The US Display Consortium: Analysis of a Public/Private Partnership

By: Albert N. Link

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Abstract:

This paper analyses the US response to Japanese and wider East Asian leadership in advanced flat panel displays, focusing in particular on the formation of the US Display Consortium. The paper discusses the circumstances in which the consortium was formed, and provides an initial evaluation of its effects to date.

Keywords: United States | Japan | public/private partnership | flat panel displays

Article:[1]

By the early 1990s, government support for a. revival of the US FPD industry was imminent. According to a US Department of Defense report:

> Flat panel displays represent a technological and business area of great concern worldwide. This is because these devices are recognized as the critical human interface device in many military and industrial systems and commercial products in an increasingly information intensive world. (1993: 1)

Given this view, the wide-spread belief that flat panel displays (FPDs) will replace the cathode ray tube (CRT) in most American weapon systems before the turn of the century, and the realization that Japan's share of the world flat panel market dwarfed that of the United States and will likely continue to do so for at least the near term, it is not surprising that governmental support for the industry was forthcoming.

Government support took a number of forms. One type of direct support came in the form of a defense-oriented initiative. The National Flat Panel Display Initiative was announced in 1994. This program provided direct funding to the then very thin domestic flat panel industry. A

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second form of indirect support came through a partnership between the Advanced Technology Program (ATP) within the US Department of Commerce's National Institute of Standards and Technology (NIST) and a research joint venture of FPD manufacturers. A group of small flat panel companies took the initiative to form a research joint venture and apply to the ATP's initial competition. The joint venture was one of the eleven initial competitors that received funding.

The purpose of this paper is to describe the origins and activities of this public/private partnership (brought about through a competitive process), and to present initial qualitative evidence about the success of the initiative.[2] The description of the partnership provides the first systematic overview of an industry-initiated effort to revive itself and to set in motion a research agenda that has the potential to begin to reposition US firms in the international flat panel market. The qualitative evidence provides an early-stage indication of the impact that the ATP program had on the venture and will likely have on industry in the future, and a guidepost for how one might begin to assess the leveraging ability of public/private partnership activities in general.

The remainder of the paper is outlined as follows. The first section provides an overview of the US FPO industry and the associated technology. The evidence is clear that the United States does not have a prominent role in the world market for flat panels, particularly for liquid crystal displays. The following section describes the ATP program and the funded FPO joint venture. The joint venture proposed in 1991 was a research program that emphasized production improvements through, among other things, automated inspection and automated repair. The paper then presents the results from a partial economic analysis of the joint venture. At the end of the ATP-funded research project it was clear that public support of this effort increased the pace at which the research occurred and thus set the stage for commercialization of the developed technology sooner than would otherwise have been the case. It is premature to draw conclusions about the competitive-enhancing impact of this research project on the still small and fragile domestic industry. Finally, some concluding remarks point to what has been achieved and what remains to be done.

OVERVIEW OF THE US FLAT PANEL DISPLAY INDUSTRY AND TECHNOLOGY

Early development of the industry[3]

Flat panel display (FPD) technology was first developed in the United States at the University of Illinois in the early 1960s. Soon thereafter, RCA, Westinghouse, and General Electric were researching the feasibility of flat panels operating on liquid crystal technology.[4] By the early 1970s, IBM was researching an alternative-plasma display technology. However, none of these companies continued their research in FPDs.

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[2] It is beyond the scope of this paper to discuss the appropriateness of government's role in innovation in general, or its support of the US FPD industry in particular. The economic rationale for public/private partnerships is that such partnerships represent a direct funding R&D policy appropriate to overcome market failure and that they are warranted, compared to fiscal tax incentives, when the R&D is generic in character. See Link (1996b, 1998).
[3] This section draws directly from Adams (1993). US Department of Defense (1993; 1994). Council on Competitiveness (1993) and Office of Technology Assessment (1995).
[4] This technology and the other technologies referenced in this section are described below.

At RCA, flat panel technology was seen as a commercial alternative to the television cathode ray tube (CRT), but because RCA's management at that time viewed this technology as a threat to its existing business, flat panel technology was never exploited to its full commercial potential. Research at Westinghouse successfully led to the development of active-matrix liquid crystal displays and electroluminescent displays, but because of the company's weak position in the television market financial support for the development of prototypes was canceled.[5] And similarly, changes in the corporate strategy at General Electric (e.g. the divestiture of their consumer electronics group in the early 1970s) effectively stopped the company's research related to FPDs. Finally, IBM, which had completed some pioneering research in plasma display technology and actually established and operated a plasma panel manufacturing plant for several years, became convinced that liquid crystal display technology was more promising. They divested their plasma operation, but were not able to find a US partner for liquid crystal research.[6]

In the late 1970s and early 1980s, other domestic companies considered entering the FPD market, but none did because of the large minimum R&O and production commitment needed.[7] These companies included Beckman Instruments, Fairchild, Hewlett-Packard, Motorola, Texas Instruments, and Timex.

