Strategies and Policies for the Domestic Flat Panel Display Industry 3

The U.S. flat panel display (FPD) industry is currently comprised of a number of relatively small and innovative firms that carry out leading-edge research, some prototype development, and manufacturing for niche and custom markets. With the exception of some low-information-content FPD manufacturing, however, there is no domestic mass manufacturing for commercial markets.

U.S. firms have developed many of the basic FPD technologies. The innovations in product development and manufacturing processes, however, have come largely from Japan, where large electronics firms have led in the commercialization of the FPD. Historical factors loom large in the domestic FPD industry's weak presence in manufacturing, largely in the form of decisions made by U.S. firms (mostly to stay out of manufacturing) and Japanese companies (to invest heavily in manufacturing). Another factor has been the role of government programs, which have sustained an innovative industry, but oriented it toward technologies and market sectors outside the commercial mainstream.

Some observers advocate public and private investments in active matrix liquid crystal display (AMLCD) manufacturing to catch up to Japanese companies. However, the enormous capital costs required by AMLCD manufacturing, and the commanding lead Japanese firms have in production technologies, lead others to suggest a leapfrog approach that entails pursuing a technology that can displace AMLCDs. Still others argue that many FPD types will become commodities, and, like dynamic random access memory chips, will be plentiful on the world market. They advocate placing an emphasis on technologies that are established and in which U.S. firms are already competitive in small, niche markets. These approaches—emphasizing catch-up, leapfrog, or established technologies—are based on different assumptions and imply different roles for the private sector and government.

Three decades of research into display technology by U.S. companies and laboratories have led to numerous approaches to displaying electronic information on a flat screen. The U.S. government, mainly through Department of Defense (DOD) research and development (R&D) programs, has been a source of support and a market for these innovations. Despite this activity, there has been limited manufacturing and few attempts to commercialize FPDs in the United States during the past 15 years. While U.S. companies have a presence in the defense and avionics markets, no firms manufacture FPDs domestically for the largest portion of the world market—portable computer displays—primarily because no firms have made the capital investments for large-scale FPD production.

The issues surrounding government support of FPD R&D and production have been debated in Congress and the executive branch for several years. A contentious trade case during 1990-93 created divisions within the industry and also drew attention to its condition. Previous Congresses have shown strong support for FPD research within DOD's Advanced Research Projects Agency (ARPA) High Definition Systems (HDS) program. In 1994, the Clinton Administration created the National Flat Panel Display Initiative, consolidating ongoing display R&D programs and offering cost-shared R&D support to firms that present a credible plan to manufacture displays for the commercial and defense markets. This initiative has drawn the FPD issue into the larger debate over the role of government in technology commercialization.

DOMESTIC EFFORTS TO COMMERCIALIZE FPD TECHNOLOGY

The commercialization of the AMLCD in the 1980s resulted from a convergence of two technologies that were several decades old. First, the existence of the liquid crystal phase of matter was identified in organic compounds by European scientists in the late 19th century; second, the concept of a switching device, constructed by layering thin films of semiconductors, was patented in the early 20th century. These ideas were ultimately combined in American laboratories in the 1970s in the form of an AMLCD. It was not until the 1980s, however, that the AMLCD was commercialized by a Japanese company.[1]

The liquid crystal state was first observed by the Austrian botanist Reinitzer in 1888, and named soon after by the German physicist Lehmann. They discovered that certain compounds had a transition state between the solid and liquid states that took the form of a cloudy liquid containing areas with crystal-like molecular structure. In 1911, the twisted-nematic structure, later to become the basis for the liquid crystal display (LCD), was described by the French scientist Mauguin. Work was carried out in the following decades in Europe and the Soviet Union, reaching a peak in the 1930s. The Marconi Wireless Telephone Co. received the first patent for a liquid crystal device—a light valve, or switch—in 1936. In the late 1950s, a research group led by James Fergason at the Westinghouse Research Laboratories discovered that liquid crystals could be used as temperature sensors. Finally, in the 1960s, the

[1] Useful references on the history of FPD development include: T. Peter Brody, "The Thin Film Transistor—A Late Flowering Bloom," *IEEE Transactions on Electron Devices*, vol. ED-31, No. 11, November 1984, pp. 1614-1628; David E. Sanger, "Invented in U.S., Spurned in U.S., A Technology Flourishes in Japan," *New York Times*, Dec. 16, 1990, p. 1; Richard Florida and David Browdy, "The Invention That Got Away," *Technology Review*, August/September 1991, p. 42; Joseph A. Castellano, *Handbook of Display Technology* (San Diego, CA: Academic Press, 1992); George H. Heilmeier, "Reflections on Innovation and Invention," *The Bridge*, winter 1992, pp. 12-16; and Damian Saccocio, "Strategy & New Business Development: The Case of the Missing U.S. Display Industry," unpublished Ph.D. thesis, Rensselaer Polytechnic Institute, Troy, NY, May 1994.

accumulated scientific knowledge was put to use in electronic displays, leading to large amounts of new research in the field.

The concept for the thin film transistor (TFT) was patented in the United States in 1933, preceding the now-dominant field effect transistor. The TFT is a solid state device that allows current to flow in proportion to a control voltage; it is an amplifier. The TFT uses layers of thin film materials, rather than the bulk single crystal silicon of which integrated circuits are made. The first working device was developed in 1962 at RCA Laboratories, using a cadmium selenide semiconductor. In addition to RCA, groups at GE, Hughes, IBM, Raytheon, Zenith, Westinghouse, and Philips were devoted to TFT research in the 1960s. By 1970, partly due to the immature state of TFT technology, the field effect transistor became the dominant approach applied to integrated circuits, and only Westinghouse pursued research on TFT devices and applications.

At RCA, George Heilmeier and Richard Williams led research into the use of liquid crystal materials in electronic displays beginning in the early 1960s. The group discovered many of the basic principles underlying liquid crystals currently in use, and fabricated crude alphanumeric, graphic, and television displays. Active matrix displays, in which switches (typically TFTs) are deposited on the display glass to control individual picture elements (or pixels), were announced by another RCA group in 1971.

But translating research breakthroughs into products was much more problematic. While the central laboratory pursued basic research, the researchers failed to sell their discoveries to the application-oriented engineers and managers elsewhere in the company. The near-term markets were simple display applications in calculators, watches, and other commodity products that RCA and other large U.S. electronics firms were moving away from. Corporate management did articulate a vision of a “picture-on-the-wall” display. However, this was a distant goal and, to the extent it was possible, it may have threatened divisions whose product expertise was based on the cathode ray tube (CRT). The product divisions did not support the research effort, and RCA canceled its efforts to commercialize LCD technology in the 1970s.

Westinghouse became involved in LCDs through the application of its thin-film transistor research and made a more extensive effort to commercialize LCD technology. As with RCA, however, the crucial commitment to manufacturing did not materialize. As a manufacturer heavily involved in both the semiconductor and television industries in the 1960s, Westinghouse had the right mix of capabilities to pioneer AMLCDs. It also had a vigorous proponent of AMLCDs in T. Peter Brody, whose research group was the first to report construction of a thin-film transistor AMLCD in the early 1970s. Demonstrations of active matrix electroluminescent (EL) panels followed the LCD work. A fully operational alphanumeric panel was developed in 1974, and a simple video display in 1978.

Internal support for display research was transferred several times during the 1970s. As the semiconductor devices groups at Westinghouse fell under the weight of competition from integrated circuits, they pulled support from the TFT research. Support was acquired from the consumer electronics divisions, which viewed LCDs as a way to reverse Westinghouse’s losses in television market share, until the firm left the television market in the early 1970s; another patron was found in the electron tube division, which was closed later in the 1970s. In 1979, the company shut down TFT and active matrix display research altogether.

The 1970s also saw the inception of firms dedicated solely to the development of liquid crystal and other display technologies. In 1969, James Fergason left Westinghouse and formed the International Liquid Crystal Co. There he invented the twisted nematic field effect (TN) LCD, which was to become the most common type of LCD. After delays in the filing, Fergason eventually received a patent for the invention in 1973. However, researchers at the Swiss firm, F. Hoffmann

LaRoche, had been carrying out similar work and published their results in 1971.[2] Finding it difficult to interest electronics companies that were using light emitting diodes for displays, and facing a court battle over ownership of the invention, Fergason sold his patent to the Swiss firm.[3] During the 1970s, other companies formed to work with liquid crystal materials, including Optel, Princeton Materials Science, Microma, and Micro Display Systems, manufacturing such items as digital watch displays.

Japanese LCD production also began in the 1970s, following a path similar to their entry into electronics—from simple, low-cost devices to more complex systems, backed by consistent manufacturing investment. Starting with simple low-information-content displays, firms like Sharp Corp. (which began research on liquid crystals in 1968 and produced the first liquid crystal calculator display in 1973) learned how to manufacture more complicated matrix displays. They were then well positioned to capitalize on the growing demand for FPDs created by the development of portable computers and televisions in the 1980s.

The 1980s witnessed a rapid increase in AMLCD development. Several startup firms in the United States emerged as spinoffs of the canceled display programs of the large firms, but the activity was primarily among Japanese electronics firms. In 1983, Seiko-Epson demonstrated the first prototype AMLCD in a pocket television. The quality of the display triggered great interest in active matrix technology: more than 20 companies around the world demonstrated AMLCD prototypes in the period 1984 to 1991.[4] In addition to AMLCD developments, alternatives to the passive matrix LCD (PMLCD) were being developed that improved display performance without the use of active elements. In the early 1980s, researchers at the Brown Boveri Research Center in Sweden developed the supertwisted nematic (STN) LCD, which greatly improved the contrast and viewing angle of PMLCDs.[5]

Peter Brody left Westinghouse in the wake of the LCD program cancellation, and was able to attract enough venture capital to start a firm called Panelvision in 1980. Panelvision bought equipment from Westinghouse's TFT labs, and began developing a process for AMLCD production. In 1984, Panelvision became the first U.S. company to sell AMLCDs. However, it was unable to build a high-volume production capability, and thus could not make enough sales to break even. Panelvision raised $13 million in venture capital during the early 1980s, which was not enough to build a plant. The firm's efforts to raise more capital were hindered by doubts among investors as to the company's ability to compete with the Japanese in manufacturing. In 1985, Panelvision's board of directors sold the firm to Litton Industries, which turned it into an aircraft cockpit display division and moved it to Canada.

Brody then sought support from U.S. computer companies for a startup to produce AMLCDs. While Apple showed interest, no computer company wanted to provide funding for such a costly undertaking, although IBM began funding internal R&D in AMLCDs in 1985. Most computer manufacturers did not consider it necessary to create a domestic base for display manufacturing; they were able to depend on Japanese firms, which were rapidly developing production capabilities for LCDs. In 1987, Brody turned to the idea of

[2] M. Schadt and W. Helfrich, "Voltage Dependent Optical Activity of a Twisted Nematic Liquid Crystal," *Applied Physics Letters*, vol. 18, No. 4, Feb. 15, 1971, pp. 127-128.

