where their qualities of long life and high brightness are particularly useful. However, LEDs are not appropriate for use in high resolution displays due to their relatively large size and expense.

The LED is formed by joining two semiconductor materials: p-type (holes) and n-type (electrons). The light in an LED is formed from the unstable condition that exists within it when voltage is applied, and an excess of

Figure 29. OLED displays are a particularly good choice for automobile instrumentation because they are viewed easily in any kind of lighting conditions, as shown in this prototype by Sharp exhibited at the Society for Information Display show in Boston, in May 2002. In addition, the displays are light-weight, which helps to reduce the overall weight of the vehicle. (Photo by author)

Figure 30. With the inclusion of an OLED display, this Samsung cell phone will operate for much longer than it would using an LCD. (Photo by author)

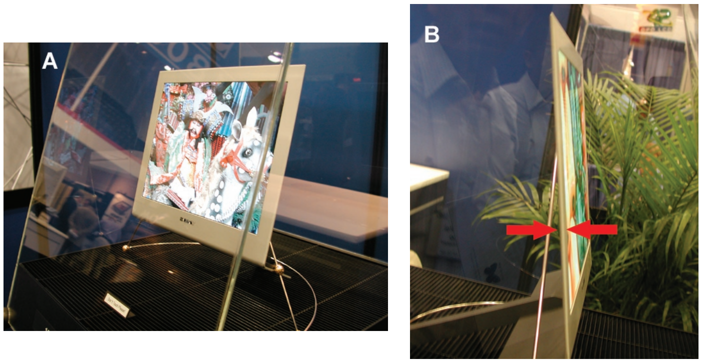


Figure 31. The switching speeds of OLED are fast enough to support the display of television, as shown on this working prototype from Sony (A). The monitor is extremely thin, having the approximate thickness of a piece of corrugated cardboard (B). (Photos by author)

Figure 32. This Pioneer radio faceplate is the first to use OLED as a component in a commercial product. (Photo by author)

potential energy is released. Electrical energy is converted into light in a process know as *electroluminescence.* In 1987, two Eastman Kodak scientists, Ching Tang and Steve Van Slyke, discovered that p-type (cathode) and n-type (anode) organic materials could be combined to make organic light-emitting diodes (OLED) with high efficiency. They produced the first OLED device prepared by vacuum sublimation, and based on small molecules (as opposed to using polymers, or large organic molecules). According to Webster Howard, vice president of technology at eMagin, a Kodak OLED licensee:

> "A typical OLED of the Kodak variety is formed by starting with a transparent electrode, which also happens to be a good emitter of holes, indium-tin oxide (ITO). The ITO is covered with a thin layer of copper phthalocyanine, which passivates the ITO and provides greater stability. Then, the p-type material, for example, a naphthaphenylene benzidine (NPB) is deposited, followed by the n-type material, for example, aluminum hydroxyquinoline (Alq). Finally, a cathode of magnesium-silver alloy is deposited. All of the films can be evaporated, making fabrication simple. Electrons and holes recombine at the interface of the n-type and p-type materials and emit, in this case, green light.
>
> "A voltage of 5-10 Volts is sufficient to drive enough current to cause a very bright emission, which is another virtue of the technology, since low voltage circuits are easier and less expensive to fabricate."[65]

In its simplest form, an OLED is composed of a layer of luminescent material held between two electrodes, one of which must be transparent, so light can be emitted. The thickness of the organic layers is about 100 nm, and the two electrodes add about another 200 nm, meaning the overall thickness and weight of the raw display is due primarily to the substrate it is built on. When electric current is conducted between the electrodes it passes through the luminescent material, and causes it to emit light the color of which is dependent upon the organic characteristics of the material. It is also possible to create a white-light emitting OLED, and several companies are working toward the production of a thin, flexible material that can be used in place of overhead fluorescent lighting (see page 35).

OLED displays, like LCD, can be manufactured either as passive or active matrix arrays. Color displays are created either by using stripes of different color emitters to create pixels of red, green, and blue subpixels, or to dope[66] the emitter so it produces white light,[67] over which red, green, and blue filters are applied. The manufacturing process is intolerant of oxygen or moisture, and must be encapsulated immediately after fabrication.

In comparison to LCDs, OLEDs provide higher efficiency and lower weight, and do not require backlighting or reflective light. Because only that part of the display that is lit requires power, the displays are highly energy efficient. Although generally produced on glass, they can also be produced on plastic, providing flexibility, which makes them especially useful for instrument panels in cars, boats, and planes; curved displays in consumer products and digital devices of all sorts; and *potentially as a substitute for paper*. There are well over 100 companies, and a similar number of universities and research labs, around the world, actively pursuing the research and development of OLED displays. Successful fabrication methods have included evaporation of small molecules in a high vacuum system, spin coating a polymer-containing solution in an inert atmosphere, screen printing, ink-jet printing, and spraying techniques.[68]

The first commercial product containing an OLED display was produced by the Pioneer Electronics Corporation in the spring of 1999 (Figure 32). Their mass-production of small-molecule, passive matrix displays consists of four fixed colors (blue, green, yellow, and orange). Their plant in Yonezawa, Japan produces 300,000 units per month. DisplaySearch estimates that total revenue from organic light emissive displays will reach $4.2 billion by 2007.[69]

LEP

A variant of OLED is Light-Emitting Polymers (also Polymer LED or PLED). This is the "polymer" version of OLED, as opposed to the "small molecule"[70] version which was originally patented by Kodak.[71] Light emitting polymers are to polymer plastic what light emitting diodes (LEDs) are to traditional semiconductors. The technology was discovered by Richard Friend and Andrew Holmes at the Cavenish Laboratory, and led to the capitalization of Cambridge Display Technology (CDT)[72] by Cambridge University in 1992 (Figure 33). The technology is based on the principle that certain conjugated polymers, such as polyprolle and polyaniline, will emit light when exposed to an electric current.

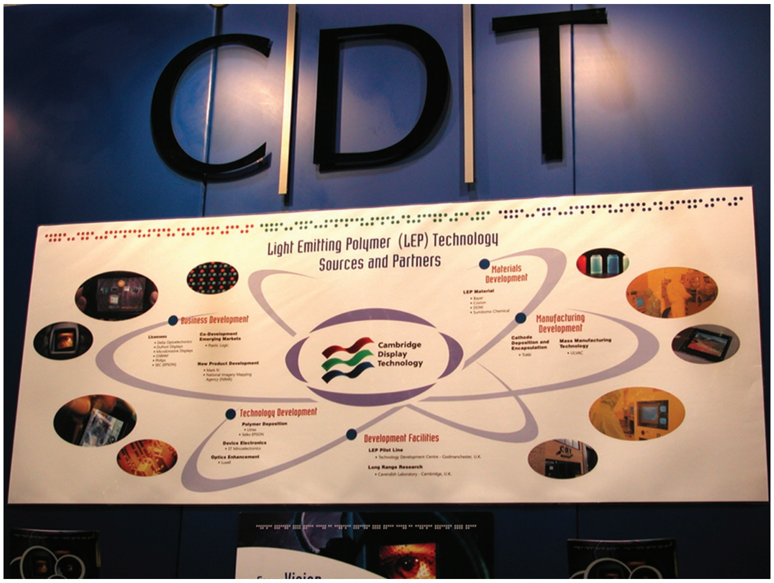


Figure 33. A sign from the Cambridge Display Technology (CDT) booth at the Society of Information Display in Boston, May 2002, shows their sources and partners. (Photo by author)

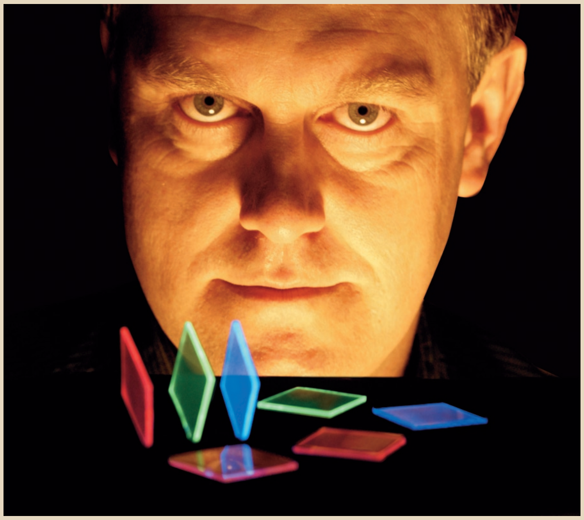
LET THERE BE LIGHT

(Edited from a press release issued July 8, 2002)

Opsys predicts that its light emitting technology could eventually replace light bulbs. They are confident that their materials can be made into flat, transparent, flexible full-color displays and light-emitting panels have the potential to become inexpensive enough to incorporate into wall coverings, furniture and even safety clothing. They may develop to be as efficient as light bulbs and not only provide information, but also décor, ambient lighting and signage applications. The potential is almost limitless. In the coming years consumers could have truly mobile information access—football scores downloaded to displays on cans of lager, animated recipes displayed on food packaging and windows that can be transformed into TV screens at the flick of a switch!

Opsys' revolutionary technology is based around newly developed chemical materials that are used in the production of flat displays, called dendrimers. These emit coloured light when subjected to an electrical current and because the dendrimers are in solution (similar to an ink), they can be printed directly onto most flat surfaces to make a display screen. This enables shaped, flexible and transparent displays to be produced.

Opsys' new dendrimer materials enable displays to be produced that have much brighter, purer colours than conventional displays. Crucially, the new dendrimer displays have been proven to be more power efficient; a vital consideration for the commercial viability of such screens, particularly in portable battery-powered products such as mobile phones and personal digital assistants (PDAs).



