Summary and Policy Issues 1

Flat panel displays (FPDs) are thin electronic devices that present images without the bulk of a picture tube. FPDs have enabled the development of products from digital wristwatches to notebook computers, have improved videocameras and other consumer goods, and will be the heart of wide screen televisions that can hang on a wall. FPDs also present critical information to military forces; they are replacing older displays in aircraft, ships, and vehicles, and are allowing the development of new systems, such as head-mounted displays for individual soldiers.

FPD technology was largely developed in American laboratories, and much of the advanced research in new FPD technologies takes place in the United States. However, the United States has not had a significant capability to manufacture FPDs. Companies capable of manufacturing displays have either decided not to do so or, lacking the necessary financial resources, have been unable to persuade other organizations to fund their efforts. U.S. firms do not have an appreciable fraction of world market share.

Over the past few years, the size and scope of activities and sales in the FPD industry have grown. As market demand for FPDs has grown and the industry has moved into a more mature phase, the role of capital expenditures and manufacturing knowledge has become preeminent. As investment costs have increased and competition has intensified, entry into the mainstream market segments has become more problematic for U.S. firms. These firms continue to pursue established niche technologies and technologies that are not commercialized. However, the market segments for niche technologies remain a small part of the overall FPD market, and new technologies must compete against an increasingly dominant entrenched technology. This situation leads to the conclusion that successful entry into this market will be costly and difficult to achieve. This conclusion, however, is not sufficient to argue against a vigorous effort to enter into the FPD market; rather, it demands that the rewards should be large, given the risks to entry.

This report addresses two issues. First, is the lack of a high-volume domestic FPD industry a cause for national concern? Why might having such an industry be important for the good of the nation? Second, if the government wishes to foster such an industry, what policies might be most effective? In particular, how likely is the Clinton Administration's National Flat Panel Display Initiative to succeed? OTA finds:

1. *A high-volume FPD industry would confer a range of commercial and military benefits on the country. However, there is a good deal of uncertainty regarding the exact nature of these benefits, and it is difficult to weigh them against the costs necessary to establish such an industry (see chapter 2).*

Although FPDs are clearly important economically and militarily, having a high-volume domestic industry may not be as critical as some have asserted. An analysis of the economic benefits of such an industry indicates that some trends in technology development and industry structure may prove as beneficial to users of FPDs as they are to producers. FPDs comprise a diverse set of technologies and applications, however, and the picture remains a mixed one.

Furthermore, while the military importance of FPDs is not altered by changes in technology and markets, these changes may increase the choices available to the military in gaining access to FPD technologies. Specifically, changes in the global FPD industry present new sources of displays. In addition to efforts to develop a high-volume domestic industry, the Department of Defense (DOD) could take advantage of these shifts and encourage the growth of existing FPD capabilities.

2. *The barriers to establishing a high-volume domestic FPD industry are formidable, and government tools to address them are limited (including those in the National Flat Panel Display Initiative). It will be difficult for even a vigorous government program to foster the development of a self-sustaining, domestic high-volume industry. However, government funding can play a role in developing domestic sources for some displays (see chapter 3).*

DOD states that its goal is to obtain early, assured, and affordable access to leading-edge display technologies. DOD's approach to reaching this goal is to encourage the development of a dual-use FPD industry that produces large volumes of displays for commercial markets and is also willing and able to give DOD early access to specialized display technology. DOD's own indicator of progress towards this goal—development of a domestic FPD industry equaling 15 percent of world production by the end of the decade—has a low probability of being achieved. However, DOD's approach does include elements that are likely to strengthen the domestic FPD industry. The difficulties inherent in DOD's approach do not discount that approach, but they provide incentive to consider other policies as well.

The weakness of the U.S. industrial base for FPDs has been a policy concern for several years, and display technology is consistently flagged as an area of concern in listings of critical technologies.[1] DOD has played the lead role in supporting the government's development of FPD technologies, largely through its Advanced Research Projects Agency (ARPA). In particular, ARPA's High

[1] The most recent report from the National Critical Technologies Review Group identified high definition displays as the only area within information and communication technologies—and one of only three among all technology areas—in which the U.S. technology position indicated a substantial lag relative to Japan or Europe; see *National Critical Technologies Report*, March 1995. Earlier reports (and the category related to FPDs) include Department of Commerce, *Emerging Technologies: A Survey of Technical and Economic Opportunities*, spring 1990 (digital imaging technology); Department of Defense, *Critical Technologies Plan*, Mar. 15, 1990 (photonics); *Report of the National Critical Technologies Panel*, March 1991 (high-definition imaging and displays); and Council on Competitiveness, *Gaining New Ground*, March 1991.

Definition Systems (HDS) program has drawn significant support from Congress.

The industry has attracted other government involvement in the form of: 1) antidumping tariffs; 2) research and development (R&D) programs under DOD and the Department of Energy (DOE), the National Aeronautics and Space Agency (NASA), and the National Science Foundation (NSF); and 3) a commercialization program under the Department of Commerce's Advanced Technology Program. OTA last investigated FPDs in the context of the high definition television (HDTV) debate of the late 1980s; since that report was prepared, circumstances have changed (see box 1-1).

INDUSTRY OVERVIEW

It is estimated that worldwide sales of FPDs will total $11.5 billion in 1995, and will double in value by the year 2000; some project the market will grow to $40 billion by the end of the decade.[2] The largest demand for FPDs is for use in computers, mainly portable systems such as laptops, notebooks, and handheld devices. These applications use liquid crystal displays (LCDs), as does consumer electronics, the next largest category. The other large application areas are business and commercial systems, and industrial, communications, and transportation systems; both applications use electroluminescent (EL) displays and plasma displays, in addition to LCDs (see box 1-2 for a description of FPD types).

Military demand accounts for less than one percent of the global FPD market, and is expected to stay relatively constant through the end of the decade.[3] Military displays use LCD, EL, and plasma technologies like the commercial markets, but often must satisfy rigorous performance specifications (for example, readability in bright sunlight, over wide viewing angles, and while subjected to a wide range of temperatures). Also, military displays often require size, packaging, and electronic interfaces that are different from displays used in the larger commercial markets. Military systems currently use a mix of custom FPDs and commercial FPDs, modified to military specifications.

The global FPD industry uses a diverse set of technologies to satisfy a broad array of applications (see appendix A). The dominant technology is the LCD, which itself comes in many forms; the primary variations are the active matrix LCD (AMLCD) and the passive matrix LCD (PMLCD). Measured by value of sales, LCDs account for approximately 87 percent of the FPD market in 1995, evenly divided between active and passive matrix types. By the year 2001, the share held by LCDs as a whole is projected to be about the same (88 percent), with AMLCDs accounting for 54 percent and PMLCDs for 34 percent.[4] As the FPD market as a whole is projected to double between 1995 and 2001, AMLCDs are expected to grow by a factor of 2.5 during that period. Smaller shares are accounted for by plasma and EL displays. In terms of value, these four FPD types make up the vast majority of the FPDs currently in use (see table 1-1).[5]

[2] Stanford Resources, Inc., projects that worldwide FPD market sales will be $19.5 billion in the year 2000 and $22.5 billion in 2001; David Mentley, Director, Display Industry Research, Stanford Resources, Inc., San Jose, CA, personal communication, Mar. 21, 1995. Projections made by Asian sources tend to be higher by as much as a factor of two; see "Scale of Liquid Crystal Industry Assessed," in *Flat Panel Display 1995*, *Nikkei Microdevices*, Dec. 9, 1994, pp. 74-80 (translation provided by Maurice Cloutier, Foreign Broadcast Information Service).

[3] Department of Defense, "Building U.S. Capabilities in Flat Panel Displays: The Flat Panel Display Task Force Final Report," October 1994, chapter III.

[4] Calculated from Stanford Resources, Inc., data, Mentley, op. cit., footnote 2.

[5] Two other types of FPDs—light emitting diodes and vacuum fluorescent displays—account for less than 10 percent of FPD sales. Although representing larger shares of the FPD market than plasma and EL displays, these are low-information-content displays, which present text and simple graphics in small display formats. These displays currently are not suitable for use in large and complex graphics applications, and are not discussed in this report.