[3] Kathleen K. Wiegner, "It's a Damned Shame," *Forbes*, July 23, 1990, p. 277.

[4] W. E. Howard, "Thin Film Transistor/Liquid Crystal Display Technology: An Introduction," *IBM Journal of Research and Development*, vol. 36, No. 1, January 1992, pp. 3-10.

[5] T. J. Scheffer, and J. Nehring, "A New, Highly Multiplexable Liquid Crystal Color Display," *Applied Physics Letters*, vol. 45, No. 10, Nov. 15, 1984, pp. 1021-1023.

creating large (20- to 40-inch diagonal) AMLCD displays for the military market, with an eye toward future high definition television (HDTV) markets. The approach was to tile small AMLCDs together in a display larger than the current 10-inch models.

With funding from well-known technologists and the venture capital arm of Westinghouse, Brody founded Magnascreen in 1988. The firm marketed its technology to defense customers and, in 1988, was awarded a contract by ARPA (at that time DARPA) to develop a 45-inch display. Technical difficulties in creating tiled displays made progress difficult in this type of FPD. In addition, the growing presence of Japanese manufacturers in the LCD market, and their announcement of the Giant Technology Corp. effort to build a 40-inch AMLCD display by 1995 (later scrapped), deterred venture capital support for the Magnascreen project, and it has not entered commercial production.

The Panelvision and Magnascreen FPD programs were not the only ones to fall short in pursuit of commercial success during the 1980s. Small firms, many started by veterans of the canceled programs at the large electronics firms, opened and closed during the decade; among them were Alphasil, Crystal Vision, LC Systems, Plasma Graphics, and Sigmatron Nova. Many large companies closed or sold off flat panel programs, including AT&T, Control Data, Exxon's EPID and Kylex, GE, GTE, IBM, NCR, and Texas Instruments.[6]

Some of the closures resulted in successful startups. The closure of the Owens-Illinois plasma effort resulted in Electro-Plasma and Photonics Systems, both of which produce plasma displays; IBM's former plasma display division became Plasmaco; and Tektronix spun off Planar, a successful electroluminescent display firm. But none of these small companies has the financial resources and manufacturing experience of a major electronics concern, and none has developed high-volume production of FPDs. Other domestic FPD operations were bought by foreign firms and transferred abroad: in addition to Panelvision (now part of Litton Systems Canada), GE's AMLCD operation was sold and moved abroad, and is now part of the French firm, Thomson LCD.

The commercialization of LCD technology demonstrates a pattern of early innovations and initial commercialization efforts at large electronics firms, followed by closure and/or spinoff of display operations to startup firms that encountered competition from large, integrated Japanese manufacturers. Domestic efforts to commercialize plasma displays (see box 3-1) and electroluminescent displays (see box 3-2) have been somewhat more successful. U.S. firms have a stronger position in these technologies than in the LCD-based displays, partially due to military demand, but neither technology accounts for more than a small part of the commercial market.

STRATEGIES FOR MARKET ENTRY

At the beginning of the 1990s, the U.S. FPD industry consisted mainly of small, research-oriented firms that produced, if anything, small volumes of displays. The FPD market was still largely low-information-content devices, though screens for portable televisions and computers were being produced in Japan. FPD sales began to grow strongly in 1990, spurred by the boom in portable computers. The vast majority of this business was captured by Japanese FPD producers. A divisive dumping case caused further fragmentation within the U.S. FPD industry because it pitted different technical approaches to manufacturing FPDs—and the companies that championed the technologies—against each other. The case also drove a wedge between the fledgling domestic FPD industry and display users (computer

[6] U. S. Congress, Office of Technology Assessment, *The Big Picture: HDTV and High Resolution Systems*, OTA-BP-CIT-64 (Washington, DC: U.S. Government Printing Office, June 1990), table 5-1, p. 71.

BOX 3-1: Commercialization of Plasma Displays

The use of the gas discharge effect for display purposes goes back as far as early demonstrations of television in 1927. The modern history of plasma displays began in the 1950s with the development of the Nixie tube, which displayed a single digit or character, and was the first nonmechanical electronic display device, The first demonstration of a plasma display was an alternating current (AC) display developed in 1964 at the University of Illinois. By the end of the 1960s, Owens-lllinois had commercialized the AC plasma display, which it called Digivue. Burroughs and Fujitsu made key innovations in AC plasma during the 1970s The first direct current (DC) plasma displays were segmented displays developed in the 1970s to replace the Nixie tube. Later in the decade, dot-matrix versions were developed

Military support of plasma research and development led to the first large displays (greater than one meter in diameter), developed by Photonics Imaging (a spinoff of the Owens-lllinois effort) in the early 1980s, Several large companies made attempts to produce plasma displays during the 1970s and 1980s, including IBM, Texas Instruments, and AT&T. The difficulties in making AC plasma displays at a low cost have shifted some of the emphasis in plasma R&D to DC versions, in 1993, the value of U.S.-produced plasma displays accounted for 22 percent of the world total; however, the entire plasma market accounts for approximately three percent of the overall flat panel display market,

SOURCES :Larry Weber, "Plasma Display s," in *Flat Panel Displays and CRTs,* Lawrence E Tannas, Jr (ed) (New York, NY Van Nostrand Reinhold, 1985), Larry Weber, "Plasma Display s," 1994 *SID International Symposium Seminar Lecture Notes* (Santa Ana, CA Societyfor information Display, 1994), vol. I; and Damian Saccocio, "Strategy & New Business Development The Case of the Missing U.S. Display Industry, " unpublished Ph.D. thesis, Rensselaer Polytechnic Institute, Troy, NY, May 1994

manufacturers) by forcing a choice over which industry to support-displays or computers.

The tensions over the dumping case did not begin to subside until 1993, when the last remaining FPD antidumping tariff was dropped and the United States Display Consortium (USDC) was formed (see box 3-3). Since that time, the trend has been toward greater cooperation among the industry (including FPD equipment and materials suppliers, manufacturers, and users), government agencies (primarily DOD), and academia. This cooperation has been a means by which the relatively small domestic display efforts can be combined. However, the domestic industry is still comprised of many small producers pursuing a host of display technologies, and there are no commercial high-volume manufacturing plants in the United States.

Appendix A gives a sense of the breadth of current FPD efforts in the United States. The industry is diverse and not easily categorized. in general, however, it is comprised of firms that are divisions of, or owned by, diversified firms and small firms that are dedicated to display production. Some of these firms produce high- and low-information-content displays, but most pursue research or are in the development stage. What many companies do have in common, especially firms at the leading edge of technology, is support provided by government R&D contracts, primarily from ARPA, and involvement in display consortia (see box 3-3).

in general, the strategies used by or available to domestic FPD firms can be described by some combination of approaches that emphasize technologies to: 1) catch up, 2) increase established niches, or 3) leapfrog. Catch-up involves investing in and gaining manufacturing experience in AMLCDs. Several technologies are currently used to serve niche markets, such as plasma, EL, and some types of LCDs Current candidates for leapfrog technologies are led by field emission displays and digital micromirror devices.

Regardless of the strategy, any attempt to enter into commercial high-volume manufacturing of FPDs will involve significant investment. If the investments made in Korea and Japan are an indication, the initial investment for an AMLCD

BOX 3-2: Commercialization of Electroluminescent Displays

Electroluminescence was first observed by the French scientist Destriau in 1936, but did not attract much attention until the 1950s when lighting and display researchers began investigating the phenomenon, The difficulties of making bright, reliable electroluminescent (EL) displays caused most research groups to abandon EL research in the 1960s. A concerted effort to commercialize EL displays was made by Sigmatron. Despite having demonstrated several products, the company attracted little investment or market interest, and went out of business by the end of the 1960s. As with liquid crystal displays LCDs the 1970s saw dedicated efforts by Japanese firms to commercialize EL technology, and Sharp was a leader. Sharp's work resulted in a monochrome EL television demonstrated in 1978, spurring U.S. firms to revisit EL displays—with the support of Army research laboratories at Fort Monmouth, New Jersey, and Fort Belvoir, Virginia.

The year 1983 was a milestone in EL development. Sharp introduced the first commercial EL display product; Grid Computer introduced one of the first portable computers, which used a six-inch diagonal, 320- by 240-pixel EL display; and Planar was spun off from the Tektronix display division. EL displays are one of the few success stories for the U.S. flat panel display industry; in 1994, Planar held over 50 percent of the world market for EL displays. As a share of the total flat panel display market, however, EL displays are even smaller than plasma, accounting for only one percent.

SOURCES Joseph A. Castellano, Handbook *of Display Technology* (San Diego, CA Academic Press, 1992), p 6, and Christopher N King, "Electroluminescent Displays, " 1994 *SID International Symposium Seminar Lecture Notes* (Santa Ana, CA Society for Information Display, 1994), vol. I.

plant—the catch-up strategy—will entail at least $400 million in capital costs, plus additional funding for upgrades. Since there is no manufacturing experience in leapfrog technologies, the investment required is difficult to estimate; however, some have estimated the cost of a field emission display plant to be $300 million. The established technologies also appear to require lower outlays than AMLCDs, with one recent exception: Fujitsu has announced that it will invest $941 million in a plant to produce plasma screens that are one meter in diagonal.[7]

Any U.S. entrant would face tough competition. Japanese firms have spent years moving from simple, low-information-content FPD manufacturing to the complex AMLCDs now made in large volumes for commercial markets. Some of these firms are entering their third generation of AMLCD manufacturing (see chapter 2). This experience has enabled them to reduce manufacturing costs, and a well-developed FPD materials and equipment infrastructure exists—largely in Japan—to supply the manufacturers.

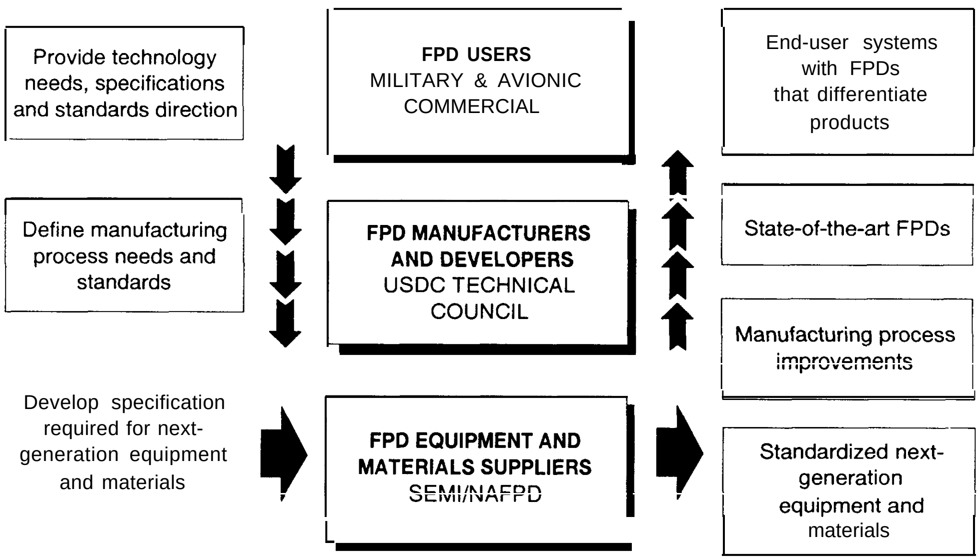
Until U.S. firms gain experience, following a catch-up strategy means competing directly with experienced manufacturers who can set a price based on a much lower manufacturing cost. Without government intervention, these firms are likely to lose money initially in order to compete in world markets. With a strategy based on established technologies, U.S. firms face the challenge of expanding their current market niches. To leapfrog the AMLCD (assuming the manufacturing cost is competitive), the new entrants will be forced to compete with an established technology, possibly requiring user education. One approach using established or leapfrog technologies would be to target markets in which AMLCD is not currently established, such as large-screen televisions or computer workstation monitors.