Japanese companies, Sharp in particular, began to specialize in flat panels in the early 1970s in response to the demand for low-information content displays (e.g. watches and portable calculators). Research in Japan progressed rapidly, and by the mid-1980s a number of Japanese companies were producing portable television screens based on active-matrix liquid crystal displays. By the end of the 1980s, aided in part by the investment support that the Japanese firms received from Ministry of International Trade and Industry (MITI), Japan had established itself as the world leader in flat panel technology.

The lack of presence of US firms in the global FPD market is due in part to the difference between R&D and manufacturing (Mcloughlin and Nunno 1995: 10):

> Several US firms were early inventors and experimenters in FPD technologies and are superb at developing new FPD technologies. However, the US commercial manufacturing base for FPD products is not as developed. A survey of US firms which either closed or sold FPD production facilities prior to 1990 found several common reasons why these firms were no longer in the industry: the belief that advanced displays were not central to the firm's business strategy; the cost of capital for establishing an FPD manufacturing line; the fear that Japanese competition is too strong to overcome; and the belief that the global economy allows purchases of FPD technology from any source, domestic or foreign.

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[5] See Florida and Kenney (1998) regarding Westinghouse. They argue that Westinghouse's problems resulted from a failure of the venture capital market to realize the potential of the technology.

[6] IBM's divested operation later became Plasmaco; IBM eventually partnered with Toshiba of Japan.

[7] Flamm (1994) views this financial barrier to entry as critical for an economic justification of government's support of the industry.

Flat panel display technology[8]

In the most general sense, a FPD consists of two glass plates with an electrically-optical material compressed between them. This sandwiched material responds to an electrical signal by reflecting or emitting light. On the glass plates are rows and columns of electrical conductors that form plates for a grid pattern, and it is the intersection of these rows and columns that define picture elements, called pixels. The modulation of light by each pixel creates the images on the screen.

There are three broad types of commercially available FPDs: liquid crystal displays, electroluminescent displays, and plasma display panels.

A *liquid crystal display* (LCD) consists of two flat glass substrates with a matrix of indium tin oxide on the inner surfaces and a polarized film on the outer surfaces. The substrates are separated by micron-sized spacers, the outer edges are sealed, and the inner void is filled with a liquid crystal fluid that changes the transmission of light corning through the plates in response to voltage applied to the cell. The light source for a LCD is generally a cathode, florescent, or halogen bulb placed behind the rear plate.

The most common FPO is a passive-matrix LCD (PMLCD). These panels were first used in watches and portable calculators as early as the 1970s. Characteristic of PMLCDs are horizontal electrodes on one plate and ve11ical electrodes on the other. Each pixel is turned on and off as voltage passes across rows and columns. Although easy to produce, PMLCDs respond slowly to electrical signals and are thus inappropriate for video use.

Active-matrix LCDs (AMLCDs) rely on rapidly-responding switching elements at each pixel (as opposed to one signal on the grid) to control the on-off state. This control is achieved by depositing at least one silicon transistor at each pixel on the inner surface of the rear glass. The advantages associated with AMLCDs are color quality and power efficiency, hence they are dominant in the notebook computer and pocket television markets. The disadvantages of AMLCDs include their small size and cost.

Whereas LCDs respond to an external light source, *electroluminescent displays* (ELDs) generate their own light source. Sandwiched between the glass substrate electrodes is a solid phosphor material that glows when exposed to an electric current. The advantages of ELDs are that they are rugged, power efficient, bright, and can be produced in large sizes; but ELDs arc in the development stage for color capabilities. ELDs are primarily used in industrial process control, military applications, medical and analytical equipment, and transportation.

Like ELDs, *plasma display panels* (PDPs) rely on emissive display technology. Phosphors are deposited on the front and back substrates of glass panels. In response to a plasma or florescent lamp, inert gas is discharged between the plates of each cell to generate light. While offering a wide viewing angle and being relatively inexpensive to produce, PDPs are not power efficient and their color brightness is inferior to that of LCDs for small displays. PDPs are used in

[8] This section draws directly from US Department of Defense (1994) and Office of Technology Assessment (1995).

industrial and commercial areas as multiviewer information screens and are being developed for HDTV.