BOX 1-1: Flat Panel Display Policy In Historical Perspective

In 1990, the Office of Technology Assessment (OTA) released a report entitled *The Big Picture: HDTV & High-Resolution Systems*.[1] The report came to the following conclusion regarding high resolution systems (HRS), which are primarily flat panel displays (FPDs):

> A strong civilian HRS technology base is necessary if many HRS technologies are to be available for defense needs at all The low costs realized for HRS technologies in the commercial sector, however, will not be automatically translated into low-cost HRS for defense applications. The complexity and specialized nature of defense systems result in long product cycles, high R&D and engineering costs, and stringent performance and reliability criteria that may have little relationship to commercial needs...[2]

Congress demonstrated its concern about the state of the domestic FPD industry by funding FPD R&D in the Department of Defense (DOD) at $75 million in fiscal years 1991 and 1992 In fiscal year 1993, Congress appropriated nearly $170 million,

In 1994, DOD announced the National Flat Panel Display Initiative (NFPDI), It continues existing FPD research, and introduces incentives for domestic firms to produce displays and for the armed services to purchase them. In light of this new policy, it is appropriate to revisit the FPD industry and relevant government policies, and to examine the current state of affairs. In the five years since OTA last studied FPD industry and policy, certain things remain unchanged, *The Big Picture* stated: "High Resolution Systems (HRS) and related technologies are likely to play an important role in future military systems HRS technologies will, however, probably be driven primarily by the needs of the commercial sector. "[3] This report confirms these findings, as does a separate OTA study,[4] However, three major changes have taken place that affect both the potential benefits of a domestic high-volume FPD industry and the costs of creating such an industry

Politico-Military Changes. *The Big Picture* gave several reasons to be concerned about relying on foreign sources for advanced technology: 1) disruption of supply lines during a crisis, 2) pressure by U.S. adversaries on foreign suppliers to withhold critical components, and 3) ease of access by U S adversaries to foreign technology sources.[5] As indicated by the example given in that report (that of Soviet access to Japanese and Norwegian milling technology for making quiet submarine propellers), the concerns at that time were based on Soviet access to-or potential control over—foreign technology with military applications, In particular, the concern was over Soviet threats to Japanese FPD producers, the only overseas sources in 1990. Today, the tensions and concerns rising from the Cold War competition between the United States and the former Soviet Union have largely dissipated,

While the threats posed today by regional conflicts and terrorist groups are serious, it is not clear how adversaries (such as terrorist groups or nations such as Iraq or North Korea) would be able to obtain FPD technology ahead of, or even as soon as, DOD—from Japanese, Korean, or European firms, or even from the former Soviet Union, In February 1995, for example, a subsidiary of the Russian ener-

(continued)

[1] U.S. Congress, Office of Technology Assessment, *The Big Picture: HDTV and High Resolution Systems,* OTA-B P-C IT-64 (Washington, DC: U S Government Printing Office, June 1990)

[2] Ibid., p 17

[3] Ibid , p 16

[4] U.S Congress, Office of Technology Assessment, *Assessing the Potential for Civil Military Integration: Selected Case Studies,* OTA-BP- ISS-158 (Washington, DC U S Government Printing Office, September 1995)

[5] Office of Technology Assessment, op. cit., footnote 1, pp. 16-17

BOX 1-1: Flat Panel Display Policy In Historical Perspective (Cont'd.)

gy company Gazprom announced a $4-million investment in SI Diamond Technology, an FPD firm based in Houston, Texas.[6] A December 1994 report by the World Technology Evaluation Center described numerous other firms in Russia, Ukraine, and Belarus that are eager to collaborate with Western companies in FPD development.[7]

Increased Diversity of Supply. In 1990, large-scale production of FPDs was just beginning There were few experienced suppliers, and the demand created by the portable computing market was in an early stage. The few companies with an operational large-scale FPD manufacturing capability were still struggling with low production yields, and were not interested in entering into any type of custom production. Currently, however, there are several high-volume FPD producers in Japan; investments made in Korea, Taiwan, and Europe will likely result in several more facilities within the next few years

In addition, the domestic industry has improved its ability to meet DOD requirements over the past few years. This is largely due to investments made during the 1990s by DOD's Advanced Research Projects Agency (ARPA) High Definition Systems Program, the Commerce Department's Advanced Technology Program, and an increased level of cooperation and collaboration within Industry DOD-funded companies such as OIS and Kopin have built capabilities for military display fabrication, Planar has expanded its electroluminescent display production, and several new firms are developing field emission displays.

The increasing diversity of high-volume FPD manufacturing (from a few Japanese producers in 1990 to many firms worldwide at present), plus the more advanced state of U.S. manufacturing, means that the risk of supply vulnerability has decreased. In evaluating the need for building a high-volume domestic industry to better satisfy the relatively small defense need, the trend toward FPD supply diversity, combined with the general openness in East-West relations detailed above, must be balanced against the cost of establishing a high-volume domestic FPD industry.

increased Barriers to Entry Into High-Volume FPD Production. In 1990, Japan did not have the commanding lead it now has; since then, Japanese producers have invested several billion dollars in FPD production facilities. These investments have put Japanese producers well ahead of manufacturers in the United States, where investments have been in the hundreds of millions of dollars during this period. The emphasis on increasing manufacturing volumes, decreasing production costs, and concentrating on standardized products means that, in large segments of the market, competition is based on manufacturing, not design. In addition, the investment required to build a high-volume domestic FPD industry has greatly increased; capital expenditures required for one world-class plant to manufacture active matrix liquid crystal displays now approach half a billion dollars.

SOURCE: Office of Technology Assessment, 1995

[6] Agis Salpukas, "Russians Invest in High-Tech U.S. Venture, " New *York Times,* Feb 11, 1995, p 35

[7] J William Deane (cd.), *WTEC Panel Report on Display Technologies in Russia, Ukraine, and Belarus* (Baltimore, MD: Loyola College in Maryland, December 1994)

BOX 1-2: What Are Flat Panel Displays?

Flat panel displays (FPDs) are electronic displays that are much thinner than their screen size, measured diagonally. Like the most common type of electronic display, the cathode ray tube (CRT), FPDs visually present electronic information, including text, graphics, and video. FPDs are also used as displays for computers, cameras, televisions, and other video systems, The FPD presents information in a thin, lightweight package that can operate on a modest amount of power, whereas the CRT requires a large package—typically as deep as the display is wide-that is heavy and consumes large amounts of power.

FPDs have been available in various forms for several decades, but they are more expensive than CRTs for most sizes and they have been slow in replacing the established CRT. However, FPDs have enabled new portable electronics devices, such as laptop and notebook computers, pocket televisions, and personal communicators, that would not be possible using CRT displays, They also have improved other systems, such as aircraft cockpit displays, by replacing existing CRTs

Unlike CRTs, which are all quite similar in terms of the basic operating principle, FPDs use several different technologies, Although they all serve the same function, and in some cases look very much the same, the different technologies have varied performance characteristics and limitations, and are manufactured using different materials and processes. However, most FPDs are generally comprised of a pair of glass plates surrounding a material that filters external light or emits its own light, and use manufacturing techniques closer to the production of semiconductor chips than televisions, Also, most FPDs operate by controlling the color and brightness of each picture element (or pixel) individually, rather than from one common source, as in the electron gun in a CRT, in general, FPDs can be categorized as follows,

Liquid crystal displays LCDs are the most prevalent type of FPD, and are used in notebook computers, pocket televisions, and personal digital assistants, LCDs use a material that acts like a shutter—blocking, dimming, or passing light unobstructed, depending on the magnitude of the electric field across the material, LCDs are lightweight and require little operating power. However, since LCDs only modify light, they require an external source of light; while ambient light is used in simple displays, complex, rapidly changing color displays require a bright light, typically mounted behind the LCD screen,

There are two primary types of LCDs *passive matrix* and *active matrix* LCDs (PMLCDs and AMLCDs, respectively), The PMLCD is the basic type of LCD; it is made by sandwiching liquid crystal material between two glass plates, each of which contains a parallel set of transparent electrical lines, The plates are arranged so that, looking through the display, the lines cross to form a checkerboard pattern, or matrix. Every intersection of two lines forms a pixel, and the voltage across that pixel determines the shade of that pixel. PMLCDs are commonly used for gasoline pump displays, pager screens, digital wristwatch readouts, and other applications that require a simple, inexpensive display; recent manufacturing improvements, however, have led to the application of PMLCDs to more complex display functions, AMLCDs use an electronic switch at every pixel, which provides faster switching and more shades. With the addition of filters that pass only certain colors, AMLCDs produce vivid color graphics in portable computer and television screens. The added complexity of manufacturing the switches results in a large, but diminishing, price premium compared with PMLCDs,

Plasma displays are used in systems that are viewed by many people, such as screens on the floor of stock exchanges. They can be manufactured in larger sizes than LCDs and, unlike LCDs are visible from angles far from straight-ahead viewing, Plasma displays use a gas trapped between the glass plates to emit light when electric current is passed through the matrix of lines on the glass, Mono-

(continued)

BOX 1-2: What Are Flat Panel Displays? (Cont'd.)

chrome (single-color) displays use a gas that emits an orange color; full-color plasma displays use phosphors (similar to a CRT) that glow when illuminated by the gas Plasma displays are heavy and require more power than LCDs, but may be more suitable for large screens to display high definition television broadcasts.

Electroluminescent (EL) displays are found in emergency rooms, on factory floors, and in commercial transportation vehicles. A phosphor film between glass plates emits light when an electric field is created across the film. EL displays are lightweight and durable, and recently have become available in full-color versions.