Doctor Paul Burn, consultant to Opsys, behind glowing slides spin-coated with Opsys' dendrimer materials.

Commenting upon the new dendrimer technology, Michael Holmes, Opsys' CEO says, "Dendrimer-based technology is an exciting breakthrough that will revolutionize the display industry. The possibilities presented are tremendously exciting. In the not too distant future, you could see transparent displays on shop windows, personal curved 'wristband' displays, light emitting panels on safety clothing and even TV's that you could roll up and carry around!"

Opsys Displays — www.opsysdisplays.com

DOE FUNDS OLED LIGHTING DEVELOPMENT

(Edited from a press release issued August 12, 2002)

Universal Display Corporation has been awarded two $100,000 Small Business Innovation Research (SBIR) contracts by the U.S. Department of Energy (DOE) to demonstrate the feasibility of using its proprietary, high-efficiency phosphorescent OLED (PHOLED™) and flexible OLED (FOLED™) technologies for general lighting applications. Since general lighting is responsible for more than 20 percent of the U.S. energy consumption, new broadband white lighting sources are needed to offer significant improvements in power efficiency and color quality with less environmental impact than traditional incandescent and fluorescent lighting.

Based on proprietary technology developed for the flat panel display industry, Universal Display and its research partners, Princeton University and the University of Southern California, have identified several new approaches to generate highly-efficient white light that may also open up significant new opportunities in the general lighting industry.

In the DOE SBIR Program entitled "White Illumination Sources Using Striped Phosphorescent OLEDs," Universal Display and its partners will focus on demonstrating a broadband white light source built on a flexible plastic substrate that consists of a series of highly-efficient red, green and blue PHOLED stripes that combine to emit white light.

In the second DOE SBIR Program entitled "Monomer-Excimer Phosphorescent OLEDs for General Lighting," Universal Display and its partners will focus on demonstrating an innovative PHOLED structure that utilizes the combined monomer and excimer excited states to achieve high-quality, efficient white emission.

The Federal SBIR Program is designed to stimulate technological innovation in the small business sector and typically consists of three phases. During the first phase, the scientific, technical and commercial merit and feasibility of a novel idea are demonstrated. If successful, a subsequent Phase II Program may be awarded that is typically $500,000 to $750,000 over a 24-month period to pursue further research and the development of a well-defined prototype. In a final Phase III Program, the demonstrated prototype is developed into a viable product for sale in the military and/or private sector.

Universal Display Corporation — www.universaldisplay.com

Figure 34. Improved screen displays, such as this prototype CDT color display built into a Palm V PDA, provide the means to read the screen under any lighting conditions and at any angle. (Photo courtesy of Cambridge Display Technology)

Figure 35. Advancements in screen technology will enable the development of new consumer electronic devices, such as this TV watch. (Photo courtesy of Cambridge Display Technology)

Unlike LCD, which requires two sheets of glass, LEP requires just one sheet of plastic or glass. In addition, since it is emissive, LEP does not require backlighting, and consequently requires less power. LEP displays also exhibit wide viewing angles, and since they are composed of plastic, can be curved and also be made flexible. The technology can be applied to existing uses, such as PDA screens (Figure 34), and for new uses, such as tv-watches (Figure 35) and wrist computers.

Printing Electronic Circuitry on Plastic

In December of 2000, the Royal Swedish Academy of Sciences awarded the Nobel Prize for Chemistry "for the discovery and development of conductive polymers" to Alan J. Heeger, Alan G. MacDiarmid, and Hideki Shirakawa. In their announcement of the award the Academy made this statement:

> "We have been taught that plastics, unlike metals, do *not* conduct electricity. In fact plastic is used as insulation round the copper wires in ordinary electric cables. Yet this year's Nobel Laureates in Chemistry are being rewarded for their revolutionary discovery that plastic *can*, after certain modifications, be made *electrically conductive.*
>
> "Plastics are polymers, molecules that repeat their structure regularly in long chains. For a polymer to be able to conduct electric current it must consist alternately of single and double bonds between the carbon atoms. It must also be "doped", which means that electrons are removed (through oxidation) or introduced (through reduction). These "holes" or extra electrons can move along the molecule — it becomes electrically conductive.
>
> "Heeger, MacDiarmid, and Shirakawa made their seminal findings at the end of the 1970s and have subsequently developed conductive polymers into a research field of great importance for chemists as well as physicists. The area has also yielded important practical applications. Conductive plastics are used in, or being developed industrially for, e.g. anti-static substances for photographic film, shields for computer screen against electromagnetic radiation, and for "smart" windows (that can exclude sunlight). In addition, semiconductive polymers have recently been developed in light-emitting diodes, solar cells and as displays in mobile telephones and mini-format television screens.
>
> "Research on conductive polymers is also closely related to the rapid development in molecular electronics. In the future we will be able to produce transistors and other electronic components consisting of individual molecules — which will dramatically increase the speed and reduce the size of our computers. A computer corresponding to what we now carry around in our bags would suddenly fit inside a watch."[73]

This new field has been named "*organic* electronics." It is "organic" because the composition of the plastics that can conduct electricity contain the kind of carbon molecules that are a part of life as we know it, despite the fact that these substances are not found in living creatures. Although plastic-based electronic circuits do not yet exhibit the high degree of conductivity of inorganic materials like copper and silicon, they do provide the immediate benefits of being lightweight, inexpensive, flexible, and of greatest significance, *printable.*

The printability of electronic components suggests they can be produced in a roll-to-roll manufacturing line, virtually on-demand. Since all of the components are printed, there is no inventory per se, and no component supply chain to contend with. The automated assembly of fine-featured thin film devices uses inexpensive materials, such as rolls of readily available polyethylene terephthalate (PET, also known as polyester), the material used to make plastic jars, soft drink bottles, injection-molded consumer products, and the mylar for overhead projector viewgraphs. The material exhibits all the qualities necessary for carrying electronics…it is clear, strong, tough, and has a barrier to gas and moisture, and resistance to heat.

ROLLTRONICS

Among the first companies to venture into the business of roll-to-roll electronics fabrication is Rolltronics.[74] They have developed a roll-to-roll manufacturing process that uses a patent portfolio licensed from Lawrence Livermore National Lab and the University of Texas at Austin. Their proposed manufacturing process begins with a roll of PET material that is over 1000' long by several feet wide. It follows through a three step process in which silicon is layered on the surface, a pattern is applied and finished, and the in-line packaging of layers is completed. The end product may be a roll of memory, displays, CPUs, batteries, sensors, RFID (Radio Frequency Identification tags used for animal tracking and merchandise anti-theft), and more. Plans include the manufacture of multi-layer devices.

Rolltronics believes they will be able to fabricate a wide variety of electronic devices, with component sizes ranging from 0.5 microns to 100 microns, based upon their capability to fabricate what they call the new "DNA." This new code consists of these elements:

- D = the display for the visual presentation of information
- T = the transistors for the logic circuits
- M = memory for storing information
- P = power for providing the electricity to activate the device

Using these code elements it is possible to design and manufacture smart appliances and portable devices that will be smaller, lighter, thinner, more energy-efficient, more durable, and less expensive than ever before. Rolltronics views this as the beginning of a new industry rather than a "competitive knock-off of the semiconductor industry." Through in-line roll-to-roll manufacturing it is possible to produce a five layer device composed of the following:

Top: The Display Components
2nd: The Display Driver Components
3rd: The Rechargeable Battery
4th: The Bi-Stable Memory
5th: The Central Processor and Antenna

Although a Rolltronics facility is not yet in operation, in July 2001 it produced the world's first amorphous silicon transistors in a roll-to-roll environment. Rolltronics produced the prototype material through a partnership with Iowa Thin Film Technologies (ITFT), a manufacturer of thin-film solar modules. ITFT is the first and only company in the world to have a working roll-to-roll line producing semiconductor devices.

The market that Rolltronics has chosen to enter is enormous, and consists of the following segments:

- Integrated Circuits: $40+ billion
  - Display backplanes for flat panel displays and signs: $38 billion
  - Biometric fingerprint sensors: $1 billion
  - Digital X-ray detector plates: $100 million
  - RFID tags for products and documents: $2 billion
- Nano-scale Molecular Memory Arrays: $60 billion
- Thin Film Rechargeable Batteries: $10 billion

Rolltronics has made a serious commitment to the environment, with plans to develop "a cradle-to-cradle mentality" so everything they build can be recycled. As impressive as that is, IBM director of physical sciences at IBM Research, Tom Theis, has taken this objective one step further with the goal of creating devices that are completely biodegradable.

FlexICs

Another of the first companies to enter the roll-to-roll manufacture of electronics on plastic is FlexICs.[75] In June 2001, FlexICs opened an 18,000 square foot pilot plant in Milpitas, CA, for the production of semiconductors on plastic. The plant includes a Class 100 cleanroom and the highly specialized equipment designed for printing semiconductors on plastic. The FlexICs process is unique in that they have developed a method of fabricating polysilicon TFTs on plastic using low temperatures (<100 degrees C), so the plastic does not deform. Their business will consist of working with display manufacturers to produce an entire display component consisting of the printed polysilicon TFT backplane with drivers, and the display material.[76]

The FlexICs process, which is based on a DARPA-funded product at Lawrence Livermore National Lab to fabricate thin-film transistors on plastic, begins with a roll of PET plastic, several feet wide. It passes through several processing chambers. The manufacturing process has been likened to a newspaper press, the difference being that the flexible plastic material that exits is not covered with ink, but with silicon-based semiconductors. Full-scale manufacturing of display backplanes for third-parties is expected to begin in 2004. FlexICs does not plan on manufacturing nor selling displays itself.