Current structure of the industry

In the early 1990s, the demand for laptop computers increased dramatically. At this time, US producers of FPDs were small, research-based companies capable only of producing small volumes of low-information content displays. US producers-Apple, Compaq, IBM, and Tandy in particular-soon needed thousands of flat panels each month in order to meet demand. However, the domestic FPO industry was unable to meet this demand or to increase its production capabilities rapidly.[9] On July 18, 1990, in response to the huge increase in FPD imports, US manufacturers filed an antidumping petition with the US Department of Commerce's International Tracie Administration (ITA) and with the International Trade Commission (ITC). While duties were placed on Japanese AMLCDs from 1991 to 1993, the end result of the anti-clumping case was not to bolster US FPD manufacturers but rather to drive certain domestic manufacturers offshore.[10]

In 1993, the National Economic Council (NEC) and President Clinton's Council of Economic Advisors concluded that the US FPD industry illustrated the need for coordination between commercial- and defense-technology. As a result of a NEC-initiated study, the National Flat Panel Display Initiative was announced in April 1994. This initiative was, according to Flamm (1994: 27), a "five-year, $587-million program to jump-start a commercial industrial base that will be able to meet DOD's needs in the next century".[11]

Even with the National Flat Panel Display Initiative, US flat panel producers have remained minor players in the global market. Table 1 shows the size of the world FPD market beginning in 1983, with projections to 2001. Noticeable in Table I is the greater than 10-fold increase in the nominal value of shipments between 1985 and 1986 due in large part to the successful introduction of a variety of new electronic products into the market by the Japanese.[12] Table 2 shows the distribution of shipments by technology for 1993, with projections to 2000. Clearly, LCDs dominated the world market in 1993 as they do now, with the greatest future growth expected in AMLCDs. Finally, Table 3 shows the 1993 world market shares (based on production volume) for Japan and the United States, by technology. According to Hess (1994), Sharp held in 1994 over 40 percent of the world market for flat panels.[13]

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[9] In the early 1990s, laptop computer screens relied on electroluminescent and plasma technology. As a result of continued investments by Japanese manufacturers they were not only able to meet increasing world demand. hut also were in a favorable research position regarding high-resolution color panels. US producers. on the other hand, lacked productive capacity in this area. Apple, Compaq, and Tandy did not have any FPD production capabilities at all. IBM had sold its production facility in 1987. See Office of Technology Assessment (1995).
[10] Office of Technology Assessment (1995).
[11] For detailed discussions of the National Flat Panel Display Initiative, see US Department of Defense (1994) and Office of Technology Assessment (1995). Sec also Flamm (1994) and Barfield (1994-95) for discussions about the economic motivations of the initiative.
[12] This increase reflects, in part, the result of Sharp's strategic move in the 1980s 10 diversify into other electronic devices besides calculators (McLoughlin and Nunno 1995).
[13] In 1991. Sharp became the first Japanese company to assemble liquid crystal displays in the United States (McLoughlin and Nunno 1995).

Table 1. World flat panel display market from 1983 to 2001 (US$ billions)

Year	Value of shipments
1983	$0.05
1984	$0.08
1985	$0.12
1986	$1.66
1987	$2.03
1988	$2.58
1989	$3.23
1990	$4.44
1991	$4.91
1992	$5.51
1993	$7.14
1994	$9.33
1995	$11.50
1996 (est.)	$13.04
1997 (est.)	$14.55
1998 (est.)	$16.12
1999 (est.)	$17.73
2000 (est.)	$19.51
2001 (est.)	$22.46

Source: Office of Technology Assessment (1995).

Table 2. Distribution of world shipments, by technology

Technology	1993	2000 (est.)
Non-Emissive (LCD)	87%	89%
AMLCD	29%	55%
PMLCD and other	58%	34%
Emissive	13%	11%
Plasma	4%	4%
Electroluminescent	1%	2%
Other	8%	5%

Source: Krishna and Thursby (1996).

Table 3. 1993 World market shares, by country

Country	LCD	AMLCD	Plasma	Electroluminescent
Japan	92%	98%	68%	47%
United States	1%	1%	19%	50%
Other	7%	1%	13%	3%

Source: Krishna and Thursby (1996).