[7] "Fujitsu Betting *On* Plasma Displays," *Electronic Engineering Times,* June 5, 1995, p. 28.

BOX 3-3: Display Consorti

Display consortia have developed as a means of addressing the disadvantages of an industry comprised mainly of small firms, and as a vehicle for presenting a unified position to government agencies in dealing with trade cases, R&D funding, and design of government programs. The United States Display Consortium (USDC), formed by industry and the Defense Department's Advanced Research Projects Agency (ARPA) in 1993, has been the most active in trying to bring together the disparate industry players into a critical mass, A conclusion reached by many in the flat panel display (FPD) industry during the dumping case of 1990-93 was that ties were needed within and between the various levels of the industry, and that the weak infrastructure for FPD manufacturing was both a result of the low level of FPD production and a barrier to increasing that level. Using experience from Sematech as a model (and hiring a former Sematech executive as its first CEO), the USDC has focused its efforts on improving the infrastructure for display manufacturing in the United States, It has gone about this task by creating links between the three main segments of the industry: equipment and materials suppliers, FPD manufacturers, and display users (see figure below),

USDC: A Vertically Integrated Approach



KEY: FPD = flat panel display; SEMI/NAFPD = Semiconductor Equipment and Materials International, North American Flat Panel Display Division; USDC = U S Display Consortium

SOURCE: U.S. Display Consortium, 1995

By coordinating the flow of information—requirements and standards—and funding from users and manufacturers to equipment and materials suppliers, USDC aims to foster the development of a more robust manufacturing infrastructure, This will improve and standardize FPD manufacturing, and lead to high-quality production of FPDs to meet users' needs, As neither the infrastructure nor the manufacturing base is well developed, the USDC sees its challenge as "the unprecedented task of developing two industries concurrently. "[1] This is in contrast to Sematech's challenge, which was to improve the infrastructure for a mature manufacturing industry, USDC members participate at three levels 1) users, 2) manufacturers and developers, and 3) equipment and materials suppliers, Membership at the end of the consortium's first year of operation represented a large segment of display manufacturers and suppliers, and several large users of displays (see table below).

(continued)

[1]Annual Report, U S Display Consortium, San Jose, CA 1994, p. 5.

BOX 3-3: Display Consortia (Co

USDC Membership

Manufacturers and developers	AT&T	Photonics imaging
	Coloray	Planar Systems
	Electro-Plasma	Plasmaco
	Kent Display Systems	Silicon Video
	Kopin	Standish Industries
	Motif	SI Diamond Technologies
	Norden Systems-Westinghouse	Three-Five Systems
	Optical Imaging Systems	Xerox Palo Alto Research Center
Commercial users	Apple Computer	Delco Electronics
	AT&T	IBM
	Chrysler	in Focus Systems
	Compaq Computer	Sun Microsystems
Military users	Allied Signal	Li ys ems a ad td.
	Honeywell Defense Avionics Systems	Rockwell International
	Hughes Electronics	Science Applications International Corp.
	Kaiser Aerospace and Electronics	Smiths Industries Aerospace
Equipment and materials suppliers	Over 100 members of the North American Flat Panel Display Division of Semiconductor Equipment and Materials International (SEMI-NAFPD)	

NOTE Texas Instruments announced its intention to join USDC in 1995
SOURCE U S Display Consortium Annual Report, 1994

USDC's activities have been coordinated closely with ARPA's display programs, and ARPA has been Instrumental in initiating and sustaining the consortium. ARPA awarded a $20-million grant for that purpose in 1993, and an additional $25 million in 1995. All grant money is matched with member funds that, in the first year of operation, reached 51 percent of the USDC's budget. Most of the USDC's expenditures fund development contracts for FPD materials and equipment suppliers; 12 such contracts were Initiated in the first year, funding development in areas such as color filters, testing, coating, etching, glass inspection and handling, lithography, and optical films.

The earliest display group was the Advanced Display Manufacturers of America (ADMA), formed to petition the government on the dumping charge, and its affiliated research arm, the American Display Consortium (ADC, formerly the ADMA Research Consortium). Currently comprised of 17 U.S. FPD developers and manufacturers, the ADC works to advance the industry by supporting research and development on several generic, precompetittve FPD manufacturing technologies. The ADC has won two National Institute for Standards and Technology Advanced Technology Program (NIST ATP) awards. A 1991 grant of $7.3 million, combined with cost sharing by ADC participants, created a five-year, $14.9-million program for the development of automated inspection and repair technologies, and advanced electronic interconnection and packaging technologies. A $6.4-million grant awarded in 1993 has funded a three-year, $13-million program for the development of color FPD manufacturing technologies, including etching and exposure tools and alignment and masking methods. ADC members perform the program research at their own facilities. Results, sometimes patented and licensed, are shared through quarterly technical reports.

The ADC is also a charter member of the Phosphor Technology Center of Excellence (PTCOE) at the Georgia Institute of Technology. This ARPA-funded, three-year, $10-million program involves the PTCOE, several universities, research centers, and the ADC in improving phosphors for use in plasma, electroluminescent, and field emission displays (initially, phosphors for liquid crystal display backlighting were on the research agenda, but have been dropped). The ADC does not financially contribute to the center, although its members receive funding for participating in phosphor research. The ADC is also closely affiliated with the USDC; two member companies represent the ADC on the USDC Governing Board, and ADC members who choose to participate in the USDC sit on its Technical Council, enabling communication and coordination of the two consortia's efforts and activities.

SOURCE: Office of Technology Assessment, 1995

Catch-Up Approaches

The catch-up strategy advocates moving down the path of the dominant technology for producing flat panel displays—AMLCD—because it represents the best combination of manufacturing experience, materials and equipment infrastructure, suitability for important commercial applications, and capability for integration with existing semiconductor manufacturing. With this strategy, U.S. firms—perhaps with government assistance—would make the required investments to enter into volume manufacturing of AMLCDs, for which there is a large and growing demand. Firms could use a combination of existing domestic technology and technology transferred from foreign manufacturers.

Catch-up entails risks that have so far proved overwhelming. First, the investment required for a state-of-the-art AMLCD manufacturing facility is on the order of $400 million. Substantial further investment would be required to cover initial losses because it is very difficult to bring manufacturing lines to an acceptable yield of workable displays. Because the leading Japanese firms have had several years and two to three generations of manufacturing experience in AMLCD technology, new entrants would immediately be subjected to pricing at or below their initial manufacturing costs.

U.S. firms could accelerate the learning process by tapping into the AMLCD manufacturing expertise of the leading Japanese FPD manufacturers. This could be accomplished by licensing agreements, joint ventures, or involvement of Japanese companies in U.S. FPD public-private consortia. The only current example is the IBM-Toshiba joint venture, Display Technology, Inc. (DTI), but all of its operations are in Japan. Sharp Corp. has initiated some FPD development at its plant in Camas, Washington, but most activity is limited to assembly of foreign-made components.

The only continuous production of AMLCDs in the United States has been at Optical Imaging Systems (OIS), which has been a low-volume supplier of displays for military and commercial avionics markets. It received a $48-million matching ARPA grant in 1993 to build a new facility, designed as a pilot plant for developing higher volume manufacturing techniques. OIS has developed plans for migrating its current manufacturing process to high-volume production in a proposed adjoining facility.

Kopin Corp., with some assistance from DOD, has begun production of small format (approximately one inch in diameter) high resolution AMLCDs for head-mounted and projection systems. Xerox Palo Alto Research Center, long a pioneer in AMLCD technology, is working with Standish and AT&T on a $50 million ARPA contract, matched dollar for dollar by the firms, to evaluate manufacturing techniques. Xerox fabricates the active matrix, Standish assembles the LCD, and AT&T packages the displays in systems. To date, these firms have not announced any plans to develop a central, high-volume facility.

Two other firms also have or are developing capabilities for domestic production. ImageQuest, a California-based firm that is majority owned by the Korean conglomerate Hyundai, is building an AMLCD production facility with the goal of competing in military and civilian avionics markets. Litton Systems Canada, which bought the U.S. firm Panelvision, has a limited AMLCD production capacity and is building a low-volume production line. Although located in Canada, it is considered a domestic firm (North American) for the purposes of DOD's Defense Production Act Title III program to foster local production of AMLCDs (see "Government Activity" below).

The large capital investments required by high-volume AMLCD manufacturing demand the participation of entities larger than any U.S. firm currently manufacturing FPDs. Several large firms could potentially play such a role. One obvious candidate is IBM, which is half-owner of DTI, one of the largest producers of AMLCDs. Others include AT&T and Motorola. All of these firms have large internal demand for FPDs and manufacturing experience in electronics. Other U.S. computer companies have been involved in FPD development (Compaq, Hewlett-Packard, and Apple are all sources of capital, and Texas Instruments is carrying out internal development); these firms could also provide large internal demand for FPDs. To date, none of these firms has announced plans to enter into domestic FPD manufacturing.

Materials suppliers such as Corning could also play a role. Corning is a leading supplier of LCD glass substrates, has established joint ventures to produce display glass in Japan and Korea, and is pursuing (with support from ARPA) a new method for fabricating color filters. Corning states that it would build a plant to finish glass (and potentially add color filters to the substrates) in the United States if sufficient demand existed.[8]

A successful catch-up would require perseverance to lower the manufacturing cost of a standardized product over several generations. An example is the videocassette recorder (VCR): while a U.S. firm pioneered video-recording technology, Japanese firms developed the technology into a low-cost consumer product (see box 3-4). Multiple generations of design, production, and market testing, together with strong attention to the development of manufacturing skills, were essential to progress from a breakthrough technology to a low-cost product. This points out some of the difficulties involved in a catch-up strategy.

Niche Market Approaches in Established Technologies

As discussed earlier, U.S. firms are strongest in niche markets that use established technologies, such as EL and plasma. Several U.S. firms have also made a good business in PMLCDs. The niche market approach would use the existing strengths of the domestic industry to increase market share in niche technologies, by both increasing shares of existing applications and creating new applications. Some of the established technologies are well suited to military, industrial, medical, and transportation market segments. Some may also be critical to development of new products, such as high definition televisions. By enhancing current efforts in known areas, the niche strategy seeks to build the domestic industry by avoiding the large investments and increasing price competition in the mainstream computer and consumer display markets.