IBM T. J. WATSON RESEARCH LAB[77]

Another initiative of significance is the work being done at the IBM T. J. Watson Research Lab in Yorktown Heights, NY. IBM has several projects underway dealing with flexible display technologies. Among them is a project that involves a process they call OTFT, for organic thin-film transistors. They have demonstrated the capability to deposit an organic semiconductor onto plastic and other materials using a printing or spray method to pattern the transistors, which measure several microns wide. They believe they will be able to match the conductive speed (referred to as "mobility") of amorphous silicon in a manufacturing environment in open air, and at room temperature. This technology holds the promise for the production of inexpensive thin-film transistors that could be used to manufacture flexible displays and a multitude of other electronic devices.

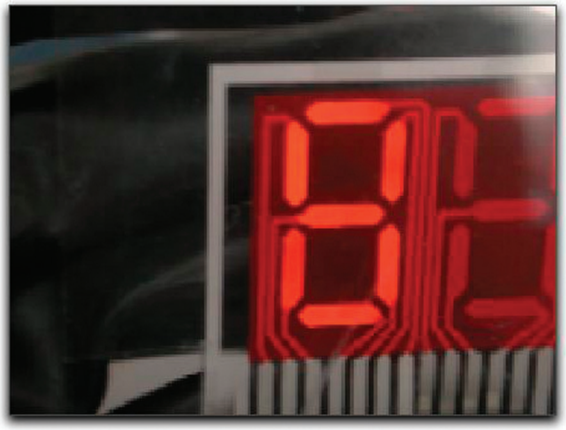


Figure 36. This is a picture of one of the first light emitting displays manufactured using ordinary screen printing technology. The first successes were achieved in May 2002. (Photo courtesy of Add-Vision)

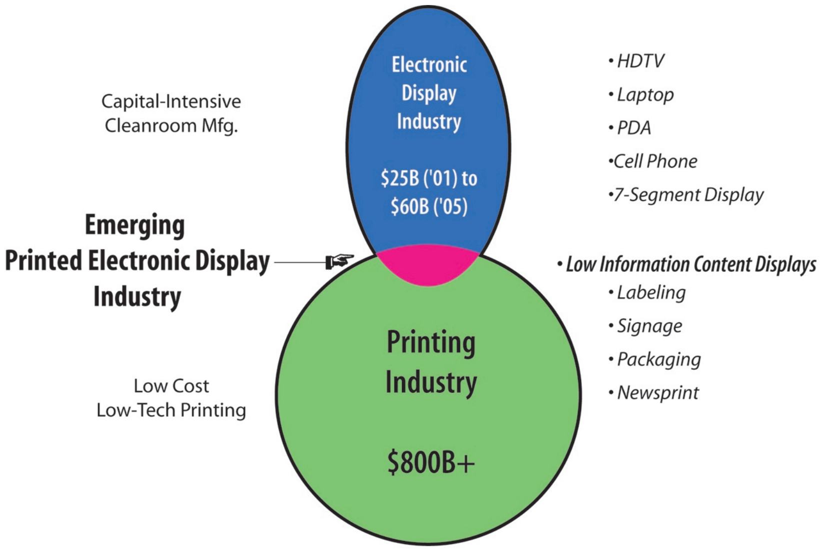


Figure 37. Add-Vision's view of the market for the emerging printed electronic display industry. (Redrawn from a diagram provided by Add-Vision)

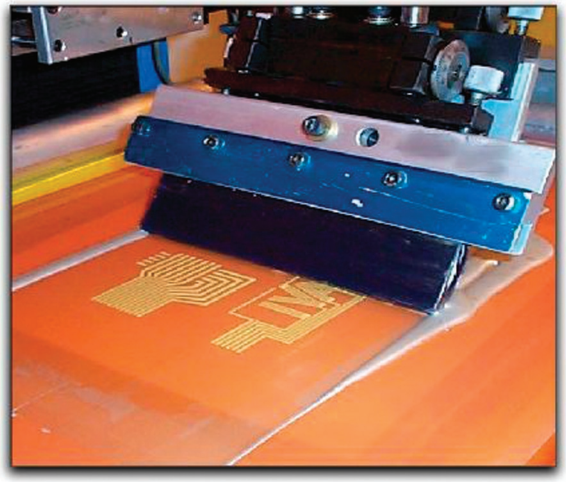


Figure 38. A conventional, unmodified screen printing press is used to produce light emitting displays in a multi-pass process. (Photo courtesy of Add-Vision)

ADD-VISION INC.[78]

Add-Vision maintains a unique position in the printable display market, having developed a patent-pending process to print inexpensive light-emitting displays (Figure 36). The company has positioned itself in the *printed electronic display industry*, formed by the overlap between the traditional electronic display industry and the printing industry (Figure 37). The displays are printed using a conventional screen printing process (Figure 38), by lower skilled workers, on almost any surface, using fewer manufacturing production steps, and in a non-clean-room environment. Unlike other display technologies, the Add-Vision process is relatively low-cost, with few of the substantial start-up costs generally associated with light-emitting polymer (LEP) display fabrication plants.

Add-Vision's manufacturing process can be accomplished entirely in open air using standard screen printing presses. The key to its technology is the capability to print an air stable top electrode as part of the LEP display. In contrast, all other manufacturing processes require an expensive clean room environment and, according to Add-Vision, "inert gas environments for evaporating and vacuum depositing non-air stable top electrode."

Displays produced using this manufacturing process will be closer in cost to printed materials than to conventional glass displays. Add-Vision estimates the average industry cost per square inch for various display manufacturing processes to be:

LCD	$1.50
LED	$1.00
Plasma	$1.00
Add-Vision	$0.15
Print Media	$0.05

It is significant that such low production costs are estimated right from the start. Like most forms of traditional print, an Add-Vision display will have a fairly short length of service — initially in the range of three to six months of active life. The target is to build an average usable life of 500 active hours of display life.

The displays embody virtually all of the qualities necessary for commercial success: they are "ultra-thin, flexible, rugged, low-voltage, low-cost, and viewable in both indoor and outdoor environments."[79] The low cost of the displays will make them appropriate for applications that are either cost-prohibitive or simply haven't been possible. Although the displays can be printed directly on almost any substrate, the company plans to produce initially "peel and stick" displays that can be incorporated in almost display environment. Their initial markets will be in labeling, signage, packaging, and newsprint, all of which will benefit from animated and dynamic messaging. The company is negotiating a manufacturing license from CDT for non-exclusive marketing rights to these markets.[80] These markets are familiar to Add-Vision, which was started in 1994 to produce thick-film phosphor EL technology displays for point of purchase displays. The company sold that business to concentrate on printable display technology.

The future of Add-Vision's technology focuses on the fabrication of truly novel display products, such as a wall-sized television that can be attached to a wall with Velcro, viewed by multiple viewers from a distance and "rolled up" for easy transport."[81] Other likely products will be "magazine and newspaper inserts, direct mail, invitation and greeting cards, and CD, DVD, and VHS cassette packaging."[82]

The advent of the Internet provided a means for virtually anyone to become a publisher, and for established print publishers to deliver through yet another channel. To date, most print newspapers and magazines have created a web presence, although most do not realize significant revenue from the effort. The problem is that most Internet users want free access, and even when a user agrees to pay for an on-line subscription, the publisher cannot count that subscriber as part of their circulation, and therefore do not benefit from potentially higher advertising rates.

Two new services — NewsStand (www.newsstand.com) (Figure 39) and Zinio (www.zinio.com) — provide publishers with another option: selling digital facsimiles of their print editions, or abandoning their print editions all together. To participate, publishers no longer need presses, paper and ink, or a fleet of delivery trucks. They can sell their complete publication in an on-screen version, and at a price similar to the print version. The issues are downloaded to the subscriber's computer and viewed through a proprietary reader. Once the issue has been transferred, users need no longer maintain a network connection, and can read the publication anywhere, anytime. This feature is of particular value to:

- Travelers, both business and leisure, who want in-depth information and the hyperlink experience generally reserved for on-line viewing. People in this category also have an aversion to carrying heavy magazines and bulky newspapers.

- Out-of-town and foreign subscribers who have to wait for the delivery of their publication or are in areas not served by the publisher.

Figure 39. The Newsstand service provides the complete print edition of a wide variety of publications in digital format for on-screen viewing. Readers have the digital advantages of searching, zooming, and navigating at a per copy cost similar to, or less than, the printed version.

- Senior citizens and others who find it difficult to hold a newspaper or view its small print.

- Computer savvy readers who prefer on-screen reading with the inherent advantages provided by computer access.

Through these services, the publication content is delivered coincident either with its "OK to print," or with its actual publication, in full-color (beyond the gamut possible in print), and in its entirety. The subscriber can also archive past issues, which is of interest to most magazine subscribers. In addition there is no need to be concerned with recycling. These services are a perfect match for e-book readers, tablet computers, and other portable digital devices that people care to carry. It will also be an important part of the infrastructure necessary when e-paper-based readers are prevalent.

There are many advantages for the reader of a digital facsimile according to consultant Andreas Pfeiffer. The first is that the information is presented in the architecture of the print edition. This is something familiar to the reader, and he or she is comfortable navigating through the headlines and columns, all of which impart a meaning in terms of the ranking of information importance. Even the typography provides clues that extend beyond the words that they express.

Pfeiffer also observes that the ads, which appear exactly as they do in print, are more effective than their web-based counterparts. "It is interesting to note that print-ads work — even on a digital page. Part of that is of course that they are delivered in space in which we have accepted their presence, but there is more to it. When we read a newspaper, we are in control, we do not have to look at an ad if we don't want to. Flipping a page is very fast, even on a digital file. However, if we are interested in the information and advertisement offers, we can zoom in very quickly."[83]

A final advantage to this mode of delivery is that subscribers are buying a product, not a service. Web-based publications typically require the reader to go to their site in order to read their publication. With digital facsimiles the reader does not have that burden, nor must they deal with the possibility that the article they read just yesterday has been taken off the site or moved to a new location. This phenomenon is a constant problem for all web users since the Internet is such a large and dynamic space.