Field emission displays (FEDs) are not commercially available, but are anticipated to fill many display needs. An FED can be thought of as a flat CRT; as in the tube, electrons are emitted from one side of the display and energize colored phosphors on the other side. Unlike the CRT, which uses one source of electrons to sweep across the screen, FEDs have hundreds of emitters for each pixel. This allows for rapid changes of the image on the screen, and has the advantage of redundancy, in the event that some of the emitters fail, there are others to make up for it

Digital micromirror devices (DMDs) are miniature arrays of tiny mirrors, built on a semiconductor chip. Each mirror can be tilted by changing the voltage at the location under that mirror. The DMD is used in a projector that shines light on the mirror array; depending on the position of a given mirror, that pixel in the display reflects the light either onto a lens that projects it onto a screen (resulting in a light pixel), or away from the lens (resulting in a dark pixel)

SOURCE Off Ice of Technology Assessment, 1995

LCDs are the most prevalent display in computer and consumer electronics applications. In portable computers, 8- to 1 l-inch LCD screens currently share the market. AMLCDscreens provide a brighter, faster, and sharper color display, but can increase the cost of a portable computer by several hundred dollars compared with a PMLCD. Consumer electronics devices, such as personal information and communication devices and electronic games, typically use low-cost PMLCDs.

Military display systems use a mix of custom-designed and -produced AMLCD, EL, and plasma displays, as well as modified commercial LCDs Large plasma displays are used in applications where there are many viewers, such as financial trading floors, and EL displays are used in medical, industrial, and transportation equipment. Digital micromirror devices (DMDs) are just beginning to be used, and field emission displays (FEDs), which have shown promise for many FPD applications, are currently in the prototype stage.

The vast majority of investments in FPD manufacturing facilities have been made by private sources in East Asia to build LCD plants. One source estimates that publicly announced investments through the early 1990s totaled $4.9 billion in Japan, $2.0 billion in Korea, $300 million in Europe, but only $200 million in the United States.[6] Japanese producers account for most FPD production worldwide. In 1994, Japanese companies produced 98 percent of AMLCDs, 90 percent of PMLCDs, 65 percent of plasma displays, and 45 percent of EL displays, measured by market

[6]U.S. Display consortium, San Jose, CA, *Annual Report 1994, p. 5.*

TABLE 1-1: Flat Panel Display Market Segments

Application areas	Size (diagonal)	Technology	Basis of purchase	Segment size
Portable computers	8-11 inch	AMLCD, PMLCD	price, performance	large
Consumer electronics	<10 inch	PM LCD	price	medium
High performance products	2-10 inch	AMLCD, EL	performance	small
Multiviewer information screens	>20 inch	Plasma, LCD, and DMD projectors	performance	small
Medical, transportation, industrial products	various	EL	performance, price	small

KEY: AM LCD = active matrix liquid crystal display; DMD = digital micromirror device; EL = electroluminescent display, LCD = liquid crystal display; PMLCD = passive matrix liquid-crystal display

SOURCE: Office of Technology Assessment, 1995.

value.[7] Manufacturers in East Asian countries other than Japan account for seven percent of PMLCD production. in AMLCDs, one Korean firm has begun volume production, another is in the preliminary stages of production, and a third has invested in a U.S.-based operation. Firms in Taiwan and Europe are also investing in AMLCD production facilities.

To a great extent, the major AMLCD producers have settled on standard display sizes and types. The standard display was the 10.4-inch VGA (video graphics array) in 1994-95, and is now moving toward SVGA (super-VGA) screens larger than 11 inches; 13-inch XGA (extended graphics array) screens have also been developed.[8] One advantage of standard sizes and formats is that they allow manufacturers to produce large quantities of the same item, which is necessary to drive down manufacturing costs. One analyst estimates that 10-inch AMLCD manufacturing costs in Japan have declined from $2,500 per finished display in 1991 to just over $1,000 in 1993; during the same period, manufacturing yields—the fraction of acceptable displays produced—have increased from 10 percent to nearly 60 percent.[9]

Increases in production capacity also have created downward pressure on prices as displays become more widely available. One source estimates that Japan's total monthly LCD output increased 62 percent from 1994 to 1995, while the price of a laptop-size AMLCD fell 30 percent from mid 1994 to early 1995.[10] Price decreases in AMLCDs may increase sales in such end-products as portable computers, in which AMLCD screens are the costliest item. AMLCD producers have also felt price pressure from inexpensive PMLCDs, whose quality has improved.

For many computer purchasers, the main decision is between the two types of LCD screens, and is made by weighing display quality against price. Within each type, there are many similarities among the different screens, and there is less differentiation on the basis of brand name than in other components, such as microprocessors. The move toward standardized products and the continuous reduction in prices suggest that, in the large and increasing portable computer market segment, there will be commodity-like product competition based on manufacturing costs. in oth-

[7] Mentley, op. cit., footnote 2; production is measured by location of company headquarters.

[8] VGA is standard for computer displays that is an array of information comprised of 640 rows and 480 columns; the intersection of every row and column represents a pixel. SVGA is an 800- by 600-pixel array, and XGA is 1024 by 768 pixels.

[9] William C. O'Mara, "AMLCD Manufacturing," in *1994 SID International Symposium Seminar Lecture Notes* (Santa Ana, CA: Society for Information Display, 1994), vol. I.

[10] Estimates from Merrill Lynch Japan and *Nihon Keizai Shinbun*, quoted in Hisayuki Mitsusada, "Advanced LCD Makers Look Beyond PCs," *Nikkei Weekly*, Mar. 20, 1995, p. 8.

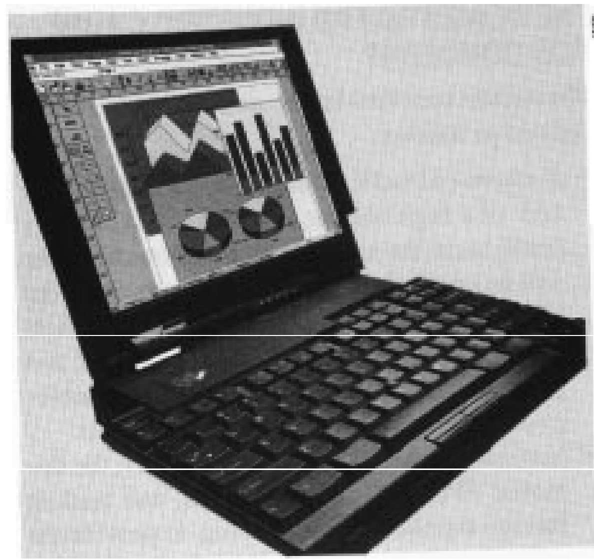
er parts of the market, applications demand more diversified FPD performance and size, so that design and customization will be as important as manufacturing costs, or perhaps more so.

An analogy can be made to the semiconductor industry: there are custom-designed, application-specific integrated circuit chips (ASICs), mass produced but design-intensive microprocessors, and commodity dynamic random access memory chips (DRAMs). AMLCDS for portable computers appear to be moving toward the commodity end, whereas other types of displays will demand diversified product designs.

There are no production facilities for portable computer displays in the United States. Several fledgling efforts produce, or are preparing to produce, AMLCDS for specialized applications, but the domestic industry is strongest in the smallest market segments—EL and plasma for military, medical, and industrial applications.

DOD has awarded funding to Optical Imaging Systems (OIS) to develop an AMLCD factory in Michigan, which will produce small volumes (relative to comrnercial-scale plants) of custom displays for military and civil avionics. DOD has also funded a consortium of Xerox, AT&T, and Standish Industries (the leading domestic PMLCD manufacturer) to develop AMLCD manufacturing capabilities; these firms have not announced plans to invest in a central production facility. Kopin has also been supported by DOD (and other government contracts), and has developed the capability to produce small, custom AMLCDs in limited quantities. Two other firms, ImageQuest (majority-owned by Hyundai) and Litton Systems Canada, have built facilities to produce AMLCDs for military use and commercial avionics. The largest display concern involving a U.S. firm is Display Technology, Inc. (DTI), a joint venture between IBM Japan and Toshiba that has built two plants in Japan.

A significant segment of the U.S. industry is pursuing FPD technologies other than AMLCDs. Planar is a world leader in electroluminescent



Probably the best known application of flat panel displays (FPDs), portable computers comprise the largest single market for high-resolution color FPDs.

FPDs, with more than half of the market. Photonics Imaging, Plasmaco, and Electro Plasma are competitive in plasma displays (display technologies and U.S. firms are described in appendix A). The U.S. industry has also been a leader in R&D on new types of displays, fueled in large part by the ARPA HDS program. ARPA grants have supported new technologies such as the DMD; ongoing programs support FED research. Both of these technologies have the potential to *leapfrog* the dominant AMLCD by offering superior performance and/or lower manufacturing costs.