U.S. firms are competitive in plasma and EL display production. Some firms, including Babcock, Cherry, and Dale, manufacture low-information-content displays in volume, but use plasma technology similar to that used in high-information-content FPDs. Others, such as Photonics, Plasmaco, and Electro Plasma, are producing large-format, high-information-content displays for military and specialized commercial markets, and have plans to manufacture for larger commercial markets, such as HDTV. Planar, the largest manufacturer of EL displays worldwide, is also the largest U.S. FPD firm, and has entered into alliances with AMLCD developers. Photonics and Planar have received numerous DOD R&D contracts to extend the capabilities of plasma and EL technology.

The leading PMLCD producer in the United States is Standish Industries, which manufactures low-information-content displays for commercial markets, and more complex displays—often using active matrix components produced by other companies such as Xerox—for military programs. Several firms, including In Focus Systems, Nview, Positive Technologies, and Proxima, repackage (usually imported) displays for commercial applications. Another leading PMLCD firm, Three-Five Systems, is moving from integrating imported LCDs to manufacturing its own domestically.

The difficulty inherent in the niche strategy is that, by definition, it does not attempt to compete in the largest segments of the market; without large markets in future applications, it is limited in growth potential. However, firms such as Planar have exploited segments that, while small relative

[8] Bob Yard, Corning Worldwide Marketing, Corning, NY, personal communication, June 21, 1995.

BOX 3-4: VCR Case Study

The commercialization of videocassette recorder (VCR) technology for the consumer market is often viewed as a classic case of U.S. firms inventing a technology, only to have Japanese firms copy it and reap the benefits of market dominance. Upon further inspection, this case points to other issues related to the gap between initial technological breakthroughs and large-scale production of a product for a mature market, Successful firms did not merely replicate an Invented artifact in large quantities, Multiple generations of Iterated design, production, and market testing, as well as strong attention to the development of manufacturing skills, were essential to win.

Ampex made the first video tape recorder (VTR) breakthrough in 1956 and cross-licensed it with RCA. Ampex then grew fearful that RCA would be first to introduce a solid-state VTR, and collaborated with Sony (also Intending to gain access to the Japanese market), Ampex marketed a solid-state VTR in 1962 and had a dominant share of the market, but then decided to pursue markets far from its core capability in magnetic recording technology, Japan's national broadcasting corporation, NHK, imported an Ampex VTR, invited engineers from electronics firms to examine it, and provided data to a VTR research group funded by the Ministry of International Trade and Industry (MITI). Rather than doing market research, Japanese firms emphasized the development of Innovative electronics products that they believed would create future markets. Forced by Ampex's refusal to grant further patent rights to develop its own technology, the Victor Company of Japan (JVC, half owned by Matsushita) was the first to release a two-head (rather than four) VTR, in 1960,

When Sony demonstrated the first solid-state VTR in 1961, using a two-head helical scan technique, Ampex did not believe it would be commercially successful. Instead, Ampex tried to leapfrog Japanese efforts with its portable Instavideo. It was well received, but never reached production because of the firm's doubts about mass production capabilities. Instead, Ampex turned to Toamco, its joint venture with Toshiba, to produce the product, but they never solved the production problems. RCA, having similar production doubts (about the scanner heads), turned to Bell& Howell, which also failed in production. Matsushita faced production problems also, but, despite cutbacks, kept its main cadre of manufacturing engineers Intact, preserving a capability for the future by temporarily assigning them to research. Sony's approach was one of systematic manufacturing efforts iterated with market tests of product generations. The company had its VCR design team build several prototypes, put them in competition with each other, selected the best, worked for 18 months on pilot models, and followed it into production. JVC also kept the design and production staffs in close contact, and selected staff with expertise in design, manufacturing, and marketing. Sony selected the losing approach (Betamax), but had built up production capabilities through production of U-Matic and Betamax lines.

What really mattered in the race to commercialize VCR technology was not the precise sequence of entry into the R&D competition, but which firms possessed the right technological capacity when the window of opportunity opened. Since product performance was bound up in manufacturing technique, the path to competitive advantage lay in incremental design improvements and the integration of design and manufacturing. Learning by trying was the central task of being a pioneer in VCRS,

But the Japanese firms also possessed a strategic clarity that was lacking in the U.S. firms. Ampex and RCA were more opportunistic, looking for breakthroughs that were elusive. The bold technical stroke was lacking because the firms had not developed the manufacturing skills that the Japanese had acquired through Incremental progress. U.S. firms also viewed shortcomings as failures rather than as learning experiences. Japanese firms had a high degree of organizational consistency and management with technical understanding during the development of VCR technology. The Japanese did not simply copy U.S. technology, They entered the field early and persisted, similar to their efforts in compact cars, digital computers, numerically controlled machine tools, semiconductor memories, and computer printers.

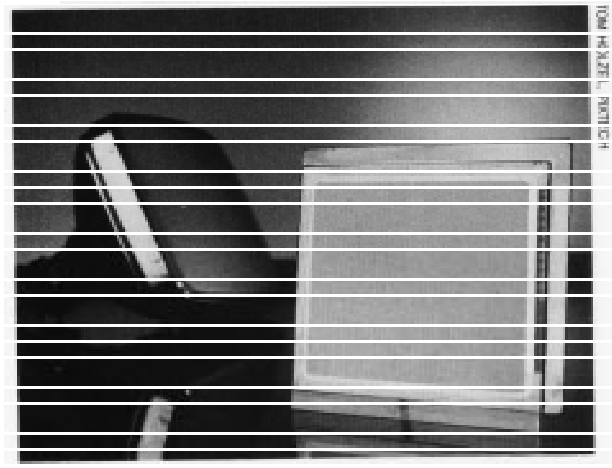
SOURCE :Richard S Rosenbloom and Michael A Cusumano, "Technological Pioneering and Competitive Advantage The Birth of the VCR Industry, " *California Management Review,* vol. 29, No 4, summer 1987, pp. 51-76 to the overall FPD market, are large absolutely; other firms, such as plasma produceers, hope to exploit demand for screens that are too large for current AMLCD manufacturing capacity. Growth areas for niche technologies could be in large-screen displays, such as HDTV applications.[9]

■ Leapfrog Efforts in New Technologies

Like the niche approach, the leapfrog strategy argues that the Japanese lead in AMLCD production is insurmountable, and that other technologies could provide a lower ratio of price to performance than the AMLCD. This approach relies on U.S. strengths in breakthrough innovations to develop a new technology with characteristics superior to the AMLCD. Leapfrog technology would shift FPD technology to a new learning curve, rather than have U.S. firms follow Japanese firms down the existing AMLCD curve. By producing a product comparable or superior to the AMLCD at a comparable or lower manufacturing cost, the leapfrog approach would position domestic firms to capture a large share of a growing market.

A growing number of firms are pursuing R&D in technologies that have the potential to leapfrog the dominant AMLCD by providing equivalent performance at a lower production cost. The leading candidate is the field emission display (FED), developed at SRI decades ago but commercialized only recently by the French company, PixTech. Texas Instruments (TI) and Raytheon (which are assisted by an ARPA contract) and, more recently, Motorola, have licensed PixTech's technology, as has the Japanese firm, Futaba. The agreements provide for cross-licensing between PixTech and FED technology developed by each of the other firms.

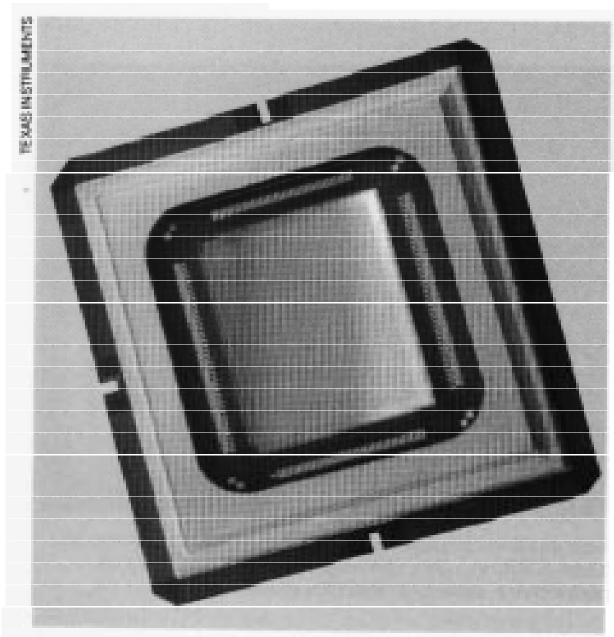
Other FED approaches are being pursued by U.S. firms, including Coloray Display, Crystallume, FED Corp., Micron Display Technology, S1 Diamond Technology, and Silicon Video Corp. Many of these firms have also received government support in the form of ARPA, Advanced Technology Program, and Small Business Innovative Research grants. While some of these firms envision competing with AMLCDs in the laptop display market, a more suitable application may be in large (greater than 20-inch diagonal) displays for television and computer monitors, a size to which producers have been unable to extend AMLCD technology. FED has the potential to outperform AMLCDs in terms of most viewing characteristics and to offer a lower manufacturing cost. It should be noted, however, that very few working FEDs have actually been made and production experience with these displays is very limited.



Field emission displays use technology similar to cathode ray tubes (CRTs) in a thin, lightweight pa&a9e and could offer performance superior to AMLCDs at lower cost.

Another leapfrog candidate is the digital micromirror device (DMD), pioneered during the early 1990s by TI with support from ARPA. TI has not yet produced the display in commercial quantities, although it has entered into product development agreements with In Focus, Nview, Proxima,

9 Fujitsu plans to produce 42-inch Plasma screens in time for the 1998 Winter Olympics in Nagano, Japan; see "Fujitsu Betting On Plasma Displays," op. cit., footnote 7.



Texas Instruments has adapted standard semiconductor manufacturing techniques to build its digital micromirror device, a miniature array of over 400,000 mirrors, for use in projection display systems.

Rank Brimar, and Sony.[10] Aura Systems is also pursuing a similar technology. The limitation of this technology is that it can only be used in projection systems, a much smaller part of the market than direct-view displays.

The leapfrog strategy has often been viewed as entailing little risk and perfectly suited to the innovative culture exemplified by Silicon Valley. But this view obscures the risks and costs this strategy entails. First, mass manufacturing of displays using a leapfrog technology could involve many unforeseen problems not encountered by the small-scale efforts to date. All of the proposed technologies require substantial investments in order to scale up from current capabilities to commercial volumes, and they require significant experience in the specifics of mass manufacturing. If history is any guide, the weaknesses of the U.S. FPD industry lie not in any lack of innovative technologies, but in the lack of access to long-term, patient capital and the willingness to tackle manufacturing challenges, which require continuous and incremental process innovations. Their dedication to solving manufacturing problems, rather than their breakthrough technology developments, has brought Japanese firms to the forefront of FPD technology.