Expert Feedback

In the course of this preliminary research, several individuals and facilities were visited to get an overview of the most significant developments in this new field. Here is a selection of some of the input gathered, much of which is directed toward the role the printing industry can play in the commercialization of these emerging display technologies.

Q: What advice would you give to printing company executives, decision-makers in the printing industry today to prepare for what will be available five years or more from now?

James R. Sheats, Ph.D.[84]
Vice President, R&D
CTO
Rolltronics

> "I think that the printing industry will need to get involved in this fabrication process for electronic display media, and of course there are a lot of people talking about printing transistors, printing devices, using the techniques of the printing industry. Most of them are fascinated by inkjet printing because it's relatively easy to do in a laboratory….I don't see any reason why anything you can do with gravure printing and so on…if you can do it with inkjet printing you should also be able to do it with gravure printing, or offset printing using the skill set. I am sure that the equipment is not just going to transfer over without any changes, but by using that expertise.
>
> "Rather than to make big capital investments in presses it makes more sense to make small capital investments in the start-up or entrepreneurial companies who are in this business rather than trying to figure out for themselves what's going to happen. I think this comes back to the issues that we discuss a lot about disruptive technologies and the innovator's dilemma, where if you're a printer or a maker of printing presses, Heidelberg, or whatever, you've got your own business to manage, and you don't want to take your eye off of that, but you know this other thing is coming up. So the idea of maintaining a presence and growing a presence, more or less separately and more or less gradually be establishing communications ties and an inside track without disturbing them is what makes sense. Lots of small investments in that fertile field is probably what's going to place you in the best way."

Glenn Sanders
Vice President, Business Development
Rolltronics

"I would say make relationships with companies that are developing technologies that are going to at least enhance or displace dots on paper. And then start researching how to be part of that application, and identify markets and applications. And also designing ways to make their content multi-purposed, and the way that many publishers are doing that is to make the storage of their content in XML format so that it can be repurposed for print or electronic distribution. And also sliced and diced so [that] if people want only this chapter or this page they can get it….Doing projects together and doing trial projects for some sort of device or some sort of content delivery."

Q: So there's the potential for hybrid products that are partially paper partially silicon/digital?

"[Yes] you could have one page in a book that displays animation or a video or something, that would be interesting."

Mike Edelhart
President and CEO
Zinio

"We do not see the Zinio digital delivery as a replacement for printed magazines. Going out even ten years we don't see that. What we do see is digital magazines providing one more tool for the publisher for cost management, circulation management, and audience development. On the high end we might become 20%, 25% of the circulation of a publication, particularly in areas of technology and certain professional interests. In other cases we will be in the 2-5% range, and we would expect most of that 2-5% to represent new business that the publisher might not have gotten either because it was not cost-effective to get it to paper, or the offer in digital, having the magazine on the tablet is just cool and happens to catch the interest of an individual.

"There is the low cost of entry and the low cost of service niche, and so there might be a spin off that might be digital only. The other approach has been more mainstream, it appears possible to do zero-issue testing or pre-launch testing digitally for a much lower cost than paper, and in a much shorter time-frame. So the response to a test mailing that went out digitally could be measured in days not weeks. The availability of that audience might be greater, the capacity to do ABC splits on initial covers and looks and feel produces a more moderate up-tick in costs. It looks like a real good, quick way to get a market read.

"The technological platform isn't even nominally close to the durability and portability of paper, and won't be anytime soon. So that's one reason why we believe that we will answer some needs for some readers and for some publishers. So where the information is professional in need, having it available to me while I'm mobile, in a persistent, searchable format, then the benefits of proximity overmaps the benefits of paper. In other circumstances paper is a great format, it's light, it's cheap, etc. and it will never go away.

"There are areas of magazine publishing where the benefits of digital distribution are going to be open to some question for some time, like fashion, some lifestyle areas…it will require a generational shift. Screen-obsessed kids as they become grown-ups may have different patterns, but it will take that long…it's a 15-20 year process, the end result of which is unknowable by us or anyone else.

"We would imagine, as what is part of what I presume you guys are working on, that the technologies that put words and images on surfaces will change too. There is a centralization about the traditional printing plant that may start to get challenged, by us and by others. We want to participate in that…we're media folks by background and are very interested in all these new devices and any new forms of screen and any new forms of getting media experiences delivered to individuals or groups.

"The existing magazine distribution system and some aspects of catalogs and other current heavy users of paper, those distribution mechanisms are broken. The newsstand distribution method for magazines is broken, the traditional audience acquisition processes, as much as delivering the magazine (those mailers, etc.) are broken. If there's a big villain in all of this it's the Postal Service. That saddles publishers with a depressing aspect of an eternally rising cost that is fundamental. So certainly, whether the product winds up being delivered on paper or on some sort of screen, current screen or new screen, the distribution mechanisms that cause the product to get from the mind of the publisher or from the mind of the catalog creator, to the ultimate customer, those are going to have to change. They're just too inefficient. They're too inefficient enough that they are likely not to be sustainable.

"There are scientific laboratory initiatives for the tablet that are exactly that [provide a free reader]. Folks will be given tablets that allow them to access certain kinds of information. I don't think you'll see it outside of professional uses for some time to come. If you look at magazine economics a publisher traditionally is prepared to lose maybe $10, $12, maybe in an extreme case, $20 to acquire a customer."

Dan Okrent
Former editor of New Media at Time Inc.
Former managing editor of LIFE magazine
Board member, Zinio

"As a board member [of Zinio] we talk about end games…are we going to go public…sell upstream…do we need to raise more money etc., and one of the things that has come up is who should be talking to? Well we should be talking to Donnelley, and we say that only because they are going to need to cover their own bases, I mean they would be a very good investor in us if this is going to work and they have to protect themselves.…There is a role for them to play quite possibly.

"There's no question that Donnelley and Quad and a few others who are big in the magazine business have the capabilities, have the connections, and have delivered for a long time too to the publishers.

"I think that the large publishers will give the devices away. Mine would be the cell phone model…you contract with me for me to deliver a certain amount of content, that might be various Time magazines, and some videos of Warner Bros. films, some music and some AOL… who knows what, and even if you confine it to what is now the printed product, you agree to subscribe to two of my weeklies for three years and here's your device. These phones that they're giving away cost a lot more than that to make…once I've got you with something delivered to you digitally on a device that you have a contract with me for that device, my chance of renewing you forever are also much better. It's like the AOL racket where once you have your AOL address you don't want to change.

"Our push [with Zinio] is with magazines for a lot of obvious reasons and our next step is going to be catalogs, who are the huge mailers. Books are really a small business relative to magazines and catalogs in this country. The entire book industry is smaller than Time. Total annual sales is about the same as Time Inc. Once you have the reader, the device, and I think it is that portable, flexible, long drive, read it on the subway, read it on the beach, read it in the bathroom device, then it will be rich media as well.

"I think that the people who manufacture paper for printing are the ones in real peril. The corollary benefit is that you don't have to ruin forests or pollute rivers, so I think there will be all sorts of other imperatives that will push it forward. I wouldn't be investing in the paper business now. The printing business is more adaptable…although the enormous investment in presses could become a thing of the past. I think that newspapers will be slower to work into this format [digital delivery] because of the daily accessibility…I don't want an operation, just hand me my damn newspaper.

"Another thing that's pushing this forward, and another industry that is both imperiling and will be imperiled is the U.S. Postal Service. By some miracle again the magazine publishers got off really, really cheap. Time Inc. is the largest customer of the Postal Service. 90% of first class mail is business-to-business, first class is the most profitable part of the postal service. Business-to-business is obviously the part that is going to be moving more and more to e-mail, and at the other end if it's not e-mailable, to FedEx, UPS or other services. As they lose the profitability that comes from first class mail they are really going to have to push the second class rates to keep the postal service going. If they push it too far the publishers will be compelled to find a cheaper way of doing it….Postal costs is the ogre under the bridge that is going to kill this business.

"Data broadcasting is an enticing thing….the idea is that whatever your device is, it's just getting a signal the way that a radio gets a signal from a broadcast tower while you sleep and your newspaper is on your screen in the morning without any kind of necessary uplink. Why not? The infrastructure is there, and as I understand it, it is not that bandwidth consumptive.

"I don't think that they [the younger generation] have either the habit as ingrained nor, more importantly the kind of fetishistic belief in print as a totem of some sort, I don't think they do.

"The Time demographic is aging so fast…that's one of their big panics. Even their young magazines…their median age has been going up in a unity fashion. They are not being replaced at the lower end. The average reader of Time is my age [54]. It's a real issue. And maybe they can speed along the adaptation and the adoption and attraction of younger readers by using technology.

"[To executives in the printing industry] I would say, "watch out." How can you make yourselves part of the process because, fundamentally put, when put up against digital technologies, you are part of the problem. You're too damn costly. I think that economics drives consumer behavior. One of the problems with publishers who have done a little bit in this area, and I'm really angry at my pals at Time Inc. for this…as they try to solicit the first digital subscriptions they're charging the same amount of money. You must share that with the consumer or it's never going to work."

Nick Sheridon
Research Director
Gyricon Media

"When we first started talking about a reusable paper we were contacted by a number of newspaper printing companies [names omitted] and they told us basically they don't want to print on paper any more. Newspapers are for disseminating information…the social costs, the environmental costs, and the actual costs of newsprint is just too high. 50-60% of the cost of getting a newspaper out is printing the paper and distributing it. So if you can use electronic paper then you save that much money…it's a huge savings. In addition, just making paper is not an environmentally clean thing.