THE ATP-FUNDED FLAT PANEL DISPLAY JOINT VENTURE

The ATP program

The goals of the Advanced Technology Program, as stated in its enabling legislation, are to assist US businesses in creating and applying the generic technology and research results necessary to:

1. commercialize significant new scientific discoveries and technologies rapidly; and

2. refine manufacturing technologies.[14]

The ATP received its first appropriation from Congress in FY 1990. The program funds research, not product development. Most of the joint-venture projects last from three to five years. Commercialization of the technology resulting from the project might overlap the research effort at a nascent level, but generally full translation of the technology into products and processes may take a number of additional years.

The ATP award to the flat panel display joint venture

In April 1991, ATP announced that one of its initial eleven competitive awards was to a joint venture managed by the American Display Consortium (ADC) to advance and strengthen the basic materials and manufacturing process technologies needed for US flat panel manufacturers to become world-class producers of low-cost, high-volume, state-of-the-art advanced display products. The initial ATP press release of the five-year $15 million project was as follows.

The trend in the multi-billion-dollar display industry for computers, televisions, and other commercially important products is toward larger and higher-resolution "flat panel" displays. Beyond the development of the display itself, successful commercialization of low-cost, high-quality FPDs will require important advances in testing and repair equipment, as well as better connection and packaging technologies. ADC, a joint venture of relatively small US producers of FPDs, proposes a linked series of research programs to develop automated inspection and repair technology essential to large-volume production of these displays and advance two generic technologies for interconnections (the electronic links between the display panel and the microchips that drive the displays) and packaging: "flip chip-on-glass" (FCOG) and silicon ICs-on-glass (SOG). The results will be applicable to the design, production, testing, and manufacture of any of the several different types of FPD. The two companies that direct the major research tasks in this project are Photonics Imaging (Northwood, Ohio), and Planar Systems, Inc. (Beaverton, Oregon). Seven other companies also will participate. The total ATP award was $7.3 million, and total project budget was $14.9 million. The project was completed in August 1996, with costs as budgeted.[15]

Both of the lead companies are relatively small. The larger of the two is Planar Systems, Inc. Planar is a public company and it is the leading domestic developer, manufacturer, and marketer of high performance electronic display products. Its technological base is electroluminescent technology. Photonics Imaging is a very small investor-owned research company. Its expertise relate to control technology as applied to automation of the production process. The other companies are small and had minor roles.

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[14] See Omnibus Trade and Competitiveness Act of 1988 (P.L.: 100-418), and as modified by the American Technology Preeminence Act of 1991 (P.I..: 102-245). These goals were also restated in the *Federal Register* on July 24, 1990 which stated "The ATP ... will assist US businesses to improve their competitive position and promote US economic growth by accelerating the development of a variety of pre-competitive generic technologies by means of grants and cooperative agreements."

[15] Total project costs amounted to $14.9 million. Actual ATP costs (pre-audit) amounted to $7.3 million over the five-year (statutory limit) funding period; actual industry costs amounted to $7.6 million.

There were two primary motivations for these two companies to organize under the umbrella of the American Display Consortia. One, the availability of government funding would supplement internal budgets so that the proposed research could be undertaken in a more timely manner. This was especially the case at Planar. At Photonics this was also the case because it was having a difficult time attracting venture capital for its project. Two, the National Cooperative Research and Development Act (NCRA) of 1984 provided antitrust indemnification to joint ventures that file their research intentions with the US Department of Justice. Both companies believed that the proposed research would be most effectively undertaken cooperatively, so the organizational joint venture structure was desirable. And, the NCRA provided the needed protection against antitrust action. If subjected to antitrust action, the joint venture would be protected by the NCRA under a rule of reason that determined whether the venture improves social welfare, and the maximum financial exposure would be actual rather than treble damages.[16]

Roles and relationships among members of the joint venture

The Advanced Display Manufacturers of America Research Consortium (ADMARC) submitted the original research proposal to the ATP. The ADMARC was formed for the specific purpose of participating in the ATP competition. As initially structured, Peter Friedman of Photonics Imaging was the Program Manager. Only three of the member companies were to be involved in the proposed research program: Photonics, Optical Imaging Systems (OIS), and Planar Systems, Inc.

Shortly after receiving funding from the ATP, the name of the consortium was changed to the American Display Consortium (ADC), and the organization was registered with the US Department of Justice under the guidelines of the National Cooperative Research Act of 1984.