A second concern is that the AMLCD is becoming entrenched and difficult to dislodge, barring any large differences in cost or performance. Once the supply structure has developed around a dominant technology, suppliers, producers, and users resist adopting a new one.

A final risk is that the trend toward integration of functions such as computing onto the display (see chapter 2) is accelerating, and it could favor AMLCDs. The transistors used in AMLCDs are similar to semiconductor devices, which operate on modest voltages. However, many of the emissive technologies require high voltages to operate. These voltages are not compatible with standard integrated circuit levels (although FED voltages are moving toward chip voltage levels, and the DMD is similar to a semiconductor chip). This could present difficulties for integrating circuitry onto the display.

The leapfrog approach requires a technical breakthrough, as well as honing the manufacturing process for an alternative technology. Both involve risks, including technical hurdles in large-scale production for a technology that has not been identified. Leapfrog approaches have a mixed record of success. While Japanese companies devoted their efforts to an analog HDTV standard, U.S. firms, first in competition and then in a collaborative effort, developed a more capable digital HDTV standard. This has given U.S. firms new opportunities to compete. However, in VCRs (see box 3-4), RCA attempted to leapfrog analog magnetic tape recorders with video disks read by lasers. Now common in stereo and computer systems, such technology was not well developed at the time (too expensive to produce), and lost out to the established video tape.

[10] Ronnie Dunn, Program Manager, Digital Imaging Venture Projects, Texas Instruments, Dallas, TX, personal communication, May 24, 1995; "Sony, TI Team Up in New Display Technology,'' Nikkei *Weekly, Mar.* 6, 1995, p. 1.

TABLE 3-1: Federal Spending on Flat Panel Displays by Fiscal Year and Agency (in millions of dollars)

Agency	FY1991	FY1992	FY1993	FY1994	FY1995	FY 91-95
Defense	77.0	79,5	167.1	173,0	100.7	597.3
Commerce	1.8	5.3	6.0	5.2	4.3	22.6
Energy	0.3	1.0	3.5	6.0	7.0	17,8
NASA	1,3	1.3	1.3	1.3	1.3	6.5
NSF	0.0	0.3	0.4	0.4	0.4	1.5
Total	80.4	87.4	178,3	185.9	113.7	645.7

KEY NASA = National Aeronautics and Space Administration, NSF = National Science Foundation

SOURCES For Department of Defense spending, see table3-2 below; for other agencies, see U.S. Congress, Congressional Research Service, *Flat Panel Display Technology: What is the Federal Role?* (Washington, DC Mar 24, 1995), table 1

GOVERNMENT ACTIVITY

U.S. government funding for FPDs, including R&D and insertion programs, has been dominated by DOD (see table 3-l). Prior to 1989, a small amount of display R&D was funded by the individual services' laboratories for their individual mission needs. Since 1989, ARPA has been the driving force in display R&D, prompted first by congressional interest and, since 1994, by Administration programs. in the Department of Commerce, the National Institute of Standards and Technology's Advanced Technology Program (ATP) has made several awards to FPD consortia for precompetitive research. The Department of Energy funds some display research in its multiprogram laboratories, and coordinates the National Center for Advanced Information Components Manufacturing (NCAICM). The National Science Foundation (NSF) also supports some FPD R&D, and the National Aeronautics and Space Administration (NASA) is retrofitting systems such as the Space Shuttle with FPDs.

ARPA-Funded Programs

in 1989, in the wake of concerns over domestic display capabilities for competition in HDTV, ARPA initiated the High Definition Systems (HDS) program, originally called High Definition Display Technology. Program funding in the first two years was $5 million and $30 million, respectively. in fiscal years 1991 and 1992, Congress appropriated $75 million for HDS. in 1993, Congress increased the HDS funding to $161 million, including $25 million designated specifically for "AMLCD Technology,"[11] and $60 million to fund NCAICM at Sandia National Laboratories. It also appropriated just under $10 million for the Tactical Display Systems program (TDS), which includes the Head Mounted Display program (HMD). Outlays were slightly less, due to a reduction in appropriations (see table 3-2).

in 1994, the Clinton Administration requested $57 million, which Congress increased to $85 million. in addition, ARPA funded $9.3 million for display R&D through the TDS program, and $25 million through the Technology Reinvestment Project. Another $40 million in DOD funds was used by authority of Title III of the Defense Production Act (see below for description), which included $30 million to partially fund the Xerox/AT&T/Standish manufacturing testbed, and $10 million for purchase incentives to the military services.[12] in 1995, the Administration requested $68 million for the ARPA HDS program, which Congress increased to $82 million. in addition, another $15 million was requested for the TDS program.

[11] As OIS was the only domestic manufacturer of AMLCDs at the time, it was widely regarded that this appropriation was earmarked for the Troy, Michigan firm. See Douglas Harbrecht, "Did Commerce Pull the Plug on Flat-Screen Makers?" Business *Week,* July 5, 1993, p. 32; and John B. Judis, "Flat Panel Flop," *The New Republic,* Aug. 9, 1993, pp. 16-21. OIS notes that they were awarded the contract based on a competition with numerous respondents; Curtis Casey, Vice President, OIS Northville, Michigan, personal communication, Apr. 17, 1995.

[12] An additional $10 million in fiscal year 1994 appropriations is being spent in fiscal year 1995.

TABLE 3-2: DOD Flat Panel Display Funding, By Source and Fiscal Year (in millions of dollars)

Program	FY1991	FY1992	FY1993	FY1994	FY1995
ARPA High Definition Systems	74.4	75.0	152.2	84.5	81.6
ARPA Tactical Display Systems[a]			10,1	9.3	14,7
ARPA Technology Reinvestment Project				25.0	
DOD Services	2.6	4,5	4,8	4.2	4,4
Defense Production Act Title III[b]				50.0	
Total	77.0	79.5	167,1	173.0	100.7

KEY ARPA = Advanced Research Projects Agency; DOD = Department of Defense

NOTES

[a]ARPA's Tactical Display Systems Program IS made up of the Head Mounted Displays (HMD) and Tactical Information Assistants (TIA) Programs, only the HMD Program is directly related to flat panel displays

[b]At the time of this writing, the Title Ill Program was expecting an additional $10 million in funding

SOURCES: U.S. Department of Defense, Advanced Research Projects Agency, *Research, Development, Test and Evaluatlon, Project Level Summary Reports,* various years; U.S. Department of Defense, *Budding U.S. Capabilities in Flat Panel Displays: Report of the Flat Panel Display Task Force,* October 1994, table 71, Mark Hartney, Program Manager, Advanced Research Projects Agency, Electronic Systems Technology Office, personal communications, July 1995,

High Definition Systems

ARPA's HDS program was initiated in 1989 to develop the domestic capability to manufacture FPDs by bringing together firms from the three levels of the FPD industry: 1) materials and equipment, 2) display manufacturers, and 3) end-users. The first phase, from 1990-92, focused on building up the capability of the materials and equipment sector of the industry, and also supported research in advanced display technologies. The first phase resulted in a series of technical breakthroughs in display R&D (see table 3-3).

Phase Two of HDS, begun in 1993, added support of FPD manufacturing testbeds to the ongoing R&D programs. The first manufacturing testbed award, for $48 million, was made to OIS which matched the grant. The plant, located in Northville Township, Michigan, is scheduled to begin production in 1995. The planned production capacity is 160,000 AMLCD displays annually.[13] OIS estimates that one-quarter of this capacity will be devoted to military needs.[14] in 1994, a $50-million award was made to a partnership consisting of AT&T, Xerox, and Standish Industries, also matched by the companies. This testbed is distributed at four sites among the firms, and will develop high resolution displays and advanced packaging for intelligence applications. in addition to meeting defense needs, the testbed will allow AT&T and Xerox to develop the capacity to supply internal display needs for market testing. Another aspect of HDS Phase Two has involved support for the domestic display manufacturing infrastructure. For that purpose, ARPA awarded $20 million to the U.S. Display Consortium (USDC; see box 3-3) in 1993, and an additional $25 million in 1995. Both awards were matched by the consortium's member companies.

ARPA HDS also funded NCAICM, a cooperative research program in FPD and microelectronics technologies operated by Sandia National Laboratories in conjunction with Los Alamos and Lawrence Livermore National Laboratories, with facility and personnel contributions from the Department of Energy (DOE). A one-time appropriation of $60 million was made for NCAICM in the 1993 Defense Appropriations Bill. Approximately $48 million is used for joint industry-lab projects, one-half involving FPDs and one-half for manufacturing other information technology components (e.g., electronics and photonics). Sandia is spending $12 million to administer the

[13]This assumes four displays are produced from every set of substrates; the line will be able to handle substrates up to 17 inches in diameter. Vincent Cannella, "Made in the USA: High Volume AMLCDs," *Semiconductor International,* February 1995.

[14]Casey, op. cit., footnote 11.

TABLE 3-3: Selected Technical Accomplishments from Phase One of ARPA's High Definition Systems Program

Company	Achievement
Xerox Corp.	13-inch diagonal AM LCD with 6.3 million pixels (most to date)
Texas Instruments	Full color HDTV format digital micromirror display (first of its kind)
Planar Systems	Full color, 10-inch diagonal EL display with VGA resolution (first color)
Photonics Imaging	Full color, 30-inch diagonal high resolution plasma monitor
Micron Display Technology	Full color, 0,7-inch FED head mounted display
Kent State University	8.5- x 1 I-Inch, 120 dots per inch reflective display with image memory
Standish Industries	Manufacturing facility for STN LCD and color filters

KEY: AMLCD = active matrix liquid crystal display, ARPA = Advanced Research Projects Agency, EL = electroluminescent, FED = field emission display, HDS = High Definition Systems, HDIV = high definition television, LCD = liquid crystal display, STN = super twisted nematic, VGA = video graphics adapter

SOURCE Department of Defense, Advanced Research Projects Agency, Electronic Systems Technology Office, "High Definition Systems Program Fact Sheet, " Mar 8, 1995

center, move facilities outside of the laboratory secure area, and carry out several precompetitive research projects approved by an oversight board (composed of national laboratory, ARPA, and industry representatives).

The goal of the display portion of the NCAICM program is to develop flexible manufacturing technologies that can be applied to low-cost, high-volume production of large area emissive FPDs, mainly plasma, FED, and EL.[15] The emphasis on non-AMLCD technologies reflects an assessment that LCDs will be limited to medium area (less than 20-inch diagonal) displays. These technologies also match the technical capabilities of the participating national laboratories.