The ARPA program has also been successful in funding universities and consortia to train researchers, develop new technologies, and foster the infrastructure needed to support a vibrant domestic industry. The U.S. Display Consortium, funded equally by ARPA and industry (FPD producers, defense contractors, and commercial FPD users), has been a cost-effective tool for infrastructure development, awarding contracts to small FPD equipment and materials suppliers who then create products available to the display manufacturers.

THE DOMESTIC FPD INDUSTRY: CAUSE FOR CONCERN?

The current concerns for the nation can be broadly defined as follows:

- *Economic Benefit*. Some observers say that the lack of a high-volume domestic FPD industry could harm the nation because domestic firms will be unable to: 1) sell to a large and growing FPD market; 2) compete in product markets that rely on FPDs as a critical component; and 3) benefit from the spillovers of FPD technology to other semiconductor-based products.
- *National Security.* According to DOD, the domestic FPD industry is not able, and leading foreign suppliers are not willing, to provide the military with *early, assured, and affordable access* to leading-edge FPD technology, which DOD asserts is critical to national security.

These concerns can be analyzed separately, but are interrelated because a stronger domestic FPD industry could result in benefits for both military and economic security. DOD frames its FPD policy strictly in military terms, but both concerns are examined here because both have been raised in support of an expanded government role in FPD development.

In the past year, FPDs have attracted attention as a policy issue because of DOD's initiative to create a domestic industry that can satisfy military needs. In 1994, at the conclusion of an interagency task force study on FPDs, DOD determined that it requires early, assured, and affordable access to leading-edge FPD technology of all types, and that it did not have such access.[11] DOD found that even though it had supported FPD R&D for years, domestic companies have not developed capabilities to meet its needs. If the domestic industry remains small, DOD reasoned, firms would be unable to support the level of R&D necessary to keep up with technology developments worldwide; thus, there is no reasonable assurance that a leading-edge domestic technological capability would be available to the military in the future.[12] Finally, DOD found that the leading sources of FPDs in Japan would not (based on corporate policy) or could not (based on interpretations of Japan's export ban on military items) work with DOD on its specialized requirements.

Because defense demand represents less than one percent of the total FPD market, DOD is pursuing a *dual-use* strategy: attempting to exploit commercial advances in R&D and manufacturing to meet defense needs. Because the technologies used in military displays are the same as those used in commercial products, DOD's approach is to bolster the ability of domestic firms to produce FPDs for both military and commercial markets. DOD then plans to take advantage of the economies of scale provided by the volumes demanded by commercial markets. Called the National Flat Panel Display Initiative (NFPDI), the policy increases funding for FPD manufacturing technologies and promotes insertion of displays into military systems, in addition to continuing an existing R&D program. A fourth part of NFPDI, designed to stimulate domestic and foreign demand for domestic FPDs, has not yet been implemented.

DOD justifies NFPDI solely in national security terms, as the most efficient method for meeting defense FPD needs. DOD states that it is not trying to build a domestic, high-volume commercial industry as an end in itself or to achieve broad economic benefit. However, the dual-use approach requires that a substantial commercial base exist to be integrated with the military base, and the commercial FPD base is currently inadequate. Thus, NFPDI aims to create a domestic base that can satisfy both military and commercial demands. This would likely create economic benefits as well, which could be regarded as spillovers from satisfying the national security goals.

It is possible to evaluate NFPDI as a method for meeting defense needs, and this report does so.

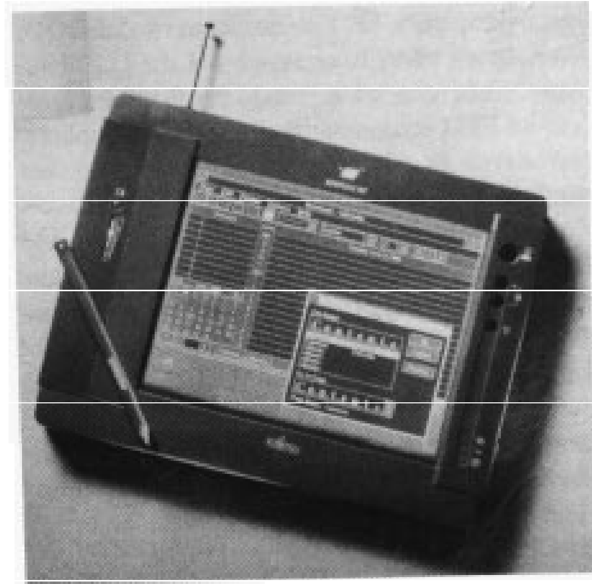
[11] Department of Defense, op. cit., footnote 3, chapter I.

[12] Department of Defense, *Dual Use Technology: A Defense Strategy for Affordable, Leading-Edge Technology*, February 1995, p. 12.

However, because some benefits would accrue to the domestic commercial base from a successful NFPDI, and many observers feel that the development of a high-volume domestic commercial FPD industry is desirable in its own right, these potential benefits should be included in an analysis of the NFPDI approach. Most of DOD's specific requirements for FPDs more closely resemble those for niche commercial market segments (such as civil avionics, industrial, and medical systems) than those for the largest commercial markets (in portable computer and communications systems and consumer electronics items). Thus, even if NFPDI is successful in meeting military needs, it may have limited impact on the largest commercial market segments.

There are also potential developments that could bolster capabilities in the domestic commercial FPD industry, while only indirectly improving the domestic capability to produce FPDs for military needs. An example would be an investment in a domestic FPD plant to produce displays for the portable computer market, the largest single FPD application.[13] Such a factory would likely be similar to current-generation factories in Japan and Korea that produce displays for notebook computers, typically at volumes of approximately one million displays annually.

This type of plant would represent a huge increase in the domestic FPD production capacity, providing a boost to domestic suppliers of materials and equipment. However, it would likely concentrate on producing large volumes of standard displays (e.g., 11-inch-screens with SVGA resolution), and might not have arty direct effect on DOD's need for early, assured, and affordable access to leading-edge FPD technology for military systems. The indirect effects could, nonetheless, be substantial. The increased understanding of FPD manufacturing processes acquired at such a plant could benefit other domestic manufacturers, and the added demand for inputs to the FPD production process would benefit the domestic infrastructure, contributing to DOD's goal of developing a dual-use industry in the United States.



FUJITSU PERSONAL SYSTEMS, INC

Liquid crystal displays have enabled the development of handheld computer and communications devices, such as this pen-based computer.

■ Economic Benefit

The economic benefits to the nation of having a high-volume domestic FPD industry present an uncertain picture. The benefits pertain to the FPD industry itself, which has undergone rapid growth in the past few years; U.S.-based users of FPDs, such as computer companies; and related industries, like semiconductor devices.

It is not clear how important these benefits are to downstream producers and related industries. They have not yet been great enough to induce firms such as computer or semiconductor manufacturers to make the investments necessary to create a high-volume, commercially oriented domestic FPD industry. However, some downstream firms have made some moves in that direc-

13 To date, there has been no U.S.-based production of such FPDs. Sharp Corp. performs final assembly of portable computer screens at its wholly owned U.S. affiliate in Camas, Washingston.

tion. Along with FPD manufacturers and DOD, downstream users have supported the U.S. Display Consortium, which funds development projects by FPD equipment and materials suppliers, and serves as a forum for communicating user ‘needs to FPD manufacturers.

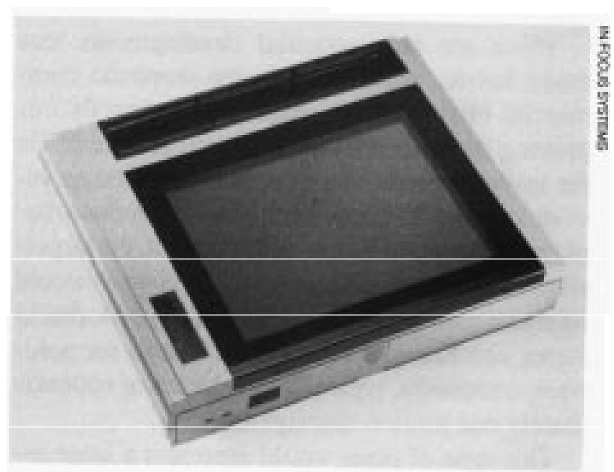
Some downstream fins, such as Compaq and Hewlett Packard, have also formed partnerships with nascent FPD producers, some of whom believe that DOD’s support has created the climate for these investments. Finally, IBM has joined with Toshiba to create DTI, now one of the world’s largest display-making operations. But DTI is 1ocated in Japan, and no firm has made the commitment to find a high-volume FPD plant located in the United States.

The FPD Industry

The industry is currently valued at $11.5 billion, and most forecasts put it at $20 billion to $40 billion by the year 2000. Having a substantial portion of that industry in the United States could provide high-value jobs. However, profitability may vary across the industry. The AMLCD industry structure has become less concentrated recently as more than 10 Japanese fins, three Korean firms, two Taiwanese firms, and one European firm have built, or are building, high-volume production facilities. If the pattern in other high-volume electronics industries is repeated here, entry by Korean and Taiwanese firms will drive down prices.