The stated objective of the project was to provide:[17]

> broad advances in manufacturing technology ... for the flat panel display community. It will initially focus its research efforts in four areas: automated inspection, automated repair, flip chip-on-glass, and polysilicon on-glass.

Initially, Photonics was to lead the automated inspection and automated repair research, Planar the flip chip-on-glass research, and OIS the polysilicon on-glass research.

During the first year of the project, OIS was sold and could not at that time continue with its research obligations. Initially, Photonics and Planar undertook OIS's research commitments. The polysilicon on-glass effort was broadened to silicon on-glass, but the scope of the research was lessened. Throughout the research project, the membership of the ADC has changed, but not all new members in the research consortium participated in the ATP-funded joint venture. In the second year of the project, Electro Plasma, Inc.; Northrop Grumman Norden Systems; Plasmaco, Inc.; and Kent Display Systems began to share research costs. Still, Photonics and Planar remained as the research leaders of the joint venture. Each of these companies brought to the project specific expertise related to sensor and connector technology as applied to flat panels.

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[16] See Link (1996c).
[17] This information comes from the year-end progress report prepared by the ATP.

The research members of the joint venture compete with one another in terms of both technology and markets. Table 4 shows the dominant FPD technology of each member and the primary market to which that technology is applied. It should not be surprising that there are no major companies involved in this joint venture. As noted above, the major electronics companies closed or sold their flat panel divisions in the 1980s.

Table 4. Dominant technology and market of the research members

Research member	Technology	Market
Photonics Imaging	Plasma	Military
Planar	ELD	Industrial
Electro Plasma	Plasma	Industrial
Kent Display	Liquid Crystal	Developmental
Northrup Grumman Norden	ELD	Military
OLS-Optical	AMLCD	Military
Plasmaco	Plasma	Developmental

Source: ADC and research members

Description of the research projects and major technical accomplishments[18]

Automated inspection. Undetected defects on a panel can result in costly repairs or even scrap if the repairs cannot be made. Manual inspection and rework of defects created in the manufacturing process can consume up to 40 percent of the total cost of production. Automated equipment now has the ability to collect data that are critical to controlling complex manufacturing processes in real time. Using such equipment in automated inspection should also be able to provide information on what to do to prevent related process problems in manufacturing. The use of automated inspection equipment and the information that it produces is expected to lower production costs and increase production yields.

The specific goals of the automated inspection project were:

- to design and manufacture an automatic inspection and manual repair station which would be suitable for inspecting patterns on flat display systems and give the capability of manually repairing the indicated defects;
- to establish a design of systems which could be manufactured and sold to the FPD industry.

Specifications for an automatic inspection station were completed and a subcontract was issued to Florod in March 1993 to build an Automated Inspection Machine (AIM-1). Although a station was manufactured, significant performance problems were noticed in the fall of 1994. Personnel at the University of Michigan were used as consultants, along with the technical staff at Photonics, to help to identify and solve the technical problems with the Florod unit. As a result of the successful interaction with the University of Michigan consultants, a contract was issued to their spin-off company, Ward Synthesis, to design and build AIM-2. Preliminary testing of

[18] This section draws directly from presentations made at the final meeting of the ADC joint venture on September 19, 1996, in Northwood, Ohio.

AIM-2 at Photonics shows that the system has the capability to successfully detect a wide variety of defects on various flat panel technologies.

Automated repair. An alternative to manual repair on small, monochrome flat panels is to produce them on a high volume basis and then build yield loss into the final price. However, as display resolution and panel size increases, along with the requirement for higher quality and color, this production strategy will no longer be economically feasible. The use of automated repair is expected to lower production costs and increase production yields.

The specific goals of the automated repair project were:

- to establish a manufacturer of a hands-off repair system for the purpose of making both ablation repairs as well as additive repairs to FPDs;
- to position pre-located defects using a database for defect type and location.

A subcontract was issued to Micron to design, assemble, and integrate an automatic repair station. The station was delivered to Photonics in December 1995 and put into use (integrated with the automatic inspection machine) in March 1996. Demonstrations of repairs to both active and passive LCD have been shown to the ADC member companies.

Technical papers related to the underlying research and operational capabilities of the repair system were delivered in 1995 at the Symposium on Electronic Imaging: Science and Technology; at the Society of Imaging Science and Technology; and at the Electronics Display Forum 95.