The projects are organized into two phases. Phase I projects involve research on precompetitive materials, processes, and equipment, utilizing NCAICM staff and facilities; the results are in the public domain. Phase II projects are joint industry/lab efforts performed at the industry sites, NCAICM facility, or other DOE labs as appropriate; the resulting intellectual property rights may be claimed by the firms. Phase I projects include development of an economic model of a flat panel display factory, construction of metrology equipment for FEDs, and construction of a phosphor characterization facility. There are 13 Phase II FPD projects, including support of color plasma development at Photonics Imaging; EL development at Planar and UNIAX Corp.; FED development led by FED Corp., Micron Display Technology, SI Diamond Technology, and Silicon Video Corp.; and development projects in areas common to all FPD technologies.

Finally, the Phosphor Technology Center of Excellence, led by the Georgia Institute of Technology, has been funded under HDS to train scientists and engineers for research and development of phosphor technologies. Five universities, the American Display Consortium, and the David Sarnoff Research Center are also founding members. The research emphasis is on emissive FPDs, since phosphors are a key component in all types of emissive displays. Originally the center planned to investigate improved phosphors for LCD backlighting, but this goal has been set aside by the member companies.[16]

Head Mounted Displays

in 1992, ARPA established the HMD program to create small, high resolution FPDs that can be mounted in military helmets. Table 3-4 lists some

[15] "Program Status Report," National Center for Advanced Information Components Manufacturing, February 1995.

[16] Paul H. Holloway et al., "Blue and Yellow Light Emitting Phosphors for Thin Film Electroluminescent Displays," in *Flat Panel Display Materials*, J. Batey, A. Chiang, and P. H. Holloway (eds.), Symposium Proceedings, vol. 345 (Pittsburgh, PA: Materials Research Society, 1994), pp. 289-298.

TABLE 3-4: Selected Results from the ARPA Helmet Mounted Display Program

Company/Team	Achievement
Kopin Corp., Planar Systems, David Sarnoff Research Center, and Standish Industries	AM LCD and AMEL displays using single crystal silicon, with 1.3 million pixels on a square-inch display
Displaytech	Low voltage reflective FLCD color display

KEY: AMLCD = active matrix liquid crystal display, AMEL = active matrix electroluminescent, ARPA = Advanced Research Projects Agency, FLCD = ferroelectric liquid crystal display

SOURCE: Department of Defense, Advanced Research Projects Agency, Electronic Systems Technology Office, "Head Mounted Displays Program Fact Sheet," Mar 9, 1995.

of the HMD results in small displays. The program has also developed several approaches to integrating FPD technology into soldier systems.

The National Flat Panel Display Initiative

in 1993, the Clinton Administration's National Economic Council (NEC) and Council of Economic Advisors identified the U.S. FPD industry as an example of the need to coordinate the commercial and defense development and production of technology-intensive systems. The NEC asked DOD to conduct a study to determine whether FPDs were important to military security, and if so, what should be done about the weakness of the domestic industry. in April 1994, after a year-long multiagency study, the National Flat Panel Display Initiative (NFPDI) was announced.[17] NFPDI seeks to apply three policy tools to help develop a domestic industry that can provide DOD with early, assured, and affordable access to FPD technologies: 1) continuation of ARPA R&D and manufacturing testbed programs, 2) awarding R&D grants to firms planning to manufacture FPDs, and 3) applying DOD funds to procurement programs if they use domestic FPDs.

NFPDI was developed to meet defense needs by fostering a high-volume commercial FPD industry.[18] The primary justification for NFPDI relates to national security: if the government cannot be assured of an unimpeded flow of a critical component, U.S. national security capabilities may be damaged. The rationale is that without a capability for volume production in the United States, the technology base for displays (i.e., what DOD has traditionally supported) is in jeopardy, regardless of the amount of R&D. The initiative comes under the Administration's dual-use policy, which calls for DOD to use commercial capabilities wherever possible and to focus on capabilities that will support both defense and commercial technology bases. The Administration has stated that national security requirements will not be met by current foreign or domestic suppliers; the leading display manufacturer (Sharp Corp.) will not make custom displays for U.S. defense needs; and U.S. firms are behind in FPD manufacturing technology.

Another rationale is related to linkages between the defense and commercial technology bases. DOD's argument is that the concentration of the display industry in Japan is a threat to the military's ability to procure advanced technology, and Japanese control over materials and equipment supplies could impede the access of U.S. display firms to those critical inputs. If a high-volume domestic FPD industry were created, larger amounts of R&D could be conducted by corporations, supported by revenue streams; ultimately, display R&D could be funded by industry at a higher level than the current government funding. To the extent that other industries draw from the same base of technology as FPDs, the lack of a U.S. research

[17] Department of Defense, "National Flat Panel Display Initiative," Apr. 28, 1994.

[18] Department of Defense, "Building U.S. Capabilities in Flat Panel Displays: Report of the Flat Panel Display Task Force." October 1994.

TABLE 3-5: Spending Plan for the National Flat Panel Display Initiative by Fiscal Year (in millions of dollars)

Program Element	FY1994	FY1995	FY1996	FY1997	FY1998	Total
Core R&D	50	82	48	68	68	316
Manufacturing testbeds	75	0	0	0	0	75
R&D Incentives	25	0	50	50	74	199
Purchase incentives	20					20
Total	170	82	98	118	142	610

NOTE
[a]At the time of this writing, the Active Matrix Liquid Crystal Cockpit Display Project of the Title I I I Program was expecting an additional $10 million in funding for purchase incentives

SOURCES: *Electronic Engineering Times,* May 2, 1994, p 1, Mark Hartney, Program Manager, Advanced Research Projects Agency, Electron/c Systems Technology Office, personal communiations, July 1995

and manufacturing base for FPDs could impede the competitiveness of those industries, and their ability to meet military needs.

The goal of the initiative is to use ongoing DOD investments in FPD research to encourage the development of a domestic capability for manufacturing FPDs in commercial volumes, which DOD expects will better serve defense needs than the current U.S. industry can. The initiative is comprised of four main elements (see table 3-5).

NFPDI can be viewed as an umbrella program consisting of: 1) existing ARPA R&D programs (including HDS and HMD); 2) ongoing ARPA manufacturing testbeds; 3) R&D incentives funded via ARPA's Technology Reinvestment Project (TRP) and the Defense Production Act, Title 111 (DPA); and 4) purchase incentives funded via DPA. Approximately two-thirds of NFPDI funding is devoted to ongoing ARPA HDS programs in R&D projects and manufacturing testbed awards, discussed previously. The two new aspects of NFPDI are the R&D and purchase incentives programs.

R&D Incentives

NFPDI awards R&D grants to firms that: 1) have demonstrated prototype or pilot production of leading-edge FPD technologies, and 2) make commitments to invest in high-volume FPD manufacturing. The awards are based on a firm's commitment to high-volume production (for commercial and defense markets), the quality of the proposed research, and a commitment to match the government R&D support. The exact type of technology is not a determining factor in the awards. The goal is to induce companies to begin manufacturing based on current technology by awarding support for follow-on or next-generation R&D.

The NFPDI awards will provide R&D grants, matched dollar for dollar by the firms; the awards are predicated on commitments by the firms to make capital investments of at least three times the government contribution. DOD estimates that private investments could total as much as 10 times the R&D grants.[19] in October 1994, DOD announced three winners in the first competition, funded by ARPA's Technology Reinvestment Project (see table 3-6). The method of indirectly funding production through the promise of R&D subsidies is designed to comply with restrictions on government production subsidies, ratified in the final version of the Uruguay Round treaty of the General Agreement on Tariffs and Trade.**

[19]Mark Hartney, Program Manager, ARPA/ESTO, Arlington, VA, personal communication, June 7, 1995.

[20]DOD notes that the policy was cleared with the Office of the U.S. Trade Representative; however, some observers have made the case that NFPDI may violate the subsidies rules. See George Kleinfeld and David Kaye, "Red Light, Green Light? The 1994 Agreement on Subsidies and Countervailing Measures, Research and Development Assistance, and U.S. Policy," *Journal of World Trade,* December 1994, p. 43.

TABLE 3-6: First Round of National Flat Panel Display Initiative R&D Incentive Awards (in millions of dollars)

Team leaders/members	Funding[a]	Description
Planar Systems Advanced Technology Materials, Allled-Signal, Boeing, Computing Devices Canada, Georgia Institute of Technology, Hewlett-Packard, Honeywell, Lawrence Livermore National Laboratory, Los Alamos National Laboratory, Oregon Graduate Institute, Positive Technologies, University of Florida	29.2	Thin film and active matrix EL display research for head mounted applications
Silicon Video Accufab Systems, Advanced Technology Materials, Lawrence Livermore National Laboratory, Planar Systems	67.2	Development of manufacturing technology for FEDs
Texas Instruments, Raytheon EG&G Power Systems, Georgia Institute of Technology, Lockheed Sanders, MRS Technology	25.5	Manufacturing research for FED production, based on technology from PixTech

KEY" ARPA = Advanced Research Projects Agency, EL = electroluminescent, FED = field emission display
NOTE:
[a]Total project cost; ARPA and team contributions subject to negotiations, ARPA plans to spend a total of *$48* million on these projects

SOURCE: Advanced Research Projects Agency, 1995

Purchase Incentives

Title III of the Defense Production Act of 1950, as amended in 1992, authorizes the President to enter into procurement of "industrial resources or critical technology items essential to the national defense" outside of the normal government procurement rules. Such procurement is authorized in the absence of a declared national emergency if the President determines that "the combination of the United States national defense demand and foreseeable nondefense demand is not less than the output of domestic industrial capacity" for the industrial resources or critical technology items, including the output that would be created by the procurement.[21]

The current Title 111 certification covers AMLCD technology exclusively, and is called the Active Matrix Liquid Crystal Cockpit Display (AMLCCD) project.[22] Through qualifications and accelerated procurement, the AMLCCD project is designed to: 1) accelerate the insertion of AMLCD technology into military avionics; 2) create cost savings through volume purchases; and 3) boost domestic manufacturing capabilities.

To date, the AMLCCD project has received $20 million.[23] The funding is used as an incentive for military programs that are designing new aircraft, designing retrofits, or procuring aircraft to consider and purchase AMLCDs for the cockpit avionics. Military programs receive project fund

[21] Defense production Act Amendments of 1992, Public Law l02-558.

[22] This specification appears to have emerged from work on a draft standard guideline for cockpit AMLCDs at Wright-Patterson AFB, the initiation of the NFPDI as a whole, and specific congressional reference to AMLCD technology in several DOD appropriations reports. See Darrel G. Hopper and Daniel D. Desjardins, "Requirements for AMLCDs in U.S. Military Applications," Cockpit Displays 11, *Proceedings of the SPIE,* vol. 2462, April 1995; Department of Defense Appropriations Bill, 1993, 102d Congress, Report 102-627, Report of the Committee on Appropriations (to accompany H.R. 5504), June 29, 1992, p. 203; Department of Defense Appropriations Act 1995, 103d Congress, H.R. 4605, Section 8119.

[23] A total of $50 million was budgeted for Title III; $30 million was used to help fund ARPA's second cost-sharing grant for an AMLCD manufacturing testbed. An additional $10 million for the AMLCCD project has been approved by DOD.