"I think that the correct way of defining the printing industry mission is to provide hardcopy information…printed information on paper or a paper-like substrate. I think we're [Gyricon] very much in the printing business. I think we're a branch of the printing business. If you narrow the printing business down to saying that it always has to be on paper, I think that's a mistake.

"We look upon the document as an electronic entity and you only print it out when you want to read it or pass it around, or annotate it. With computer technology the cost of storage is getting cheaper and cheaper.

"We look upon ourselves as a branch of the printing industry. When we measure the optical properties of this stuff [Gyricon] we use the same tools, same optical equipment as the printing industry. We think in terms of printing. To me, RIT, I think, should look at printing on paper and it should look at electronic printing…you really should look at both, and not limit yourself to paper. By paper we make a distinction…we talk about pulp paper, which is paper derived from wood pulp, and we look at e-paper. But it's all paper, it's got paper-like qualities and what I mean by that is that you can look at this thing [Gyricon sign] at a lot of different angles and see it…you can't do that with most liquid crystal displays. Once you've formed the image, the image is there permanently…until you erase it. It works by reflective light, that's the key thing, the most important thing, it works by reflective light. And so in terms of the collective unconsciousness of the people, it's common, it's something they're used to."

Chuck Edwards
President, CEO
Litrex

"[Is there a role for the U. S. Printing Industry?]. Absolutely, isn't what they print just a limitation of how they see printing. The idea is they run…printers run machines, and build a product. Today, the only product they really do is colored pigments on flexible substrates that create a static display. So if you say, similar equipment, similar process, but now its producing a different type of product…I would still consider that the American printing industry. Just that they'd have to change what they think printing is."

John Rogers
Director
Condensed Matter Physics Research
Bell Labs
Lucent Technologies

"I guess if you were Time Inc. my suggestion would be invest in some of these companies because this technology is probably going to happen, at some point it would be nice to own a piece of it. Especially if you're in that business. If you look at the E Ink web site there are a number of different newspapers and paper product companies who are investors in that."

Neil Budde
Publisher
The Wall Street Journal Online

"Over time, I still believe that particularly audio could become more and more important in the delivery of news and the sort of information we have. My ideal product at the moment would be a very simple way in which the radio in my car had the 45 minute summary of the Wall Street Journal and that I didn't have to do anything to get it there every morning….what I'd love to have is my car radio have a WIFI to my home network and it does all of the work and when I get in the car and start driving to work I can listen to a summary of the Wall Street Journal. So I think that audio has a place, we just haven't gotten to the making it convenient.

"Over time I believe that increasing use of video will become more important. We focus on where video complements the story we're telling, primarily through text. For example if you have a clip of a CEO being interviewed on a story we're writing about, we link the two."

Peter Meirs
Director
Alternative Media Technologies
Time Inc.

"We're going to reach a point where it's going to be a lifestyle choice more than anything else. If you're someone who needs print in their life, you're retired, you're not ready to change, you've got disposable income that you can pay for the rapidly rising newsstand price, you may be willing to do that because you get that sort of value. We're going to reach a point where the reader becomes indifferent to the medium. We're getting very close to that right now. I spend a lot of time at MIT with the Media Lab and they developed things like electronic ink…and it really won't matter if it's electronic or not.

"I think we're going to make some progress with electronic magazines, but it isn't until we get to the point where people stop talking about reading on-screen…it's when that indifference point occurs that will be the peridemic [sic] threshold of change.

"The class of 2006 was born in 1984, the same year that Apple Macintosh came out. Chances are that everyone who's a starting freshman this year grew up scholastically with computers in their classroom. If you're 18 in 2002, you were probably 10 or 11 the first time you had access to the Internet. The appreciation for consuming content digitally is completely different generally and generationally….they are conditioned differently.

"We're thinking that the audience for electronic magazines will be people who are more interested in content than the user experience, and that they would value the ability to aggregate a variety of publications into one space so when they travel they have access to them.

"If you've spent thirty years of your career making paper and find yourself in a position where making more paper is the only way you're going to grow your business and someone's telling you that in five years there's going to be a significant decay in that model, you're going to find more reasons to be resistant than to figure out how to synthesize those conditions as to how to grow your business."

Janice Mahon
Vice President of Technology Commercialization
Universal Display Corporation

"I think that many print forms in the future have the potential to become dynamic. From e-books, magazines to newspapers, advertising billboards could all become electronic in the future. It's mainly a question of scaling the technology to larger sizes.

"The benefit of organic materials today over say silicon-based backplane will be processability and cost. To become ubiquitous…cost, cost, cost is really the driver. So if you get to the point where you're using inkjet or direct printing techniques to build these displays, which one can do with these organic materials, then you have the potential to build very inexpensive and cost-effective device in a fairly rapid process frame."

J. Norman Bardsley
Director, Roadmaps & Standards
U.S. Display Consortium

"My guess is that it will be between five and fifteen years [before there is a display device inexpensive enough to be given for free by publishers]. There may be more than one way for that to happen. It may be that the way that this develops is that in every room of your house you have fixed displays, many of them on the wall on which you can see what you want to see as you move from room to room. Or it may be that you have something that you can fold and put on your lap. The problems of making flexible displays that meet the expectations of the reader are not trivial."

Stuart Evans
CEO
Plastic Logic

"We have technology that lets us inkjet print semiconductor fluids to make electronic circuits. And if you compare what we've got with silicon, silicon's got the burdens of working with high temperatures, vacuums, and photolithography, and we think we can avoid all of those by using printing to make electronics. The applications for our technology are very wide-spread, and we focus on two to begin with. The first is to make active matrix backplanes for displays, and we think we'll be very good at making them on large and flexible substrates. And the other application we're interested in is electronic labels that will replace barcodes. And if they are going to become so pervasive that you're going to put them on every box of cereal, then printing is the only way to make it happen. Another thing that may be interesting to people in the printing world is this: silicon fabs these days cost billions of dollars…a printing electronics fab ought to cost much, much less.

"If we look forward a few years to when this technology is in pervasive daily use I think we'll see flexible displays. Perhaps you'll buy your newspaper once a year and you'll get the news downloaded to it everyday.

"We'll get to very low-cost positions because we'll use inexpensive materials at great advantage by direct writing as you do with inkjet printing…you only put down the materials you need, you don't have to etch and remove a lot of material…that will lead to very high volumes of plastic printed electronics certainly by the end of this decade, and probably by 2006."

Site Visitations
(with main contacts)

- Bell Labs Lucent Technologies
  John A. Rogers
- E Ink
  John Thorn
- eMAGIN
  Webster Howard
- FlexICs, Inc.
  Kang Sun
- Gyricon Media, Inc.
  Nick Sheridon
- Iridigm
  Mark Miles
- Kodak Research Labs
  John Burtis
- Laboratory for Laser Energetics, UR
  Kenneth L. Marshall
- Litrex Corporation
  Chuck Edwards
- The Wall Street Journal Online
  Neil F. Budde
- Naval Research Laboratory
  Zakya H. Kafafi
- Philips Mobile Display Systems
  Peter Kurstjens
- Plastic Logic
  Stuart Evans
- Rolltronics
  Glenn Saunders
- Thomas J. Watson Research Lab, IBM
  Christos Dimitrakopoulos
- Time Inc.
  Dan Okrent
- Time Inc.
  Peter Meirs
- Universal Display Corporation
  Janice K. Mahon
- USA TODAY
  Miles Weissman
- U.S. Display Consortium
  Norman Bardsley
- U.S. Government Printing Office
  Andy Sherman
- Zinio
  Mike Edelhart

Conclusion

The development of new display technologies which resemble print on paper suggests both a significant challenge to, and a difficult-to-realize opportunity for, the printing industry. Printers must begin to think of themselves not as printers, but as display-makers. A new industry of displaymakers is arising, and it will be difficult to compete with them. It should also be recognized, that technology is multi-faceted, and that in addition to low-cost electronically-imageable papers and their allied display technologies, the printing industry will be challenged by:

- Low-Cost Printed Computers
- Printable Electronic Devices, including Low-Cost E-readers
- Data Broadcasting which may redefine the distribution of information
- Low-Cost, High-Resolution, Paper-Like Color Displays
- Wall-Paper Displays (large-format flat panel displays that cover all or part of one or more walls)
- Tablet Computers with Paper-Like Color Displays and Book-Quality Typography and Page Layout
- Wireless Connectivity (“Radio Paper”)
- High-Resolution Bifocal Color Headset Displays
- The Convergence of a Variety of Electronic Devices
  - Cell Phones with Pull-Out Flexible Displays
  - PDAs with Display Screen Projection
  - Wireless Internet Headsets with Voice In/Voice Out
  - Smart Glasses with Transparent Display Capability
  - Wearable Computers with Virtual Keyboards and Displays
  - Wristwatches with Full PC Functionality

Works Cited

Arrison, Sonia. "What Digital Divide?" *CNET News.Com* 13 Mar. 2002. 19 Sept. 2002 <http://news.com.com/2010-1078-858537.html>.

Battey, J. "Delivering on the Electronic-Paper Promise." *InfoWorld* 23.16 (2001): 38.

Coursey, David. "Tablet PC: You'll Love It, Hate It—or Won't Care." *ZDNet AnchorDesk* 25 June 2002. 19 Sept. 2002 <http://www.zdnet.com/anchordesk/stories/story/0,10738,2872001,00.html>.

Dean, J. "Fear of Paperlessness." *Government Executive* 33.12 (2001): 72-74.

DiMario, M. F. *Strategic Business Plan FY 2001-2005, Part V—Strategic Environment Assessment: Identification of Agency's Strengths and Potential for Future Success.* Washington: U. S. GPO, 2000.