Flip chip-on-glass. Flip chip-on-glass (FCOG) is a technology used to achieve a cost-effective interconnect density between a flat screen display panel and the driver of the integrated circuit (IC). The FCOG technology is important because glass may replace silicon and the printed circuit board as the common substrate for device integration. Once developed, FCOG technology will enable US manufacturers of FPDs to leap-frog the current state-of-the-art for high resolution interconnect technology. As a result, production costs should decrease and reliability should increase.

The specific goals of the flip chip-on-glass project were:

- to evaluate and develop FCOG technologies;
- to evaluate the reliability and performance of the most promising FCOG technologies;
- to develop cost-effective equipment for the assembly of FCOG.

It was concluded that FCOG technology was not economical at the time (according to the members of this project they were investigating a technology well ahead of the state-of-the-art). What did result was a tape automated bonding (TAB) process for mounting silicon integrated circuit (IC) dies on a reel of polyimide tape.

To explain, the TAB tape manufacturer patterns a reel of tape with the circuitry for a particular IC die. The IC manufacturer sends IC wafers to the TAB tape manufacturer and the TAB tape manufacturer bonds the individual die to the tape reel in an automated reel-to-reel process. What results is called a tape carrier package (TCP). Also in this bonding process, each individual die is tested to verify that it works properly;[19] if a die does not work properly it is excised from the tape thus leaving a hole in the tape. The TAB tape is then sent to the display manufacturer, and the display manufacturer has automated equipment to align and bond the tape to the display glass with an anisotropic conductive adhesive. In this process, the good die are excised off of the tape, aligned to the display electrodes, and then bonded to the glass.

As part of the research of the FPO joint venture, Planar developed a process to bond driver ICs that were supplied by IC vendors onto a reel of TAB tape.[20] In other words, Planar developed a process to attach the anisotropic adhesive to the glass display panel, align the excised ICs to the electrodes on the display panels, and bond the ICs to the glass panel.[21] This process technology replaces the current elastromeric or heat seal interconnection technology between a plastic packaged IC and the display glass.

Silicon on-glass. The scope of the silicon on-glass project was lessened owing to OIS's inability to participate fully in the research. The objective of the research that was planned was to increase the level of circuit integration on the display substrate by stacking and interconnecting memory and/or decoding logic on the FPO line driver chips.

A contract was issued to Micro SMT to develop the desired packaging process. If successful, the FPO assembly process would be substantially improved. About one-third less area and assembly operation would be required. However, when the packages were tested at Photonics, it was determined that some of the chips could not tolerate higher voltages. Thus, this project's funding was reduced and the unused funds were directed to support the other initiatives.

New research projects. Funds diverted from the silicon on-glass project and funds saved on the FCOG contract totaled about $3 million. These moneys were used to fund new research projects that complemented the automated inspection and repair project and the FCOG project.

Related to automated inspection and repair, three additional research projects were undertaken in the final two years of the joint venture. The Large Area Photomaster Inspection and Repair project was led by Planar. Initially, there was no technical infrastructure for phototooling to support FPDs. This project successfully involved extending the inspection and repair technology research by Photonics toward artwork design. All FPO technologies require the use of photolithographic mark tooling to fabricate the display glass. The key feature of photomasks for FPDs, compared to ICs for example, is their size--a 24 × 24 inch mask compared to a 6 × 6 inch mask. The Defect Inspection Enhancements project was led by Electro Plasma. Its focus was to improve manufacturing operations and its accomplishments were the introduction of new inspection methods in the manufacturing line.

[19] This testing insures what is known in the industry as "Known Good Die".
[20] The commercial assembly equipment that was used for this process was purchased by Planar outside of the funds from ATP.
[21] A subcontract to develop an automated version of the bonder was issued to Research Devices, Inc., but the contract was canceled because the company was unable to ensure that the apparatus had all of the specified capabilities.

Related to flip chip-on-glass, four additional projects were undertaken with the redirected funds. The goal of the Driver Interconnects Using Multi-Chip Module Laminates project was overseen by OIS. The focus of the research was to develop a method of connecting LCD drivers to the display in a way that lowered costs and improved reliability when compared to the current method of tape automated bonding (TAB). Ball Grid Array (BGA) technology was developed to accomplish this, and at present it is undergoing final environmental testing. The objective of the Development of TCP Process for High Volume, Low Cost Flat Panel Production was to establish a high volume take carrier package (TCP) assembly to mount the TCP drivers on the display glass. TCP bonding equipment was successfully developed, qualified, and tested for reliability in the Planar FPD manufacturing line. The Driver Interconnects for Large Area Displays project was led by Northrop and Electro Plasma. The objective of this research was to identify an Anisotropic Conductive Adhesive (ACA) suitable for high-density interconnection and test them at high voltages. Also ACAs were successfully tested to military environmental conditions. Finally, the Chip-on-Glass Process Improvements project was led by Plasmaco. It had as an objective to improve the chip-on-glass manufacturing process, and it resulted in better metalization and etching processes.