While product diversification exists in much of the FPD industry, AMLCDs for portable computers—a large part of the FPDs produced—are moving toward commodity goods; that is, products with similar core features that are produced by multiple sources and compete on the basis of price, rather than any distinguishing characteristics. Commodities tend to command low profit margins unless the production capacity is insufficient to meet demand.

A recent report by a Japanese investment firm states that a typical firm that began production in 1992 did not reach profitability until 1994, is likely to show zero profits throughout the second half of 1995, and will return small profits in 1996 and 1997.[14] Although AMLCD manufacturers had been unable to keep up with demand during the early 1990s, the huge level of investment in AMLCD production in Japan and Korea appears to be more than sufficient to meet worldwide demand.[15]



Liquid crystal display projection panels can be used with overhead projectors to present high resolution computer graphics and video in group settings.

However, other commercial market segments-such as commercial avionics and automotive displays—will involve specialized products, produced in lower quantities, that will probably command relatively high profit margins based on their particular features. FPD applications are quite diverse and have different demands

14 Hideki Wakabayashi, “Is Confidence in the Growth Potential of the LCD Panel Market About to Collapse?” Nomura Research Institute, Tokyo, Japan, May 25, 1995.

15 One market analyst has documented that announced capacity to produce portable computer screens is five times the demand for screens, although announced capacity is greater than actual capacity, which in turn is greater than actual output. See David Mentley, “The Notebook Computer Market and Display Manufacturing Capacity,” *SEMI International Display Report,* vol. 4, No. 4, May 16, 1995.

with regard to display size, shape, resolution, power consumption, brightness, color, speed of switching, interface to other components, and tolerance of environmental stresses, such as sunlight readability, physical impact, acceleration, temperature, and electromagnetic energy.

These niche segments are likely to be more attractive to U.S. firms for two reasons: 1) the profits will likely be higher than for standardized displays, and 2) U.S. firms tend to compete better on the basis of improving product features than on the basis of cutting manufacturing costs. However, these markets will not be ceded to U.S. firms; some Japanese and Korean LCD producers are moving into this market to diversify their commercial markets, and firms such as Hosiden and Sextant Avionique are already established producers.

Downstream Industries

The commercial benefit of having a high-volume domestic FPD industry would extend beyond the FPD industry itself to include downstream U.S. industries such as computers, communications equipment, and consumer products. Often the display is the component that differentiates the downstream product; in such cases, it is important for the downstream firm to be able to purchase the best FPDs available. However, because many Japanese FPD producers are vertically integrated electronics companies, their first priority could be to supply displays needed for the firm's own end-products. As a result, the U.S. firms that make competing end-products might have to wait longer for the latest displays. Currently, large U.S. FPD purchasers can negotiate early access because of their buying power; however, this may not be the case for firms that require smaller volumes or more specialized products. A strong U.S. FPD industry would make downstream U.S. firms much less dependent on Japanese FPD producers.

However, even in the absence of a strong U.S. industry, the competition among FPD producers in Japan means that many producers want outside customers to provide assured orders for their products. Also, the entry of new FPD producers based in Japan, Korea, Taiwan, and Europe will give U.S. display users more options, though many of these new producers are also integrated electronics firms that could give priority to in-house needs.

Access to the best off-the-shelf FPDs is not always enough. Sometimes U.S. end-product producers need displays customized to their specifications. The best product design might require, for example, a different size display, a new way of fitting the display into the product housing, or a special electronic interface between the display and other components. Here, too, Japanese dominance of the FPD industry could pose difficulties for U.S. firms. In many cases, Japanese FPD producers have not been interested in customizing displays to U.S. customers' specifications, particularly for small numbers of displays. This may change, however, as announced capacity increases are realized.

In addition, U.S. customers may hesitate to share sensitive product development information with Japanese display producers who might use that information to produce competing products. The often-cited example of this problem is Sharp Corp.'s Wizard personal digital assistant that Sharp introduced soon after the Apple Newton, which was produced by Sharp for Apple. Computer companies typically protect their designs by using rigorous nondisclosure agreements with their FPD suppliers. These agreements are designed to limit the flow of design information to competitors, including those within the same corporate group as the display manufacturer. This seems to provide a good deal of protection, but the possibility of integrating other functions onto the display (see below) heightens concerns among some of these companies. The appearance of new FPD suppliers will ease these concerns somewhat by giving U.S. firms more choices, though new suppliers could also limit supply or compromise designs.

The only domestic downstream firm that has moved to gain direct control over FPD production is IBM, whose Japanese subsidiary is a joint owner of DTI, a leading FPD manufacturer located in

Japan. This approach allows IBM some vertical integration of FPD production and computer manufacturing, but it has to cooperate in display design and production with its co-owner, Toshiba, a competitor in portable computers.

Integration

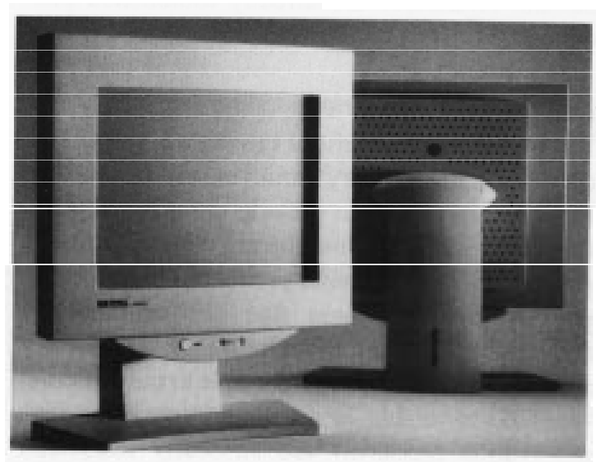
A technical trend that involves building electronic components on the display itself could have serious implications for the end-users of displays in the future. By integrating some of an end product's nondisplay functions into the design and manufacture of the FPD, there may be savings in weight, power, number of components, and system costs. Such integration would add value to the display, and would likely shift profits from the end-product manufacturer to the FPD manufacturer. Integration would also lead to increased control over the system design and functionality by the FPD manufacturer, which would increase end-product producers' concerns about access to needed displays and control over product development.

There is a spectrum of integration possibilities, from a bare display to a computer on a display. The current level of integration in computer screens involves mounting on the display only the circuits that directly drive the display elements, along with a few associated integrated circuits. The level of integration could increase through advances in chip packaging and mounting, further development of emissive displays (in which electronics can be mounted on the back of the display without obstructing the light source), or advances in depositing semiconductor circuits onto display glass. Some experts predict that the next level of integration will include the set of chips that define the images to be displayed. The ability to integrate extensive circuits, such as memory or microprocessor functions, is much further off, and the reasons for doing so are not yet clear.

Spill over to Related Industries

Another commercial benefit would be the spillover of manufacturing technology into the semiconductor industry. Production of semiconductor chips and FPDs shares some materials, equipment, and processing techniques. Therefore, a high-volume domestic FPD industry could strengthen the base of materials and equipment suppliers for the semiconductor industry, and develop process expertise that can help semiconductor producers.

The spillover is most prevalent in the equipment and materials inputs. FPD manufacturing equipment leads some sectors of the semiconductor industry because it is designed to handle large substrates and minimize contamination over large areas during manufacturing. In the actual manufacturing process, differences in required linewidths, substrate size, output per substrate, and cost of materials limit spillover.


ZIBA DESIGN, INC.

Flat panel display desktop computer monitor offer compact design and low power consumption compared with cathode ray tube (CRT) monitors.

Because the semiconductor industry is likely to remain much larger than the FPD industry, it could provide a strong incentive for the development of needed material and equipment inputs, even in the absence of a domestic FPD industry. However, for some equipment and materials suppliers, a high-volume FPD industry would probably represent a large portion of their business.

■ National Security

While FPDs are increasingly important to the information-driven military, the low volumes and nonstandard requirements of military FPDs make defense contracts unattractive to many commercially oriented FPD producers. DOD's goal is to guarantee early, assured, and affordable access to FPD technology so it can design leading-edge technology into military systems. DOD states that investigations of Japanese display suppliers revealed that these firms will not provide it with early and assured access to leading-edge FPD technology. DOD also states that it cannot afford to purchase displays from a small, specialized domestic industry. Such an industry will have high unit costs and will require large R&D subsidies to keep up with the much larger commercial industry (and even then will likely lag behind commercial technologies).

However, the picture is not entirely clear. The military has a variety of FPD needs; some can be met by commercial displays, and others require custom-designed FPDs. DOD can use three complementary strategies to gain secure access to FPD technology and systems: 1) foreign FPD firms, 2) U.S. niche FPD firms serving defense and commercial needs, and 3) a possible future high-volume, commercially oriented U.S. FPD industry. The need for developing the third source depends on the adequacy of the first two, what the third would add, and what it would cost.

