The invention that got away

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By failing to capitalize on Peter Brody's "active-matrix" display technology, the U.S. handed the Japanese another electronics monopoly.

LAST spring, portable computers with a new kind of display technology began to roll off production lines. In contrast to the sometimes cloudy displays on conventional laptop computers, these lightweight color screens rival high-quality desktop monitors in brightness and clarity. This new kind of display will eventually appear in myriad products, including a TV set that you will hang on the living room wall or fit in a briefcase. These displays will come from a variety of companies--every one of them Japanese. But the technology that makes these displays possible was invented in the United States.

The loss of this display technology reveals fundamental weaknesses of the U.S. high-technology system. Not only did our large corporations lack the vision and the persistence to turn this invention into a marketable product, but the venture capital financiers, who made possible such high-technology industries as semiconductors and personal computers, failed too. Neither large nor small firms were able to match a dazzling innovation with the manufacturing muscle needed for commercial production. As a result, a vital technology developed in the United States slipped away.

This case suggests that the United States is beginning to pay the price for the entrepreneurial "renaissance" of the 1980s. More than 100,000 high-technology companies were launched during that decade. The venture capital pool surged from less than $5 billion to more than $30 billion. Silicon Valley and Route 128 were held out as examples of the benefits of freewheeling entrepreneurship fed by venture capital. Management gurus, business consultants, and academics sang the praises of this vigorous form of industrial development.

But high-technology entrepreneurship has not worked as well as envisioned. In technology after technology, our small venture capital#backed firms are falling prey to large foreign competitors, most of them Japanese. In fact, it has become clear that the small start-ups suffer from many of the same structural and organizational weaknesses that plague our stodgy corporate behemoths.

Nowhere is this phenomenon more striking than in the area of flat-panel displays. An important element of the new generation of displays is a technology called active matrix, which uses advanced microelectronics techniques to produce brighter, sharper images than previous units (see the sidebar on page 45). Active-matrix technology will replace the bulky cathode-ray tubes (CRTs) that inhabit today's televisions and computer monitors. It will thus drive many of the emerging electronics markets of the twenty-first century.

Today's small-screen flat-panel displays are used mainly in laptop computers and cockpit displays. But future uses include medical imaging systems, teleconferencing, automobile dashboards, and even readouts for traditional home appliances. Larger displays are likely to be a principle component of the multibillion-dollar market for high-definition television. Flat-panel displays will be, in a word, everywhere. Worldwide sales already exceed $4 billion (up from $2.4 billion in 1988), and they are projected to reach $14 billion by 1997.

Over the past two or three decades, the U.S. companies that invented and incubated the technology have squandered a seemingly insurmountable lead. Japan now owns 98 percent of the world market for flat-panel displays and virtually 100 percent of the market for those using active-matrix technology. For the United States, this is a case not just of declining competitiveness but of near total annihilation in a key electronic technology.

The story of how this invention got away reveals a typical pattern. A large company, in this case Westinghouse, was unwilling to gear up for the high-volume production required to turn a new technology it had invented into a commercial success. And in contrast to the popular picture of creative technologists reaching their goals once they break free from corporate bureaucracies, entrepreneurs and venture capitalists were unable or unwilling to jump in and save the day. Like Westinghouse, the venture capital#backed start-ups failed to develop the needed production capabilities.

But this is more than another dreary tale of industry's failure. It is also the story of one scientist's unrelenting crusade to bring his invention to market.

Found and Lost at Westinghouse

In the early 1960s, Westinghouse was a leading producer of televisions and semiconductors, and it focused a significant part of its R&D on developing new technologies in both fields. In semiconductors, for example, Westinghouse engineers began to explore new devices that would be simpler, smaller, and easier to manufacture than traditional transistors.

One promising class of devices was thin-film transistors. Unlike conventional transistors, thin-film devices can be fabricated in arrays that can cover large areas. It gradually became evident that one of their most revolutionary applications was in flat-screen television displays, or what Westinghouse executives came to call "the screen on the wall." Thin-film transistors might make practical an active-matrix liquid-crystal display (LCD) superior to the LCDs then being produced. An active-matrix display works like a large semiconductor memory chip. Picture data are written on the screen in the same way that bits are written onto a memory chip.