A partial economic analysis of the joint venture

The ATP has an evaluation program to ensure that the funded projects meet technological milestones; to determine their short-nm economic impacts and, ultimately, their long-nm economic impacts; and to improve the program's effectiveness.[22] The partial economic analysis described in this section was requested by the ATP at the end of the research project. Albeit that the research had just completed, at least preliminary assessments of technical accomplishments and partial economic impacts on the companies could be made.[23] It is still premature to evaluate systematically impacts on the rest of the economy.

As discussed in this section, even a partial economic analysis conducted at the end of the research project provides sufficient evidence to conclude that the ATP program's role was successful. First, the technical accomplishments generally met or exceeded the proposed research goals, and the accomplishments were realized sooner and at a lower cost through the ATP-sponsored joint venture. Second, efforts are now underway to commercialize the developed technology. Beyond the leveraging success of the ATP program, has the overall endeavor benefited the domestic flat panel industry? Unfortunately, the verdict is still out. Such is the relevant question to ask and answer from the perspective of the United States as a participant in the global flat panel market. However, with the technology only now at the commercialization stage, one can only speculate as to the answer.

Methodology for data collection

A characteristic of the research conducted in this joint venture is that research projects were for the most part conducted by single member companies, as opposed to members of the joint venture working in concert with one another on a particular project. Accordingly, it was decided

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[22] See Link (1993) for a description of the ATP evaluation plan.
[23] Sec Link and Scott (1998) for provisional assessment.

through discussions with Peter Friedman of Photonics that the only effective way to collect partial economic impact data was to interview participant representatives at the September 1996 end of project meeting, and at that time attempt to solicit cooperation from members, on a one-by-one basis, to participate in a follow-up electronic mail survey. The survey questions covered five areas: technical accomplishments, economic implication of ATP's funding involvement, commercialization of results, spillovers of technical knowledge, and effects on competitiveness. A limitation of this methodology is that the data collected represent opinions from participants (expressed preferences) rather than market-determined economic outcomes from the research of the joint venture (revealed preferences). The participants in the FPD joint venture are obviously those in the most informed position to discuss research accomplishments since market-based impacts will not be observed for some time.[24]

Survey results

Technical accomplishments. The question posed to each identified respondent was: *Please state in lay terms the objective of the research your company undertook as part of this larger project and the major technical accomplishments realized.*
The information collected from this question was reported above as "technical accomplishments".

Role of ATP funding. The question posed to each identified respondent was: *Would this research have taken place in your company absent the ATP funds? If NO, please estimate how many person years of effort it would take, hypothetically, to have conducted the research in house? If YES, please describe in general terms the advantages of having the ATP moneys (e.g. research would have occurred sooner than would otherwise have been the case).*

There was uniform agreement that ATP funding has increased the pace of the research, although some of the research would not have occurred in the absence of ATP funds. Regarding automated inspection and repair, and the related projects, the unanimous opinion was that the research would not have occurred by any member of the joint venture, or by anyone else in the industry, in the absence of ATP funds. Those involved were of the opinion that, hypothetically, if the research had been undertaken, it would have taken an additional three years to complete and an additional seven to nine person years of effort plus related equipment costs. These additional labor and equipment costs were estimated through the survey to be, in total, at least $4 million over those three years.

Regarding the flip chip-on-glass and related projects, the unanimous opinion was that this research would have been undertaken, but, "to a much lesser extent and at a much slower pace". One researcher commented: "We would have waited to see what the Japanese competitors would come out with, and then evaluate and possibly copy their interconnect technologies." Another commented that ATP funds "quickened the pace of the research by between one and two years". The Japanese industry which dominates the FPD business has chosen TCP packaging as the standard package and thus to low-cost solution for driver ICs. Thus, if US manufacturers are to remain competitive they must also use TCP packaging in their production processes.

[24] See Link (1996a) for a discussion of NIST"s economic impact analysis strategy.