Foreign Access

In preparing its report on FPDs during 1993-94, DOD mainly investigated and/or held discussions with four firms based in Japan—Sharp, NEC, DTI, and Hosiden—that accounted for more than 90 percent of AMLCD sales in 1993.[16] DOD found that NEC and DTI were captive producers, not selling displays on the open market; and Hosiden was judged to be in a precarious financial state. Sharp, the leading FPD manufacturer, stated unequivocally that it would not directly supply DOD with displays and would not make customized FPDs for DOD's use. Its stated reason was that, as a matter of corporate policy, it is a consumer firm and will not sell directly for military uses (some Japanese firms fear that selling in the military market will besmirch their reputation with Japanese consumers). Sharp may, in part, be concerned that Japanese export control laws could be interpreted to restrict selling even standard commercial displays to foreign defense forces.

There is also a fundamental business reason for Sharp's refusal. The small volumes, detailed specifications, and intrusive verification procedures demanded by military procurement are not attractive to a high-volume FPD producer. Such a company must concentrate on increasing the throughput and yield of existing product lines. Responding to detailed specifications for a few thousand displays is not justifiable for an operation that produces millions of displays per year. Such production economics will influence decisions regardless of location or ownership of the facility.

However, Sharp and other Japanese firms do supply off-the-shelf displays to DOD's contractors, who then customize the displays for military use. OTA interviews with these contractors have not revealed problems with timely supply of FPD technology; however, potential problems exist in adapting system designs to changes in FPD designs and ensuring an adequate supply of replacement displays after the systems are fielded and the original design is no longer manufactured. Also, while Sharp continues to be the leading AMLCD manufacturer, its share of Japanese LCD production has fallen recently. Sharp's share of Japanese AMLCD production fell from 42 percent in 1993 to 36 percent in 1994; during the same period, its share of PMLCD production fell from 24 to 20 percent.[17]

[16] DOD points out that it is continuously monitoring developments in Asia and is holding follow-on discussions with FPD producers. Richard Van Atta, Special Assistant, Office of Dual Use Technology Policy and International Programs, U.S. Department of Defense, personal communication, June 7, 1995.

[17] Market shares calculated from "Scale of Liquid Crystal Industry Assessed," op. cit., footnote 2, chart 2 for firms' production estimates, and figure 1 for estimates of total production; years cited are Japanese fiscal years, which begin on April 1.

Flat panel displays present video and fright instrumentation date in cockpit avionics using a fraction of the space and weight of cathode ray tubes and electromechanical displays.

There are numerous other suppliers in Japan, one established supplier in Korea, and a few other Korean, European, and Taiwanese firms now investing in AMLCD production. There is a possibility that ongoing production investments will result in large amounts of oversupply in the AMLCD market, which could give DOD's contractors more leverage over suppliers. The increasing application of AMLCDs to commercial avionics and automotive systems may also increase the availability of FPDs suitable for military systems.

Currently, commercial off-the-shelf displays are available to domestic integrators for as little as one-third the cost of comparable custom-made military displays.[18] Thus, foreign display producers are, and could continue to be, a promising source of low-cost displays for some of DOD's needs. The U.S. government could take measures to enhance this source, for example, by seeking clarification of Japanese laws regarding export of dual-use products. It could also encourage Asian producers to invest in manufacturing sites in the United States. However, relying on foreign sources for certain types of FPDs could conceivably put the military in a vulnerable position, susceptible to interruptions of supply and to manufacturers not always willing to provide DOD with early and assured access to FPD technology.

Niche Producers

DOD could continue to build and sustain an FPD industry that concentrates on low-volume military and commercial applications. Because military needs are projected to remain small in volume for the next 15 years (in the low tens of thousands annually through the year 2009), those needs could be filled largely by a small domestic industry that would also concentrate on applications with similar requirements, such as commercial avionics. As in the previous approach, military demands would be met by off-the-shelf items wherever possible, and by custom production in selected critical applications. U.S. firms are relatively strong in niche technologies and applications, such as EL, plasma, and custom AMLCD displays for military, industrial, and medical applications. This is, to a large degree, the result of several years of investments by ARPA's HDS program. These technologies and applications are somewhat distinct from mainstream AMLCD application areas such as portable computers.

DOD has concluded that the small domestic capacity is not suitable for filling defense needs, and present trends will not lead to this capacity. In addition, DOD states that buying from low-volume domestic producers would mean high per-unit costs.[19] Another concern is that the industry's relatively small revenues could fund only limited

[18] OTA estimates based on interviews with military program offices.

[19] DOD estimates that the cost per unit for a small-scale defense unique producer is 100 times that of a larger, dual-use plant. Kenneth Flamm, Principal Deputy Assistant Secretary (Economic Security) and Special Assistant (Dual Use Technology Policy), U.S. Department of Defense, OTA briefing, May 18, 1995.

R&D, making it difficult to keep up with the much larger global industry in product development and manufacturing, and denying military planners the ability to utilize leading-edge display technologies. DOD argues that it would need to continually pump in massive amounts of R&D support to help the U.S. industry keep up and, even then, the U.S. industry would likely fall behind. The department has concluded that both high unit costs and the requirement for R&D subsidies would lead to high total costs to DOD for a domestic industry dependent on niche markets.

However, there are other possible outcomes. During fiscal years 1991-95, relatively modest R&D support (on average $117 million per year from DOD and another $10 million per year from other government agencies) has made the U.S. industry substantially better able to meet defense needs. For example, in AMLCDs, OIS has completed a pilot plant and Xerox and Planar have joined together to produce military displays. Litton Systems Canada and ImageQuest have also built low-volume AMLCD production facilities, and plan to compete in the military market.

DOD could also help the U.S. industry tap into developments abroad. As the Japanese have shown in many industries, following the technological leader closely need not cost nearly as much as blazing the technological trail. Being a follower might cause concerns for DOD's access to leading-edge displays. However, because the development cycle for military systems is several times longer than for commercial FPDs, any technology lags would likely be overshadowed by the development time of the system of which the FPD is a part. Nevertheless, it could be argued that the long development time increases the need for early access to display technology by military systems integrators. To address time lags, DOD is moving to accelerate the insertion of FPD technology into existing and planned military systems.

Another area in which the domestic FPD industry could take advantage of foreign investments is in manufacturing technology. Much manufacturing technology is embodied in materials and equipment used to manufacture FPDs, and the availability of this equipment outside of Japan has allowed the development of FPD plants in Korea and Taiwan. It is reasonable to assume that Japanese equipment and materials suppliers would also sell to U.S. FPD manufacturers. However, as with finished displays, foreign materials and equipment suppliers might not always supply U.S. FPD firms in a timely manner. Also, tariffs on input materials, which are often higher than for finished displays, can put U.S. manufacturers at a disadvantage. Rationalizing the tariff structure could help domestic producers.

The lack of a high-volume U.S. FPD industry could cause the U.S. supply base for FPD materials and equipment to deteriorate, increasing U.S. dependence on foreign suppliers. Several U.S. firms have developed key inputs to the FPD production process, including Corning's glass substrate, Texas Instruments' driver chips, and MRS Technology's panel printer equipment. These firms are forced to concentrate their business—and in some cases production—in Japan where the bulk of FPD manufacturing occurs. They could be reliable domestic sources; some U.S. production facilities (including OIS and ImageQuest) have been equipped with mostly U.S.-made inputs.

High-Volume Domestic Dual-Use Industry

The U.S. FPD industry has less than three percent of the world market. Therefore, the domestic industry can fund only a small fraction of the world's R&D on FPDs, and could thus have trouble keeping up with the latest technology. DOD seeks to substantially increase the market share of domestic producers, which would greatly increase its ability to stay at the leading edge. Given the small military demand, a larger U.S. industry would have to serve primarily commercial markets.

However, to create a high-volume commercial FPD industry requires large investments. The capital investments in a world-class FPD manufacturing facility (close to half a billion dollars in capital costs for AMLCDs, less for other technologies) must be followed by a period during which an unknown investment of time and money must be made to develop a reliable manufacturing process. Because U.S. firms have not indicated a will-

Compact flat panel displays enable the use of global positioning system (GPS) data and electronic maps to help drivers find their way

ingness to make such investments, the dual-use approach will likely require substantial government investment.

There is some tension between achieving a large U.S. industry and making that industry relevant to DOD's needs. The requirements of the largest applications-AMLCDs for portable computers and consumer electronics-are different from many military applications. Because much of the competition in FPDs is based on high-volume manufacturing, R&D done for these applications might not have great relevance to what DOD requires. Smaller commercial market segments, such as commercial avionics, more closely match military applications.

Also, it is not clear how much a large U.S. industry would reduce unit costs for custom military displays. A large commercial plant would likely produce displays for portable computers, which require large runs to increase production yield. Once volume commercial production had begun, it is likely that DOD would still face the problem of requiring small volumes of product whose specifications are different from most commercial products, requiring separate production runs or separate lines. Although domestic manufacturers may be more willing than foreign firms to adapt commercial lines to fulfill such needs, the added cost due to tailored production would still result in military displays with relatively high unit costs.