TABLE 3-7: Title III Active Matrix Liquid Crystal Cockpit Display Project

Military program	Number of AMLCDs	Funding ($ millions)	Funding for	Program status
AH-64 Longbow	over 4,000[a]	7.60	qualification	qualifications testing
DVE	over 2,500[a]	0.75	qualification	qualifications testing
P-3C (two programs)	500[b]	1.59	purchases	production in 1996
	280[b]	0.70	qualification	qualifications testing
CH-46	665[b]	4.23	purchases	low rate initial production
C-141	376[b]	3.39	purchases	production in 1996
Common Display Program (AV-8B, F-18)	2,500[a]	1,25	qualification	qualifications testing

KEY: AMLCD = active matrix liquid crystal display, DVE = driver vision enhancement

NOTES

[a]Potential number of displays required for retrofit or upgrade of existing platforms

[b]Actual number of displays under contract for platform retrofit.

SOURCES “Active Matrix Liquid Crystal Cockpit Display Project, ” DOD briefing slides received June 7, 1995, John Blevins, Active Matrix Liquid Crystal Cockpit Display project office, Wright-Patterson AFB, personal communication, July 21, 1995; Darrel G Hopper and Daniel D Desjardins, “Requirements for AMLCDs in U S Military Applications,” Cockpit Displays II, Proceedings *of the SPIE, vol 2463,* April 1995, table 1

ing to defray the cost of qualifying (that is, testing in the operating environment) and for accelerated and volume purchases of AMLCDs.24 in return, the program must require, and the contract must use, a domestic AMLCD manufacturer.[25] Programs are selected for funding based on their requirements, planned procurement, and potential impact on the industry. Seven programs currently participate in the project (see table 3-7).

DOD believes the Title III project could stimulate demand by more than 4,000 AMLCDs and boost domestic sales by as much as 400 percent in fiscal year 1996.[26] This could help low-volume manufacturers to develop production experience and help military programs extend limited resources. Title 111 has the additional benefit of fostering display commonality across programs. For instance, the Common Displays Program of the Naval Air Warfare Center is helping the AV-8B and F-1 8 programs qualify the same display, accelerating insertion by almost a year.[27]

Participating program offices receive several benefits from taking part in Title III. It enables them to procure high performance AMLCDs for new and retrofitted systems that operate in strenuous environments; these include bubble-canopy and high-altitude aircraft such as F-22s and F- 18s. By supporting qualification activity, Title III funding introduces FPD technology to programs that otherwise might not consider it; for example, the AH-64 Longbow program will upgrade its cockpit design from CRTs to AMLCDs.28 Although Title III purchase incentives reduce the cost of domestic, custom-made AMLCDs, there

[24]The AMLCCD project only provides funding for purchases of unfinished AMLCDs; the basic unit includes the glass substrates, active matrix array and color filters, and row-and-column drivers. For a description of AMLCDs, see appendix A.

[25]For the purposes of the Title III program, *domestic* refers to any business that performs research, development, and manufacturing in the United States or Canada. The program’s contract with the prime contractor will typically have a separate line item that stipulates the amount that the prime contractor is to use for a domestic display manufacturer, and another that requires that products delivered under the contract make use of that display.

[26]U.S. Department of Defense, “Active Matrix Liquid Crystal Cockpit Display Project,” briefing material received June 7, 1995.

27 John Blevins, AMLCCD Project Office, Wright-Patterson AFB, OH, personal communication, July 21, 1995. The Common Displays Program develops common avionics requirements across platforms by promoting communication between users and suppliers to define performance specifications and leveraging these specifications for use in other platforms. Harlan Smith, Air Combat Electronics Office, Naval Air Warfare Center, Indianapolis, IN, personal communication, July 17, 1995.

[28]Frank Bick, Army Aviation Troop Command, personal communication, June 26, 1995.

continues to be a large cost differential between commercial and custom displays (see chapter 2). For some programs, even Title III funding cannot bridge the gap between the cost of custom AMLCDs and the programs' limited budgets. Instead, these programs relax some performance requirements, and use less expensive, commercial AMLCDs.[29] Price reductions in domestic AMLCDs for commercial avionics are closing this gap.[30]

The Title III requirement for domestic manufacturers excludes some defense integrators that purchase commercial AMLCDs from foreign sources and ruggedize them (see box 2-3). These firms argue that such requirements prevent programs from considering their lower cost products. Others argue that the domestic requirement puts all integrators on an equal footing; even using a domestic source, the integrators could draw on their ability to ruggedize inexpensively to produce a high performance, lower cost product.[31]

Partly as a result of congressional interest, Title III funding is limited to AMLCDs (unlike the rest of NFPDI). However, AMLCDs are not a good match for all of the wide range of DOD's FPD needs; for instance, large area displays in Airborne Warning and Command Systems planes could use plasma or projection FPDs to replace existing CRTs. Broadening Title III projects to other FPD technologies could bring these incentives to other applications, further equip DOD with state-of-the-art technology, and bolster the domestic FPD industry.

Trade Policy

Trade policy can also affect the incentives for investment in FPD manufacturing. One area is tariffs. Tariffs on imported FPDs are low—zero on FPDs for computer applications with a diagonal screen size up to 12 inches, 3.7 percent on FPDs for computer applications with larger screens, and 5 percent on FPDs for televisions. In comparison, FPD tariffs are zero in Japan, 4.4 to 4.9 percent in the European Union (EU), 5 to 7.5 percent in Taiwan, and 9 percent in Korea. FPD parts and components imported into the United States often face higher tariffs, discouraging domestic FPD manufacturing.

Antidumping Duties

Another possible trade policy tool is the imposition of antidumping duties when imports are sold at less than fair value. Such duties are permitted under the rules of international trade, though recent changes in these rules narrow their permitted application somewhat. Formally, and as a matter of expressed Administration policy, antidumping cases are legal proceedings, to be decided on legal rather than policy grounds; in practice, policy concerns sometimes enter into dumping determinations.

The FPD industry has already tried to use antidumping duties as a weapon against imports. While substantial duties were placed on AMLCDs from Japan from 1991 to 1993, the result of those duties was to drive some computer manufacturing offshore rather than to encourage U.S. AMLCD

[29] Colonel Dan Hamilton (Ret.), Combined Air National Guard and Air Force Reserve F-16 Program, Ogden Air Logistics Center, Hill AFB, UT, personal communication, June 27, 1995; Frank McKinney, Assistant Program Manager for Systems Engineering, Naval Air Systems Command, Arlington, VA, personal communication, June 28, 1995; and Bob Lehman, Team Leader, Navy UH-1N Program, Naval Air Warfare Center, Warminster, PA, personal communication, July 5, 1995.

[30] One Program Officer found that Title III funding helped bridge the remaining price gap; Commander Ted Klapka, Deputy Assistant Program Manager for Systems Engineering, P-3C, Maritime Surveillance Aircraft Program Office, Arlington, VA, personal communication, July 13, 1995. For discussion of commercial avionics, see box 2-4.

[31] Defense integrator, personal communications, June 5 and July 24, 1995.

production; no new producer emerged, and no existing producer substantially increased production. The case also engendered friction by pitting U.S. FPD producers against U.S. computer manufacturers, and some FPD producers against others. This conflict had to be overcome before U.S. industry could work cooperatively (see box 3-3).

The FPD Antidumping Case

In the early 1990s, the FPD market grew sharply and Japanese FPD producers reaped the rewards. As miniaturized disk drives, keyboards, and other components became available at reasonable prices, computer manufacturers developed the first truly portable computer, the laptop. Laptops required FPDs; the CRTs used in desktop computers were too heavy and bulky and used too much power. Early laptops used EL and plasma displays, but the desire for high-resolution color graphics led manufacturers to the LCD. U.S. laptop manufacturers (primarily IBM, Apple, Compaq, and Tandy) required thousands of displays per month. U.S. FPD producers had never produced such volumes, and lacked the capital to ramp up for such production.

Many Japanese FPD producers, in contrast, had experience in volume manufacturing, ready access to capital, and internal demand for displays. While orders from U.S. laptop manufacturers to U.S. display producers might have enabled the latter to get financing to ramp up production, U.S. laptop manufacturers did not want to rely on unproved suppliers. Instead, the orders went to Japanese display producers, helping them to increase their already superior manufacturing capacity.

As one weapon against imports, in July 1990, several American FPD producers filed a joint antidumping petition with the U.S. Department of Commerce's International Trade Administration (ITA) and with the U.S. International Trade Commission (ITC), an independent government agency whose commissioners are appointed to long terms by the President, but who are not otherwise responsible to the President. The petition alleged that high-information-content FPDs from Japan were being sold in the U.S. market at less than fair value (i.e., *dumped*), and that the sales at below fair value had caused material injury to the U.S. industry that produced such displays.[32] Under U.S. law, if these allegations were found to be true, the government would levy antidumping duties on those imports in an amount sufficient to bring the price up to the imports' fair value.

Antidumping investigations proceed as follows. The ITA divides the imports in question into one or more *classes* or *kinds* of merchandise. For each class of merchandise, ITA determines whether any petitioners produce a *like product* in the United States; if not, that class of merchandise is removed from the investigation. For each remaining class, the ITA determines whether U.S. sales at less than fair value have occurred and, if so, what the dumping margins are (i.e., the percentages by which the sale prices need to be increased by antidumping duties to bring them up to fair value). For each class in which sales at less than fair value have occurred, the ITC defines which domestic industry produces like products, and determines whether the dumped imports in that class have been a cause of material injury to the corresponding U.S. industry. (The ITC's definition of like products need not agree with the ITA's definition.)[33] The purpose behind the notions of *class of merchandise* and *like product* is that antidumping duties are justified only if U.S. producers and for-

[32] U.S. Department of Commerce, International Trade Administration, Import Administration, "High Information Content Flat Panel Displays and Display Glass Therefor From Japan," *Federal Register* 55(142):30042-30043, July 24, 1990. High-information-content flat panel displays were defined as having at least 120,000 pixels, with or without color, and using liquid crystal, plasma, or electroluminescent technologies.

[33] 19 U.S.C. 1673, 1677(4)(A); see *Hosiden Corp.* v. *United States*, United States Court of International Trade, Case No. 91-10-00720, Slip Op. 92-229 (Goldberg, J.), Dec. 29, 1992.

eign producers of dumped imports actually compete.

Formally, the FPD antidumping case was decided by applying the legal concepts of class of merchandise, fair value, like products, material injury, and causation to the facts at hand. However, both the legal concepts and the facts were sufficiently ambiguous that, in practice, both the ITA and the ITC, if they wished, had plenty of flexibility to let their decisions be influenced by political views that legally had no weight. Such views include whether the country needed a commercial FPD industry, what responsibility laptop manufacturers had to support a domestic FPD industry, and to what extent antidumping duties would harm U.S. laptop manufacturers and/or force their operations offshore (see box 3-5). It is difficult to say to what extent such political considerations influenced the decisions of the ITA and ITC.