D'Innocnzio, Anne. "Merchants Look to Save Money, Stay Competitive with Electronic Price Signs for Shoppers, the Aisle's Price Matches the Cash Register's." *St. Louis Post-Dispatch* 27 July 2001: C9.

"DisplaySearch Seminars Reveal Updated FPD Market Outlook: 47% Growth to >$32 Billion Projected." *DisplaySearch* 29 May 2002. 20 Sept. 2002 <http://www.displaysearch.com/press/2002/052902.htm>.

Ditlea, Steve. "Electronic Paper Chase." *Computer Letter* 2001. 19 Sept. 2002 <http://www.prism.washington.edu/lc/CLWEBCLB/electpaper.html>.

Dorsch, J. "Flexible Electronics: On the Brink of a Tech Revolution." *Semiconductor Magazine* 2.11 (2001).

Duran, M. "E Ink, Gyricon on Pace to Make Reusable Paper Household Name." *Newspapers & Technology* Feb. 2002.

Fidler, Roger F. "Life After 2001: Redefining Print Media in the Cyber Age." *Institute for Cyber Information—Future of Print Media Summer* 1998. 19 Sept. 2002 <http://futureprint.kent.edu/articles/fidler01.htm>.

Finn, M. "Next-Generation Display Technologies." Seybold Seminars. Boston. 11 Apr. 2001.

Geller, Masha. "Just an Online Minute...AAAA Day 3." *MediaPost* 15 Feb. 2002. 19 Sept. 2002 <http://www.mediapost.com/dtls_dsp_onlineminute.cfm?minuteID=107738&archive=mi>.

Gorman, Jessica. "New Device Opens Next Chapter on E-paper." *Science News Online* 28 Apr. 2001. 19 Sept. 2002 < http://www.sciencenews.org/20010428/fob5.asp>.

Works Cited

Hemphill, Barbara. “Will the Internet Replace Your Filing Cabinet?” *Manage Magazine* Sept./Oct. 2001. 19 Sept. 2002 <http://www.nma1.org/Members/manage/SeptOct2001/willtheinternetreplaceyour.htm>.

Honey, Kim. “Beyond Paper: Part 1, Will Pixels Kill Paper?” *Globetechnology.com* 5 Mar. 2001. 19 Sept. 2002 <http://www.globetechnology.com>.

Howard, Webster E. “OLED Technology Primer: Organic Light Emitting Diodes (OLED).” *eMagin* 2001. 19 Sept. 2002 <http://www.emagin.com/oledpri.htm>.

“Internet Use Doubles Every 100 Days.” News bulletin. *Communications Media Center at New York Law School* 19 Apr. 1998.

Jefferson, Steve. “Low-cost, Flexible Displays Will Lighten Your Reading.” *InfoWorld* 17 Oct. 2000. 19 Sept. 2002 < http://www.infoworld.com/articles/tc/xml/00/10/16/001016tchybrid.xml>.

Kharif, Olga. “Tomorrow’s Paper-Thin Screen Gems.” *BusinessWeek Online* 18 June 2002. 19 Sept. 2002 < http://www.businessweek.com/technology/content/jun2002/tc20020617_5587.htm>.

Kunkel, Paul. “Scrap the Presses—Print and the Web are Racing Toward the Biggest Media Merger in History.” *Wired News* Aug. 2000. 19 Sept. 2002 < http://www.wired.com/wired/archive/8.08/epapers.html>.

Leeds, R. G., Jr. “Print Is Losing Its Market to Various Forms of Digital Expression.” Washington: U. S. GPO, 2002.

Mandelbaum, J. *The CyberSkeptic’s Guide to Internet Research* 2002.

McLeod, Duncan. “Is Paper-based Media Doomed?” *FutureCompany* 22 Sept. 2000. 19 Sept. 2002 <http://www.futurecompany.co.za/2000/09/22/editorial.htm>.

Morkes, John, and Jakob Nielsen. “Applying Writing Guidelines to Web Pages.” 6 Jan. 1998. 20 Sept. 2002 <http://www.useit.com/papers/webwriting/rewriting.html>.

Müller, P. *Organic Light-Emitting Diodes for Microsystems.* IBM Research, Zurich Research Laboratory. 2001.

Nielsen, Jakob. “Measuring the Usability of Reading on the Web.” *Jakob Nielsen’s Alertbox* 1 Oct.1997. 20 Sept. 2002 <http://www.useit.com/alertbox/readingmetrics.html>.

---. “The End of Legacy Media (Newspapers, Magazines, Books, TV Networks).” *Jakob Nielsen’s Alertbox* 23 Aug. 1998. 20 Sept. 2002 <http://www.useit.com/alertbox/980823.html>.

Okrent, Daniel. *The Death of Print? Hearst New Media Lecture.* Columbia Graduate School of Journalism. New York, NY. 1999. <http://indigo.ie/~liztai/elizabeth/deathofprint.htm>.

Quinn, Richard A. “The Myth of the Paperless Office: Why We’re Losing the War.” *Document Processing Technology* June 2002. 20 Sept. 2002<http://www.dptmag.com/editorial2.asp?ID=65>.

Robert, John. Moderator. “Next-Generation Display Technology and Devices.” Seybold Seminars. Boston. 2000.

Romano, F. BookTech Keynote Address. *BookTech 2002.* New York. CAPV Analysis. 2002.

Rushlo, Michelle. "Companies Race to Develop Electronic Paper." *Upside* 12 Dec. 2000. 20 Sept. 2002 <http://www.upside.com/texis/mvm/story?id=3a3131a41>.

Sachdev, Chhavi. "Prototype Shows Electronic Paper Potential." *TRN News* 23 May 2001. 20 Sept. 2002 <http://www.trnmag.com/Stories/052301/Prototype_shows_electronic_paper_potential_052301.html>.

Saul, Anne. "Newspapers' Brand Strength Gives Online Information Credibility." *G News Watch* 2 July 1999. 20 Sept. 2002 <http://www.gannett.com/go/newswatch/99/july/nw0702-1.htm>.

Saunders, Bill. "The Pull of Paper." *Guardian Unlimited* 26 Nov. 2001. 20 Sept. 2002 <http://gujobs.guardian.co.uk/officehours/story/0,9897,605840,00.html>.

Singer, Peter. "Flexible Displays Advance." *Semiconductor International* 24.13: 36. 1 Nov. 2001.

Starkweather, Gary. "Next-Generation Display Technologies." *Seybold Seminars.* San Francisco. 2000. <http://seminars.seyboldreports.com/seminars/2000_san_francisco/30/30_transcript.html>.

Sung-jin, K. "LG.Philips Launches World's 1st 5th-Generation TFT-LCD Factory." *Korea Times InfoTech* 2002.

Vaknin, Sam. "The Future of Electronic Publishing." *Electronic Book Web* 15 Jan. 2002. 20 Sept. 2002 <http://12.108.175.91/ebookweb/discuss/msgReader$976>.

Walker, Geoff . "Tablet PC Update." *Tablet PC Magazine* 1.1 (Spring 2002). 20 Sept. 2002 <http://www.pencomputing.com/pdf/TabletPC_Magazine001.pdf>.

"What Is Print as an Information Technology?" *GAIN: The Portal to the Graphic Arts Industry* 2002. 20 Sept. 2002 <http://www.gain.org/servlet/gateway/printIT/print.html>.

"When in Doubt We Print It Out." *New Zealand Management* 48 (2001): 11.

Endnotes

[1] "In the early 1900s, when transportation was changing, the train industry had the opportunity to purchase and control both air and auto industries. However, they saw themselves in the rail business instead of the transportation industry, and they regrettably lost out on one of the greatest business opportunities ever." <http://www.metamatrixconsulting.com/newsletters/newsD4_May_2000b.htm>. Printers must begin to think of themselves as manufacturers of displays.

[2] GAIN: The portal to the graphic arts industry. "What Is Print as an Information Technology?" <http://www.gain.org/servlet/gateway/printIT/main.html>.

[3] The Imation Matchprint™ Virtual Proofing provides a near-perfect rendition of an analog Matchprint proof. This technology, according to an Imation press release, "brings the industry a look at the future of digital proofing—a monitor-based proof that truly—and automatically—replicates the hardcopy color." <http://www.imation.com/en_US/main.jhtml?Id=10_02_02&Article=2001_09_06_ct_mpvirtual.xml>.

[4] The permanence of paper is an advantage when it serves as a legal record of such things as a property deed, a birth, an insurance policy, a tax return, or other significant transactions or events. There are also legal requirements for maintaining documents, such as the length of the life of a policyholder for an insurance company, or seven years for a patient's medical records. There remains a concern that digital documents are less secure, can more easily be lost or destroyed, and are more prone to improper access by those who do not have a valid reason or need.

[5] *CAPV Analysis: BookTech 2002,* Feb. 18, 2002, prediction by BookTech speaker Frank Romano in his keynote address.

[6] "Newspapers' Web Traffic Grows Apace." *AIM's Research Update Service.* Volume 5, Number 27. 10, July 2002. <http://www.interactivemarketing.org>.

[7] Saul, Anne. "Newspapers' Brand Strength Gives Online Information Credibility." *News Watch.* <http://www.gannett.com/go/newswatch/99/july/nw0702-1.htm>.

[8] Mandelbaum, Judith. "Mercury Center: The Evolution of a Cyber Pioneer." *The CyberSkeptic's Guide to Internet Research.* Feb. 2000. <http://www.bibliodata.com/skeptic/200002/mercury.html>.

[9] Recorded during a personal interview at the GPO, May 15, 2002.

[10] *NAPL.* "NAPL Update Shows Print Decline." PrintOnDemand.com. http://www.printondemand.com/2002-08-21.1029971417.html. August 21, 2002. "Total print sales are expected to decline in 2002, marking the industry's second consecutive year of declining sales in nearly three decades."