As a result of ATP funds, the process technology to utilize TCP packaging exists between one and two years earlier than it would have in the absence of ATP funding. There is a cost savings implication to this hastened process technology development. It was estimated by the members of the joint venture that the use of the TCP process technology will save display manufacturers about $0.015 per line, or for the average sized panel, about $19.20 in material costs compared to the current technology.[25] Based on a current estimate by the members of the domestic panels per year that this cost-savings estimate would apply to, the technology will save the domestic industry about $1.4 million per year. And since ATP funds hastened the development of the technology between one and two years, a first-order estimate of the industry savings from this technology over one and a half years is about $2.1 million.

Commercialization of results. The question posed to each identified respondent was: *Specifically, what has been commercialized by your company as a direct result of your involvement in this project? What is expected to be commercialized, and when, as a direct result of your involvement in this project? Do you have any estimate of the expected annual sales from commercialization?*

The automated inspection and repair equipment was at the demonstration point and efforts are now underway at Photonics to commercialize the product in the very near future. The commercialization of the automated inspection and repair technology places the United States in a favorable position relative to others in the world market. For example, it was estimated that the HDTV size plasma display market will be 3 million monitors per year at about $2,800 per monitor in the year 2000. That is, the size of the market upon which automated inspection and repair is initially expected to have an impact is estimated to reach $8.4 billion by the year 2000.[26] Of that, a conservative estimate is that US companies will capture approximately 10-12 percent of that market, or about $924 million (using an 11 percent estimate). Currently, the size of the US industry to which the technology applies is about $12.9 million. Thus, the domestic large plasma display market will increase by more than a factor of over 70 during the next three years. The net cost savings from automated inspection and repair are estimated to be approximately 10 percent of the market price of the display.[27] This means that the ATP-assisted development of automated inspection and repair technology will save US display manufacturers approximately $92.4 million over the next three years.[28]

Spillover effects. The question posed to the identified respondent was: *Can you give some examples of how research conducted in another company involved in this project has been used by your company? Can you give me some instances where your research results have been shared with others in the industry that are not involved in the ATP project?*

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[25] This per-line materials cost savings was provided by Chris King at Planar. Members were quick to point out that the impact of this technology is larger than the pure material cost savings because manufacturers could not compete in the world market for color FPDs and dual scan monochrome FPDs much longer without the high resolution TCP drivers.

[26] These estimates were provided by Peter Friedman based on a paper by Hideki Wakabayashi delivered at the Imaging 2001 USDC Business Conference on January 28, 1997.

[27] Net cost savings are net of the cost of the automated inspection and repair equipment. This estimate was provided by Photonics.

[28] Of course, this calculation assumes that there would not have developed a competing automated inspection and repair technology to that developed as a part of the flat panel display joint venture. This assumption represents the opinion of the members of the joint venture.

Regarding the automated inspection and repair project, there have not been any significant spillover benefits from others in the joint venture to these projects beyond the new research projects begun with funds from the silicon on-glass project, but the results from the automated inspection and repair project have been demonstrated to both joint venture members and others in the industry.

Competitiveness issues. The question posed to each identified respondent was: *Regarding the competitive position of the US flat panel display industry in the world market, was the US industry prior to the ATP award Jar behind, behind, even, ahead, or far ahead of Japan in terms of world market shares? Now, at the close of the project, where is the US indusf1J1-Jar behind, behind, even, ahead, or far ahead of Japan in terms of world market shares?*

The general consensus was that this single ATP-funded project has helped the United States defend its current, yet small, world market position. As one respondent stated:

> The US was far behind Japan in the flat panel display market [at the beginning of the project]. The US is still far behind Japan but we have made some improvement in the technology available to us. It will take a little more time and more cooperation from the US government to really close the gap.

CONCLUDING REMARKS

While the findings from a single case analysis of a public/private partnership are certainly insufficient to generalize about the effectiveness of direct funding as an innovation policy tool to revive a critical but waning domestic industry-whether the results are gathered at project end or even after a spillover period of time has elapsed-they are nonetheless interesting and can offer guideposts to those involved in innovation policy. From this study of the US FPO industry two conclusions are evident. One, this case study of the US FPO industry clearly demonstrates that, when deemed appropriate by policy officials, the US innovation policy mechanism can operate swiftly. And two, when a critical industry has fallen, in terms of its technical capabilities to complete in global markets, to the level that the US FPO industry had, it will take time before the effectiveness of any innovation policy mechanism can be fully evaluated. As discussed qualitatively in this paper, there is evidence to suggest that the industry has already saved on research costs and gained in time to market. It is, however, still premature to pass judgment as to the long-run effect of ATP's funding leverage on the competitive vitality of the industry.

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