Initially, the ITA defined all high-information-content FPDs as being in one class of merchandise, and the ITC defined the corresponding U.S. industry as all producers of high-information-content FPDs. Late in the process, however, ITA reversed its decision and found four classes of merchandise—PMLCDs, AMLCDs, EL displays, and plasma displays—on the grounds that the classes had different functional capabilities (e.g., power consumption, viewing angle, brightness, and weight) that "establish the boundaries of the FPD's ultimate use and customer expectations."[34]

This change profoundly affected the investigation's results. No petitioner produced PMLCDs; therefore, ITA removed PMLCDs from the investigation.[35] The ITA found dumping margins of under half a percent for plasma displays, which, under U.S. law, are regarded *de minimus*, and the products are considered not to be dumped. Thus, PMLCDs and plasma displays—which accounted for over 75 percent of the value of high-information-content FPDs imported from Japan in 1990—could continue to be imported as before.[36] The ITA found dumping margins of 62 percent for AMLCDs and 7 percent for EL displays.[37] In 1990, AMLCDs accounted for only about 15 percent by value of Japanese high-information-content FPDs, and EL displays accounted for under 5 percent.[38] (In contrast, U.S. production of high-information-content FPDs was predominantly ELs.[39]) In order for antidumping duties to be levied against these imports, the ITC had to find that, though relatively modest in amount, these imports had caused material injury to U.S. manufacturers of like products.

Despite ITA's switch, the ITC found that all types of high-information-content FPDs were *like* both the imported AMLCDs and the imported EL displays, based on "overlaps in physical characteristics and uses."[40] Thus, the ITC considered injury to the U.S. high-information-content FPD producers as a whole. In August 1991, the ITC deemed it appropriate to consider the injury from

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[34] U.S. Department of Commerce, International Trade Administration, Import Administration, "High Information Content Flat Panel Displays and Display Glass Therefor From Japan: Final Determination; Rescission of Investigation and Partial Dismissal of Petition," *Federal Register* 56(136):32376-32402, July 16, 1991, p. 32379.

[35] Ibid., pp. 32380-32382.

[36] U.S. International Trade Commission, *Certain High-Information Content Flat Panel Displays and Display Glass Therefor From Japan: Determination of the Commission, Investigation No. 731-TA-469,* USITC Publication 2413, August 1991, p. 9.

[37] U.S. Department of Commerce, op. cit., footnote 34, p. 32401.

[38] U. S. International Trade Commission, op. cit., footnote 36, p. 9, fn. 1.

[39] U.S. International Trade Commission, *Certain High-Information Content Flat Panel Displays and Display Glass Therefor From Japan: Views on Remand in Investigation No. 731-TA-469 (Final)*, USITC Publication 2610, March 1993, p. I-22.

[40] Ibid., p. I-12; see also U. S. International Trade Commission, op. cit., footnote 36, pp. 7-12.

BOX 3-5: The Effects of FPD Tariffs on Domestic Computer Production

An issue of great importance hovered over the public debate concerning the flat panel display (FPD) dumping case: to what extent would the imposition of tariffs on FPDs negatively impact the domestic production of laptop computers? Specifically, what was the impact of the tariffs on domestic computer manufacturing employment? The computer industry asked the Commerce Department to carry out a balancing test, in which jobs in the small FPD industry would be weighed against jobs in the computer industry, By statute this consideration was irrelevant; however, some believe that the Commerce Department did informally consider such downstream effects,

Since displays represented a large fraction of the cost of producing laptops, in some cases making up half of the production cost, U.S. manufacturers of laptop computers (Apple, Compaq, IBM, and Tandy) argued that imposition of any substantial duties on active matrix liquid crystal displays (AMLCDs) would force them to move domestic production offshore. It should be noted, however, that there were no tariffs imposed on passive matrix Iiquid crystal displays (PMLCDs) or plasma displays, which together accounted for over 98 percent of laptop displays in 1991. The AMLCD market was growing rapidly at the time, however.

Japanese computer manufacturers (many of which manufactured displays, and were thus named in the dumping case) had recently begun moving final assembly operations to the United States This was partly in response to the 100-percent duty levied on laptops imported from Japan in 1987, in retaliation for Japan's slowness in opening its semiconductor market, After a semiconductor agreement was reached in 1991, the duty was revoked, removing the penalty for assembling laptops offshore and importing them to the United States. With the imposition of stiff tariffs on the single most expensive component of laptops, assembly in the United States became much more costly (anhdumping duties were not assessed on finished products containing AMLCDs, such as laptops).

After the antidumping duties were imposed, the Japanese company, NEC, canceled plans to assemble laptops in Massachusetts. [1]in September 1991, Toshiba announced that its American subsidiary would cease assembling laptops with AM LCD screens, moving operations back to Japan Hosiden Corp., supplier for the Apple PowerBook series, stopped shipping screens soon after duties were imposed, diverting shipments instead to Apple's plant in lreland.[2]in addition, Dolch Computer Systems moved its laptop production from California to Germany, and Compaq shifted production abroad from Texas [3]

in October 1991, IBM and Apple unsuccessfully petitioned the Commerce Department for permission to set up foreign trade subzones, which would allow them to import AMLCDs duty-free for assembly at their U S laptop manufacturing sites. The completed laptops would then be subject only to the four-percent U S computer tariff, or duty-free export [4]in November 1991, IBM's chairman, John Akers, stated that the computer-maker might be forced to move assembly of laptops containing AMLCDs offshore because the displays, imported from the IBM-Toshiba joint venture Display Technology Inc. , were subject to the AM LCD tariff [5]IBM closed its North Carolina assembly plant in 1992

(continued)

[1]Douglas Harbrecht, "Did Commerce Pull the Plug on Flat-Screen Makers?" *Business* Week, July 5, 1993, p 32

[2]David E. Sanger, "U.S. Tariff Appears To Backfire, " New *York Times,* Sept *26,* 1991, p. D. 1 The Commerce Department has estimated that Apple Imported 70,000 laptops from its Ireland facility in the first year of the anhdumping order

[3]Lisa Picarille, "Government Color LCD Tariffs Hurt Companies, " *Infoworld, Nov* 18, 1991, p S83, John M Gleason and Muthu Karuppan, "Folly in Trade and Technology Policy, " *IEEE Technology and Society Magazine,* summer 1993, pp. 6-7

[4]Jack Robertson, "IBM, Apple Computer Seek Trade Zone for Display s," *Electronic News,* Oct. *28,* 1991, p 1

[5]David E Sanger, "1 B M Chief Issues Threat on U S Tariff," New *York Times, Nov. 8,* 1991, p D4.

BOX 3-5: The Effects of FPD Tariffs on Domestic Computer Production (Cont'd.)

Ultimately, the effects of the tariff may have been limited by the fact that, in many cases, only final assembly of laptop computers was taking place in the United States; many components, in addition to displays, are manufactured offshore, As a result, the jobs lost due to moving assembly offshore may be few and of a nature that added little value, Finally, lost assembly jobs probably were relatively few compared with the across-the-board layoffs by computer-makers in the 1990s.[6]

in principle, the antidumping duties could have induced Japanese AMLCD manufacturers to transfer production to U.S. sites, However, officials from Toshiba and NEC attested to the difficulties of increasing production yields in their Japanese plants, The immense difficulties manufacturers were having ruled out transfer of technology to the United States,[7] Sharp opened an AMLCD facility in Camas, Washington, in 1992; however, only final assembly work is done at this facility

The effect of dumping duties on downstream (or upstream) industries is not currently a factor in the deliberations of the International Trade Administration or the International Trade Commission because the trade laws do not provide for such consideration, But it may be crucial to gauge the effects of trade decisions on related industries. Many proposed remedies for enhancing the international competitiveness of domestic manufacturers include a revamping of trade laws or an increased coordination of technology and trade policies,[8]

SOURCE: Office of Technology Assessment, 1995

[6] Neal Boudetta, "Battle Heats Up Over Flat-Panel Tariff, " PC *Week,* February 1993

[7] Shin Kusunoki, "Japan to the Rescue?" *Electronics,* October 1991, pp. 27-28

[8] For an example, see council On Competitiveness, "The Flat Panel Display Antidumping Decision, " in *Road map for Results Trade Policy, Technology and American Competitiveness,* (Washington, DC: July 1993), pp. 23-38.

both AMLCD and EL imports together, and found that the combined imports were a cause of material injury to the U.S. FPD producers.[41] As a result, antidumping duties were initially levied on both AMLCDs and EL displays from Japan.[42] However, on appeal, the Court of International Trade found that the ITA's determination that AMLCDs and EL displays constituted separate classes of merchandise compelled the ITC to consider separately the injury from each class of imports, and remanded the case to the ITC with instructions to do so.[43]

On remand, the ITC found, in March 1993, that the AMLCD imports, while modest, were a cause of material injury to the U.S. industry, especially by making it harder for U.S. firms to get investment capital needed to gain production experience and realize economies of scale. However, the ITC found that the smaller EL imports were not a cause of material injury. Thus, antidumping duties were levied only on AMLCD imports.[44] However, these duties were removed shortly thereafter. in November 1992, OIS the only petitioner to produce AMLCDs, and under new ownership, had re-

[41] U.S. International Trade Commission, op. cit., footnote 36, pp. 23-27.

[42] U.S. Department of Commerce, International Trade Administration, Import Administration, "High Information Content Flat Panel Displays and Display Glass Therefor From Japan: Antidumping Duty Orders, *Federal Register* 56(171):43741-43742, Sept. 4, 1991.

[43] Hosiden v. United States, Op. cit., footnote 33, p. 18.

[44] U.S. International Trade Commission, op. cit., footnote 39, pp. I-1; I-1, fn. 3, I-15 through I-22; II-1; and VI-1 through VI-9.

quested that the duties be removed. In March 1993, the ITA removed the duties on the grounds that no domestic producer of like products supported retaining the duties.[45]

This history does not mean that antidumping duties could never be a part of a U.S. policy to foster an FPD industry. In the antidumping case, the Commerce Department seemed hostile to the domestic FPD industry and seemed to work at cross-purposes with the ITC. If the Commerce Department had handled the case differently, which it had discretion to do, different FPD manufacturers would not have been pitted against each other, and duties would likely have been imposed on more types of FPDs and been in force longer. However, several cautions would apply to any use of antidumping proceedings as a policy tool. First, there are ramifications in terms of international trade rules and international goodwill. Second, antidumping duties would hurt downstream industries, such as computers, that might then need some offsetting government help. Third, antidumping duties by themselves, as was shown, are no guarantee that domestic production will start; if at all, such duties can be effective only as a supplement to domestic programs.

[45] U.S. Department of Commerce, International Trade Administration, Import Administration, "High Information Content Flat Panel Displays and Display Glass Therefor From Japan: Final Results of Changed Circumstances Administrative Review, Revocation of the Order and Termination of Administrative Review," *Federal Register* 58(121):34409-34414, June 25, 1993.