[11] “The Death of Print?” Dan Okrent, Editor-at-Large, Time Inc., presented as the Hearst New Media Lecture, December 14, 1999, 7:00 p.m. at the Columbia Graduate School of Journalism. The entire lecture can be found at: <http://www.jrn.columbia.edu/events/news/2000-12/hearst2.asp>.

[12] The number of Internet users continues to grow and include those on the wrong side of the “Digital Divide.” The Department of Commerce report, “A Nation online: How Americans are expanding their use of the Internet,” has found that more than half of Americans are online, with significant increases irrespective of income, education, age, race, ethnicity or gender. Despite concerns that a digital divide exists in what the NAACP’s Kweisi Mfume has called “technological segregation,” the DOC report included findings that “between December 1998 and September 2001, Internet use by individuals in the lowest income households (those earning less than $15,000 per year) increased at a 25% annual growth rate.” In addition, by 2001, 25% of those considered lower income, were online. Arrison, Sonia. “What digital divide?” cnet news.com. 13 March 2002. <http://news.com.com/2010-1078-858537.html>.

[13] Nielsen, Jakob. “The End of Legacy Media (Newspapers, Magazines, Books, TV Networks).” *Jakob Nielsen’s Alertbox.* 23 Aug. 1998. <http://www.useit.com/alertbox/980823.html>.

[14] Over 200 million personal printers have been sold since 1998 and they all need paper. The Gartner Group estimated that the number of laser printers in the United States increased 1200% and fax machines by 2200% in the 1990s. anonymous. “When in doubt we print it out.” *New Zealand Management.* July 2001.

[15] “Publishing Strategies Conference Keynote,” *Seybold Seminars Boston.* 9 February, 2000.

[16] Quinn, Richard. “The Myth of the Paperless Office: Why We’re Losing the War.” *Document Processing Technology.* June 2002. 27.

[17] Smokey, Sheila. “Re: Library Recycle Question.” E-mail to Michael Kleper. 26 Jul 2002.

[18] Anderson, Helen. “Re: Fwd: What becomes of old newspapers and magazines?” E-mail to Michael Kleper. 25 Jul 2002.

[19] http://www.lehigh.edu/ir/friends/LindermanFAQSept01.htm

[20] Despite predictions of the paperless office, paper consumption has actually risen significantly on a per capita basis. In Canada, according to the Forest Products Association of Canada, the production of printing and writing paper has increased from 946,000 metric tonnes (a tonne weights slightly more, 1 ton = 1.0160469088 tonnes) in 1980, to 1,560,000 metric tonnes in 1990, to 2,221,000 metric tonnes in 2000. The Forest Products Association of Canada 2000 Annual Review states: “Just about every innovation in the digital revolution was supposed to cut out more paper. Precisely the opposite continues to happen.” It has also been observed that the use of e-mail, a prime anti-paper activity, can actually increase paper use, some say by as much as 40%. This is due to the fact that because e-mail is such an easy form of messaging that it leads to many more messages, and thus many get printed. Users are also more likely to print an e-mail if it runs longer than one screen-full.

[21] “Ink-on-paper today remains the most egalitarian of information formats. It is accessible, transportable, and economical. It continues to serve as an effective safeguard for ensuring that those without access to computers can still use Government information, and for guaranteeing both the authenticity of official Government information as well as permanence. The transition to electronics must be handled responsibly with the interests of all citizens in mind. While we envision a gradual

decline in GPO's size as the mix of electronic and traditional work we produce changes over time, maintaining a well-equipped and expertly staffed printing and dissemination capability for the foreseeable future will give us an important tool to manage this transition." *United States Government Printing Office Strategic Business Plan FY 2001-2005, Part V: Strategic Environment Assessment: Identification of Agency's Strengths and Potential for Future Success* <http://www.access.gpo.gov/public-affairs/stratpln.html#assess>.

[22] Walker, Geoff. "Tablet PC Update." *Tablet PC.* Spring 2002. A7.

[23] Quoted from an Estari press release, "Pennsylvania Firm to Launch Dual-Screen Laptop," April 2, 2002, Harrisburg, PA.

[24] Paper bulk can be considered a positive in that it provides visual clues as to the volume of content that it contains. Users can quickly flip through the pages to gauge the content and its density, and when reading can readily differentiate what has been read from what hasn't. In addition, paper is normally bound in some fashion, or filed into folders or held with some other familiar filing or fastening system. A sense of size and length is important in the use of media. According to popular culturist Richard Saul Wurman, "When I pick up a book, if it's a novel, I know that I have so many more pages to read. I know where I am in the story. When I watch a movie that I know is two hours, I know that no matter what happens in the first five minutes, it's not the end of the movie. It's going to take two hours to go through the plot. I have a sense of where I am. This is not a trivial issue. It gives me a base. It's a centering thing." <http://www.edge.org/digerati/wurman/>.

[25] Nielsen, Jakob. "Measuring the Usability of Reading on the Web." <http://www.useit.com/alertbox/readingmetrics.html>, and "Applying Writing Guidelines to Web Pages, " John Morkes and Jakob Nielsen, 6 January 1998. <http://www.useit.com/papers/webwriting/webwriting.html>.

[26] <http://www.kmworld.com/publications/whitepapers/KM/potter.pdf>.

[27] According to Teach America, as quoted by Gary Starkweather of Microsoft at the Next-Generation Display Technologies session, Seybold Seminars, San Francisco, September, 2000.

[28] <http://www.armymedicine.army.mil/medcom/medlinet/Quote/sld018.htm>.

[29] "Internet Use Doubles Every 100 Days." Communications Media Center at New York Law School. 19 April 1998. <http://www.cmcnyls.edu/bulletins/IntUD100.HTM>.

[30] Mark Finn, V.P. DisplaySearch, speaking at the Next-Generation Displays Technologies session. *Seybold Seminars Boston.* September, 2001.

[31] Anonymous. "Electronic Paper Chase." *Computer Letter.* 18 June 2001. This is the opinion expressed both by interim CEO Robert Sprague of GyriconMedia and CEO Jim Iuliano of E Ink.

[32] Kent displays, using Cholesteric LCD Technology, are the only LCDs that approach the reflectivity of ink on paper in direct sunlight with a peak reflectivity value of 70%. <http://www.kentdisplays.com/advantage/sunlight.htm>.

[33] Contrast ratio is the ratio of intensity between the darkest and lightest areas of a display or surface.

[34] The management of color control on a printer or press (which is a subtractive process), is much more complicated and time-consuming than on a color monitor (which is an additive process). In addition, the color that an individual views on their monitor is relatively consistent,

whereas output from a multitude of print sources will never attain consistency, which may be difficult enough to produce from a single source. In addition, LCDs are emissive (transmissive) displays which have built-in light sources that put out a relatively uniform amount of light, whereas paper, which is a reflective display, is dependent upon ambient light (reflective), which is less controllable. A hybrid form of LCD display is "transflective," meaning that the backlight can be turned off, and the display can be viewed using ambient light. Such displays, first used in cell phones, provide users with the capability to clearly see the display in sunlight or a dark room.

[35] Gary Starkweather of Microsoft has observed that if the CRT were new technology it would be rejected for safety reasons since it is essentially an evacuated tube made of approximately two cubic feet of glass and containing phosphor on the inside along with an anode and charged with 35,000 volts.

[36] "Introduction to Liquid Crystal Displays," <http://abalone.cwru.edu/tutorial/enhanced/files/led/intro.htm>.

[37] Sung-jin, Kim. "LG.Philips Launches World's 1st 5th-Generation TFT-LCD Factory." *Korea Times InfoTech.* 24 May 2002.

[38] Battery-powered LCD displays, which are used in laptop computers and other consumer electronic devices, may lose up to 95% of their back light source strength since the light must pass through polarizers, glass, liquid, crystals, filters, and electrodes. (http://www.acq.osd.mil/es/fpd2_1a.html).

[39] "By far the best VDTs on the market today are the TFT range. These are produced from Liquid Crystal Display technology which was previously only found in Laptops. Not only do they save space, electricity and are more portable; they also are much softer on the eyes due to the materials used i.e. the mesh screens. Using a TFT is comparable with reading text from paper." *The Computer Eye Strain Information Website,* <http://www.geocities.com/computereyecare/>.

[40] Source: <http://www.pctechguide.com/07panels.htm>. Brightness is a relative measure; the higher the number, the higher the brightness of the white display.

[41] Efforts have been made to increase the effective resolution of LCD screens without increasing the number of pixels. This is done using font rendering technologies such as Adobe's CoolType and Microsoft's ClearType. These technologies utilize each pixel's subpixel as if they were unique pixels in and of themselves, with a separately controlled pixel intensity. This effectively triples the monitor's horizontal resolution by 3X, and makes the use of relatively low resolution displays suitable for e-book and other forms of on-screen reading.

[42] Business Editors & High-Tech Writers. "DisplaySearch Seminars Reveal Updated FPD Market Outlook; 47% Growth to $32.3 Billion Projected." *Business Wire.* 29 May 2002. <http://servlet.businesswire.com>.

[43] Universal Display Corporation, 375 Phillips Blvd., Ewing, NJ 08618, 609 671-0980, <http://www.universaldisplay.com>, fax: 609 671-0995.

[44] The Alto was a grand experiment to move from doing business on paper, to doing business on-screen. Xerox appropriately designed a portrait monitor to represent the normal orientation of paper, which was not only familiar to readers, but required no scrolling to view a full page. This became the model for companies that built dedicated word processing systems in the 1970s and 1980s.