STRATEGIES AND POLICIES FOR A DOMESTIC FPD INDUSTRY

The second issue addressed by this report is an analysis of policies for fostering a high-volume domestic FPD industry. The discussion of military and economic benefits identified reasons why government has some interest in developing such an industry in the United States. In order to analyze existing or proposed policies seeking to address the weak state of the U.S. FPD sector, it is helpful to review the history of both private efforts to commercialize FPD technology, and government programs to support generic FPD R&D and product development for military requirements.

This examination reveals limitations to government influence in developing a high-volume FPD industry because: 1) U.S. firms have historically chosen not to enter into FPD production, and 2) the government's display requirements (to date, largely for military purposes) are small and somewhat different from mainstream commercial products. Nevertheless, government support has sustained the industry through difficult times, and could provide some incentives for broadening the current production base.

DOD's current policy, the National Flat Panel Display Initiative (NFPDI), has set a goal of securing early, assured, and affordable access to leading-edge FPD technology. DOD's plan for attaining this goal is to invest in dual-use FPD technologies, and to induce industry to invest in high-volume production capacity. However, DOD's goal could potentially be reached by taking advantage of existing commercial FPD sources (which are largely foreign) and custom military FPD capabilities in the United States.

I Commercialization History

The majority of key FPD innovations were made in the United States. Demonstrations of the first liquid crystal, active matrix, plasma, and electroluminescent displays were all made by the end of the 1970s at U.S. laboratories, often within large electronics corporations. None of these companies seriously tried to commercialize FPD technology; several Japanese firms did. The history goes through three time periods.

In the 1970s, as simple devices that could display text and numbers became available, many firms viewed FPDs as suitable mainly for low-cost, low-information-content displays for products such as watches and calculators—consumer markets that many U.S. firms were exiting at the time. Some firms decided that displays were important to their business, but opted to stay with the mature cathode ray tube or to adopt light-emitting diodes (which were initially competitive with LCDs, but were inferior for color or graphic displays). By the end of the decade, as FPD innovators such as Westinghouse and RCA were exiting consumer electronics altogether, they either closed down or sold off their FPD efforts. As these firms discontinued support for FPD research, a new group of startup FPD firms was formed.

In contrast, Japanese electronics firms were very interested in the watch and portable calculator markets, and developed LCDs as a way of differentiating their products. The first firm, Sharp Corp., took notice of the work in American laboratories and began its own research in 1973.

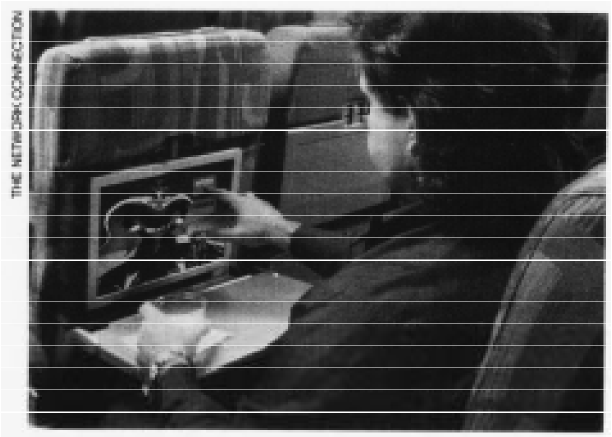
During the 1980s, U.S. startup firms ran up against an increasingly large development effort among Japanese firms that were moving from simple to complex FPDs. By the mid-1980s, several Japanese firms had developed portable television products using AMLCD screens. Aided by some government programs, low capital costs relative to the United States, and large amounts of internal capital, Japanese firms began to make investments in LCD production plants by the end of the decade. The small U.S. firms were able to secure startup and R&D funding, but very few were able to raise enough money to build the facilities required for FPD manufacturing. By the end of the decade, many of the nascent U.S. efforts had failed.

In the 1990s, earlier Japanese investments have resulted in the capacity to produce sophisticated FPDs for consumer markets, and the pace of investment has increased. Announced investments made by several firms are approximately $400 million for each state-of-the-art AMLCD manufacturing line; some of the firms have built several lines. In this key FPD technology, Japanese firms have developed an impressive store of manufacturing expertise, the result of billions of dollars in manufacturing investments and several generations of display production.

The level of manufacturing sophistication, as well as the sheer volume of production capacity installed and announced in Japan, has created the latest barrier to volume production of FPDs in the United States. U.S. investments made during the last few years, primarily by DOD and other government agencies, have sustained the domestic R&D effort, and several promising technologies have been identified and, in some cases, taken to the prototype stage. But private sector commitments to large-scale production of FPDs have not yet materialized.

Strategies for Market Entry

There are several ways to develop a high-volume domestic FPD industry. The first is to increase the size of existing niche markets. By developing new product types and applications, the market share held by U.S. firms in LCD (including custom AMLCD), EL, and plasma technologies could be increased, even as the size of the overall market grows. The advantages of such an approach are: 1) it builds on existing strengths of the domestic industry, 2) it develops capabilities in technologies of use to military systems, 3) it does not require fundamental breakthroughs in technology, and 4) the minimum efficient scale for such an FPD plant is not large as in AMLCD plants for computer/consumer markets. This strategy is limited by projections that call for market shares of FPDs other than active matrix LCDs to diminish to a third of the market by the end of the decade; market shares of plasma and EL are projected to remain at a few



Flat panel displays in aircraft seat backs allow passengers to individuality select information and entertainment choices.

percent. However, advances in HDTV could lead to a large demand for large-screen monitors, an application that some have advocated will be best filled by plasma displays.

Another approach would be to enter into high-volume production for the largest and fastest growing market segment-AMLCDs for computer and consumer goods. This would require large investments in the type of manufacturing technology used by East Asian companies in several large AMLCD plants, and would involve catching up to the market leaders by gaining experience in mass manufacturing. While it may be the only way to capture a large portion of the FPD market over the next several years, it would require a series of plant investments in the half-billion-dollar range, along with a variable amount of investment during the startup period at each facility. While such an approach would satisfy some of DOD's FPD needs, modification of many of the displays would still be required, and not all of DOD's requirements can be met by AMLCDs.

A final approach would be to exploit a ***leapfrog*** display technology that could either displace AMLCDs as the market leader or create significant new market niches. Ideally, such a technology would offer both relatively low manufacturing costs and performance not offered by existing display technologies. Many analysts have suggested that field emission displays (FEDs) have the potential for unseating AMLCDs in the largest market segments. Several U.S. firms are at the forefront of FED research, but the performance and manufacturing costs of standard devices have yet to be determined. Another potential leapfrog device is the digital micromirror display (DMD), which could provide large-screen performance superior to any known FPD. However, the DMD is only suitable for projection display systems, and is not a candidate for direct-view or portable devices.

■ Government Activity

Government activity in the FPD industry has taken two principal forms: 1) R&D support for development of military and generic commercial FPD technologies, and 2) enforcement of U.S. antidumping laws. The support has largely come from DOD research grants and cost-shared manufacturing development contracts. The FPD antidumping case during 1990-93 served mainly to alienate FPD producers from end-users and to separate producers' interests by FPD technology, rather than providing an incentive for domestic production,

Government funding for FPD R&D has averaged more than $100 million per year from 1991 to 1995. Most of this was through ARPA's HDS program, an outgrowth of the concerns in the late 1980s that the United States should have a domestic HDTV industry.[20] The ARPA HDS program has made progress in developing an infrastructure for FPD development by supporting equipment and materials vendors through efforts such as the U.S. Display Consortium and the Phosphor Technology Center of Excellence. It has also made grants-matched by private sector recipients—to build pilot facilities (called manufacturing testbeds) for domestic FPD manufacturing.

[20] See U.S. Congress, Office of Technology Assessment ***The BigPicture:HDTV and High Resolution*** *Systems,* OTA-BP-CIT-64 (Washington, DC: U.S. Government Printing Office, June 1990).

Smaller efforts have been funded by the National Institute of Standards and Technology in the Department of Commerce, under its Advanced Technology Program, for development of generic FPD manufacturing technologies. The Department of Energy's national laboratories have also funded FPD development work, and carry out a DOD-funded FPD manufacturing program in the National Center for Advanced Information Components Manufacturing. Basic research in FPD technology has been supported by the National Science Foundation, and NASA has funded the insertion of FPDs into its systems, most notably the Space Shuttle.

The experience of the FPD antidumping case demonstrated the limited utility of trade laws as a tool to foster a domestic industry. First, there were legal issues, such as the definition of the FPD industry, that were not addressed by the government in a coordinated manner. Second, there were limitations—such as application of the antidumping duty to FPDs only, and not to end-products containing FPDs—that made the antidumping duties less effective. Most importantly, the antidumping laws are not well suited to address the lack of a high-volume domestic FPD industry, something that was determined more by investment choices of U.S. firms than the pricing practices of Japanese firms.

The National Flat Panel Display Initiative (NFPDI)

DOD developed NFPDI because it concluded that maintaining the status quo of R&D and (since 1993) manufacturing testbed funding would not lead to the development of a domestic capability to guarantee early, assured, and affordable access to leading-edge FPD technology, and that foreign firms were not willing or able to offer such access. DOD believes that by investing in NFPDI now, it can provide incentives to the private sector to make the large investments required for high-volume commercial production, leading to a self-sustaining domestic industry that will allow the military to buy cheaper FPDs in the future. DOD's target is for U.S. production of FPDs to comprise 15 percent of the global FPD market by the year 2000, from less than three percent in 1994.

NFPDI uses some of each of the strategies identified earlier: foreign access, niche markets, and developing higher volume production. DOD states that it will continue discussions with foreign producers over access to FPD technologies, and that the NFPDI grants are open to foreign-owned firms that commit to U.S. production. Other aspects of NFPDI continue previous programs that emphasize specialized defense needs, such as continued support of AMLCD manufacturing testbeds at OIS and at Xerox/AT&T/Standish, and the ARPA HDS core R&D program. However, the thrust—providing incentives for domestic commercial and military production—is to encourage higher volume, commercially oriented production. NFPDI is best understood as an umbrella program that includes the preexisting core R&D and manufacturing testbed programs funded through ARPA and two new elements:

1. a series of competitions that award R&D incentives to firms willing to commit to domestic production, and
2. purchase incentives for the armed services to insert FPDs into existing and future military systems.

The R&D incentives program has so far committed $48 million overall to three teams that have presented the most credible business plans for moving from prototype versions of FPDs to domestic volume production. The incentives are in the form of government-funded R&D, matched by the firms, to be used on significant process or product technology improvements. In order to receive an incentive, a firm must have made a credible demonstration of its technological capabilities and have devised clear and feasible plans for moving the technology into military applications. In addition to matching the R&D funds from DOD, the firms are required to make a commitment to investing at least three times the

Medical, industrial, and transportation systems require the display of bright, sharp images in a rugged package, such as this electroluminescent display

amount of the R&D incentive in production plant and equipment.[21]

The purchase incentives are through the Defense Production Act's Title III program, and provide support to military system program offices in return for adoption, or acceleration of adoption, of domestically produced FPD technology. To date, the Title III program has funded AMLCD technology exclusively, partly through supporting the Xerox/AT&T/Standish manufacturing testbed and partly through incentives to military programs that use AMLCDs. Rationalization of purchases by the entire executive branch, although suggested by DOD, has not gone forward.

There are several concerns regarding DOD's approach. First, while NFPDI may assist in the creation of domestic FPD plants, the special nature of military displays will still raise the cost relative to commercial FPDs. Many of the specific attributes of military displays are in packaging, which requires external modifications to the raw display, and in the specific sizes or shapes required by military systems. Some types of military displays, such as head-mounted systems, have little commercial demand.

Second, it is not clear that the NFPDI funding level, timing, and point of application will result in a successful program. DOD has estimated that a 15-percent global market share by U.S. firms (up from less than 3 percent in 1994) would result in a sustainable domestic industry. This market share would have required approximately $1.2 billion in sales by U.S. firms in 1994; the actual industry sales were less than $200 million.[22] Projections for the year 2000 (DOD's target date for 15-percent market penetration), using growth trends in current applications only, are for global FPDsales of $20 billion; more optimistic predictions that take into account predictions of new display applications go as high as $40 billion. Thus, to reach DOD's target, domestic sales must reach $3 billion to $6 billion by 2000. Stanford Resources, Inc., has estimated the investment-to-revenue ratio for an AMLCD plant to be l-to-l; by this estimate, $3 billion to $6 billion would be required in total investments in the next few years.[23]

DOD's program plan is to award less than $200 million in R&D incentives, which require cost-sharing, to firms with credible plans for commer-

[21] Mark Hartney, Program Manager, ARPA/ESTOq, U.S. Department ofq Defense, personal communication, June 7, 1995; Richard Van Atta, Special Assistant, Office of Dual Use Technology Policy and International Programs, U.S. Department of Defense, personal communication, Aug. 2, 1995.

[22] Stanford Resources, Inc., estimates that the value of North American FPD production was$197million in 1994, out of a world market of $8.2 billion; George Aboud, Stanford Resources, Inc., San Jose, CA, personal communication, June 12, 1995.

23This estimate is for AMLCD plants, and only covers the physical plant and equipment expenditures; it does not consider additional investment required during the startup period. Other types of plants may require less investment; for instance, field emission display developers anticipate that capital expenditures could be more than $100 million less than AMLCD plants. The investment to revenue ratio for such a plant is uncertain at this time.

cial production using current generation technology. The cost-sharing will result in $400 million in R&D spending, shared equally by DOD and firms. In addition, DOD requires that $600 million (three times the DOD grants) in plant and equipment investments be committed by the firms. Thus, DOD anticipates at least $1 billion in direct investment to result from NFPDI, which is one-third to one-sixth of the amount required to reach the target market share.

However, DOD makes two further assumptions. First, it estimates that the program will stimulate an additional $600 million to $1.4 billion in private sector investment in FPD manufacturing facilities. This additional investment would increase the total to a range of $1.6 billion to $2.4 billion. Second, DOD argues that, given an improved understanding of AMLCD manufacturing an the potential for lower cost approaches to FPD manufacturing, a more appropriate investment-to-revenue ratio would be in the range of 0.5-to-1 to 0.8-to-1.[24] If the investment-to-revenue ratio is relaxed by one-third, to 0.67-to-1, reaching 15 percent market share would require $2 billion to $4 billion in investments. With these two assumptions, the potential investment range straddles the low end of estimated requirements.

As foreign experience has shown, it takes several years of construction and trial manufacturing runs to bring a facility up to efficient, high-volume production. However, the construction of such plants has not yet begun in the United States. This also lowers the probability of developing a domestic industry with 15 percent of global FPD sales by the year 2000. DOD's plans for reaching this goal may need to be modified, or the goal may need to be changed. It will be important to monitor the progress of the first three recipients of the NFPDI R&D incentives toward high-volume production; to date, none has announced plans for high-volume production.

Finally, the NFPDI funds that are directly aimed at providing incentives for production are primarily for next-generation products. However, discussions with industry indicate that funds for improving the current manufacturing process would probably be a more effective incentive.[25]

The goals for NFPDI could be realigned to be more realistic, while at the same time serving DOD's needs. By emphasizing technologies other than AMLCD, DOD could build on a solid foundation in EL and plasma production and in development of leapfrog technologies. Under this approach, DOD could try to increase the production volumes for non-AMLCD displays. For AMLCDs, DOD could rely on low-cost foreign suppliers for most applications and high-cost, domestic sources for custom applications. DOD may already be moving in this direction: although the manufacturing testbed awards made in 1993 and 1994 use AMLCD technology, the three NFPDI awards announced last fall went to EL and FED proposals. At the same time, if AMLCDs increase in market share as projected, it will be very difficult to capture an appreciable part of the overall FPD market without high-volume AMLCD plants.

In seeking to strengthen NFPDI, Congress could consider the following policy options:

- DOD could pursue relationships with foreign suppliers more seriously, including the possibility of U.S.-based production. One possibility for U.S. manufacturing is to transfer technology from Display Technology, Inc., via its American parent, IBM. Another possibility would be for Sharp Corp. to invest in AMLCD production at its plant in Camas, Washington,

[24] Flamm, op. cit., footnote 19.

[25] DOD notes that there is not always a sharp distinction between current and next-generation production technology. Hartney, op. cit., footnote 21.

where it currently performs final assembly of FPDs. The government could provide incentives for such technology transfers.

- The U.S. government could negotiate with the Japanese government to clarify Japan's export control laws for dual-use technology.
- The R&D incentive awards (which support next-generation R&D as an incentive to high-volume domestic manufacturing) could be replaced by either support for current-generation manufacturing technology development or guaranteed purchases (see below).
- The government could guarantee FPD purchases of certain quantities at certain prices. Such guarantees could encourage private equity investment and might allow firms to get bank loans. However, because U.S. military needs will only represent a few percent of the world FPD market, guarantees of such purchases by themselves cannot induce investment sufficient to capture a substantial share of the world market. U.S. government civilian needs for flat panel displays or products incorporating them (e.g., computers) represent additional market share, but guaranteeing that business to U.S. FPD makers would likely run afoul of international trade rules.
- Congress could work with the Administration to broaden the DPA's Title III program to include technologies other than AMLCDs. This would give military planners more flexibility in choosing FPD technologies, and would support growth of niche markets in established technologies and, potentially, leapfrog approaches to FPDs.