[45] Ergonomic, safety and health concerns regarding CRT monitors continue to be of concern today, although perhaps, without basis. "Radiation Emissions from Video Display Terminals," a report from the Australian Radiation Protection and Nuclear Safety Agency's web site lists alleged health effects from visual display terminal (CRT) exposure to include eye problems, skin disorders, and adverse pregnancy outcomes. Their studies, concluded that "The electromagnetic radiation emissions from VDTs that were measured by ARPANSA are alleged to be responsible for adverse health effects among VDT operators. These allegations are not supported by either animal studies or reliable epidemiological studies." April 10, 2002, <http://www.arpansa.gov.au/is_vdtrd.htm>.

[46] Mann, Charles C. "Electronic Paper Turns the Page." Technology Review. March, 2001.

[47] The spheres are 50 to 100 microns, about the thickness of human hair, and smaller than a grain of sand. The spheres are technically referred to as "bichromal beads." Gyricon presently uses 50 micron beads yielding a resolution of 200 dpi. Reducing the bead size to 30 microns will provide a resolution of 300 dpi. Here is how Matt Howard, a research scientist at Gyricon describes the process of making the Gyricon material: "The first step in the manufacturing process is to create the beads. This is a very novel technique that we developed at PARC, Xerox's Palo Alto Research Center. We create the beads by shooting a jet of liquid wax, molten wax, or plastic onto a spinning disk that's rotating at very high speed. This wax forms a film on the disk as it's flung out to the edge of the disk under centrifugal force. At the edge of the disk, the black wax on one side and the white wax on the other combine to form a black-and-white film that then breaks up into what we call tiny ligaments, stable structures that set up around the edge of the disk. The ligaments are fed on one side, and they eject little droplets of black-and-white material on the other side. The droplets fly through the air and freeze spherically into tiny black-and-white beads. The beads are then mixed into a slurry of uncured or jellylike elastomer, a rubber material. That material is then metered out onto a plate or a web in a very thin layer. Heat is applied and the jellylike material turns hard. It cures and then can be rolled up under a drum. At this point, the material is not active. It won't respond to electric fields because the beads are stuck in the material….We free the beads up by soaking the material in what we call a plasticizing oil. The oil swells the rubber like water swells a sponge, but it doesn't swell the beads. A cavity forms around each bead. It expands around a bead and then backfills with oil, leaving the bead free to rotate." ("Next-Generation Display Technology and Devices," *Seybold Seminars Boston,* February, 2000.)

[48] "Next-Generation Display Technology and Devices," *Seybold Seminars Boston,* February, 2000.

[49] A circa 2054 version of Gannett's flagship newspaper, *USA Today*, is featured in the 2002 Steven Speilberg movie, Minority Report. The newspaper appears to be made of an OLED-like material, flexible, full-color, with animation, video and real-time updating.

[50] Rushlo, Michelle. "Companies race to develop electronic paper." 12 December 2000, <http://www.upside.com/texis/mvm/print-it?id=3a3131a41&t->.

[51] Electronic signage provided by Gyricon and E Ink, although an excellent replacement for standard static printed signs, does not yet support full color or rich media. Gyricon's refresh rate is as slow as once every 2-3 seconds and E Ink's is from one to ten times per second, although they expect improvements over time. An experiment involving point of purchase advertising being conducted by AdSpace of Las Vegas, NV, is replacing the conventional printed movie poster in Loews Theater lobbies with flat screen monitors. The monitors can run full video of current features and coming events, and also ads for third parties. The monitors are provided at no cost to the theatre chain, rather AdSpace sells advertising and shares the revenue with Loews.

[52] A single sign requires only three AA batteries to run for more than one year.

[53] D'Innocnzio, Anne. "Merchants look to save money, stay competitive with electronic price signs for shoppers, the aisle's price matches the cash registers." AP. *St. Louis Post-Dispatch.* St. Louis, MO. 27 July 2001. p.C9.

[54] Kharif, Olga,"Tomorrow's Paper-thin Screen Gems." *BusinessWeek online,* 18 June 2002.

[55] Battey, Jim. "Delivering on the electronic-paper promise." *Infoworld.* Framingham, 16 April 2001. Vol. 23. Issue 16. 38.

[56] It is estimated that e-paper material can be written and rewritten up to 300 million times.

[57] E Ink has received investments from newspapers, such as *Central Newspapers,* and media groups, such as Havas

[58] Titanium dioxide is the whitest substance on earth. It is used to provide whiteness, brightness and opacity to many products including cosmetics, toothpaste, paints, inks, coatings, fibers and food.

[59] Battey, Jim. "Delivering on the electronic-paper promise." *Infoworld.* Framingham, 16 April 2001. Vol. 23. Issue 16. 38.

[60] Sachdev, Chhavi . "Prototype shows electronic paper potential." TRN News. 23 May 2001. <http://www.trnmag.com/Stories/052301/ Prototype_shows_electronic_ paper_potential_ 052301.html>.

[61] Gorman, Jessica. "New device opens next chapter on E-paper." *Science News.* Washington. 28 April 2001. Vol. 159. Issue 17. 262.

[62] E Ink Corporation, 733 Concord Avenue, Cambridge, MA 02138, 617 499-6000, <http://www.eink.com>, fax: 617 499-6200.

[63] Rushlo, Michelle. "Companies race to develop electronic paper." 12 December 2000. <http://www.upside.com/texis/mvm/print-it?id=3a3131a41&t->.

[64] Duran, Marcelo. "E Ink, Gyricon on pace to make reusable paper household name." *Newspapers & Technology.* February, 2002.

[65] Howard, Webster E. "OLED Technology Primer: Organic Light Emitting Diodes (OLED)." eMagin Corporation. 2001. <http://www.emagin.com/oledpri.htm>.

[66] A dopant, which is used to "dope," is an add-on that is used to change the physical characteristics in terms of conductivity, injection properties, or emission color.

[67] OSRAM, Hellabrunner Strasse 1, 81543 München, +49-89-62 13-0, <http://www.osram.com>, fax: +49-89-62 13-20 20.

[68] Müller, Peter. "Organic Light-Emitting Diodes for Microsystems." IBM Research, Zurich Research Laboratory. 17 December 2001. Switzerland.

[69] "Dupont and Cambridge Display Technology Sign Agreement to Advance the Commercialization of Light Emitting Polymer Displays," <http://www.uniax.com/html/ pressrelease102501.htm>.

[70] "Small molecule OLEDs are composed of thin films that themselves consist of individual molecules (consisting of fewer than 10-100 atoms) packed into many individual small crystal grains (or in some cases they are completely amorphous). In the case of polymers, the thin films consist of polymer molecules that are composed of large extended chains (thousands or many thousands of atoms) of repeating sequences of atoms. These materials are often soluble in some organic solvents; as a result, they can be deposited from solutions (e.g. ink jet printing, screen printing, etc.), and it is mainly for this reason that they could have some advantages relative to the small molecule materials." John Rogers, Bell Laboratories, personal communication, August 21, 2002.

[71] The first Kodak patent expires in 2003, although Kodak holds many patents that extend beyond 2003. Kodak has formed a strategic alliance with Sanyo (SK Display Corp.). Since 1997 more than 8,800 OLED patents have been filed by Japanese companies including Sharp, Matsushita, NEC, Fujitsu, SEL, and others.

[72] Cambridge Display Technology, Greenwich House, Madingley Rise, Madingley Road, Cambridge CB3 0TX, +44 (0) 1223 723 555 http://www.cdtltd.co.uk/, fax: +44 (0) 1223 723 556. Cambridge Display Technology is the original patent-holder on PLED technology.

[73] <http://www.nobel.se/chemistry/laureates/2000/press.html>. A more in-depth explanation of the discoveries is to be found at <http://www.nobel.se/chemistry/laureates/2000/public.html>.

[74] Rolltronics, 750 Menlo Ave., #200, Menlo Park, CA 94025, 650 566-8471, <http://www.rolltronics.com>.

[75] FlexICs, Inc., 165 Topaz Street, Milpitas, CA 95035, 408 262-3441, <http://www.flexics.com>, e-mail: info@flexics.com, fax: 408 262-3880.

[76] Singer, Peter. "Flexible displays advance." *Semiconductor International.* Newton. Nov. 2001. Vol. 24. Issue 13. 36.

[77] IBM, T. J. Watson Research Center, P.O. Box 218, 1101 Kitchawan Road, Route 134, Yorktown Heights, NY 10598.

[78] Add-Vision, 1500 Green Hills Road, Suite 206, Scotts Valley, CA 95066, 831 438-8192, <http://www.add-vision.com>.

[79] "Executive Summary to Business Plan," Add-Vision, Inc., 2002, page 1.

[80] "Add-Vision is designing in exclusivity by creating and protecting the only manufacturing process that can hit the low cost requirements for the cost sensitive markets we are pursuing."E-mail correspondence from Matt Wilkinson, president and CEO, Add-Vision, Sept. 18, 2002.

[81] Ibid, page 2.

[82] Ibid, page 4.

[83] The Pfeiffer Report, <http://www.pfeifferreport.com/trends/ett_newsstand.html>.

[84] In the middle of the fifteenth century Gutenberg refined a system that automated the reproduction of hand written texts, providing a manufacturing facility that could surpass the output of hundreds of scribes, and equal or surpass the quality of their work. Today, James R. Sheats, of Rolltronics predicts that a single roll-to-roll production line, printing electronic circuits on flexible plastic base, can exceed the square footage production of all of the glass-based electronic display manufacturers worldwide.

R·I·T

Printing Industry Center

An Alfred P. Sloan Foundation Center

Rochester Institute of Technology
College of Imaging Arts and Sciences
55 Lomb Memorial Drive
Rochester, NY 14623
Phone: (585) 475-2733
Fax: (585) 475-7279
http://print.rit.edu