Westinghouse was not alone in these early days of flat-panel display development. RCA had large-scale efforts in both thin-film technology and flat-panel displays. Other companies--including General Electric, Hughes Aircraft, Raytheon, Zenith, Burroughs, Owens-Illinois, and IBM--were also active in the field. But most of them abandoned their efforts when they failed to come up with a way to produce inexpensive, manufacturable flat-panel displays. By the early 1970s, Westinghouse had the field almost to itself.

Scientists at Westinghouse launched a major effort to create active-matrix displays using thin-film transistors. The R&D team was headed by T. Peter Brody, a Hungarian-born scientist who had come to Westinghouse to build what he hoped would be the world's leading thin-film transistor research group. As group leader, Brody wrote some important technical papers on the subject. He received some support early on from Westinghouse's semiconductor unit in Youngwood, Pa., and later from the molecular electronics division in Baltimore.

By the mid-1960s, Westinghouse's semiconductor efforts were faltering under the weight of competition from companies such as Texas Instruments, Motorola, and Fairchild. Under mounting pressure from central corporate management to turn a profit, Westinghouse's molecular electronics division turned away from thin films and focused on improving conventional transistors. And as the company's semiconductor units began to lose money, they were less able to sponsor R&D like Brody's thin-film work. They gave it only tenuous support, regarding it as a quixotic attempt to reinvent a wheel that already rolled smoothly. In 1967, top Westinghouse management gave Brody three months to get funding from other divisions or face the axe.

This ultimatum reflected a corporate funding structure that proved more problematic for Brody than technical opposition. At Westinghouse in the 1960s and 1970s, as at most big companies of the era, R&D groups were required to generate funds from the operating divisions. That meant that scientists like Brody had to sell their ideas to the executives who ran those divisions. In making sales pitches, scientists often exuded an optimism not firmly rooted in reality and tended to promise more than they could deliver. This approach sometimes backfired, and projects would be cut off by division executives who found that timetables were not being met.

In his efforts to generate corporate support, Brody fell into precisely this rut. Many Westinghouse executives attest that Brody was not only an excellent technologist but a superb advocate. Yet his enthusiasm at times outran his management skills, and he was frequently unable to stay on schedule.

After making the rounds of Westinghouse divisions, Brody got several to sign on in support of the thin-film transistor research. (In the interim, he received military contracts to keep his work going.) At Westinghouse, his biggest supporters were the consumer electronics division and the electron tube division. Consumer Electronics was a large and powerful organization with a long history in radios, televisions, and home appliances. The division saw flat-panel displays as a way for Westinghouse to gain ground on RCA and others in the television business, where Westinghouse was losing market share.

The plan was to make the elusive TV-screen-on-a-wall. William Coates, then an executive in Consumer Electronics, became Brody's champion. From the mid-1960s to the early 1970s, the division pumped millions of dollars into his work. "We were a hundred miles ahead of anybody," recalls Coates, who says he believed that Brody's work "was going to make Westinghouse."

In contrast to the technological parochialism at Westinghouse's semiconductor units, Consumer Electronics had no qualms about Brody's use of thin-film transistors. "We could care less about what technology he used," says Coates. "If he could make us a flat screen that was going to cost less than a cathode-ray tube--wow!"

Brody's effort suffered a major blow in the early 1970s, when Westinghouse decided to stop making televisions. The company had seen its market share dwindle to 3 percent of the black-and-white and 1 percent of the color television market. Fortunately for Brody, Coates moved over to head the company's electron tube division, which continued to make replacement picture tubes for Westinghouse TVs and to supply other manufacturers. Coates was able to get his division to fund Brody at more than $1 million per year, allowing the thin-film group to set up a prototyping facility. But this reprieve was only temporary. Coates left, and although his successor continued to support Brody, the electron tube division began to lose money and was eventually shut down.

By the mid-1970s, the technology had reached a crossroads. Besides liquidating its television division, Westinghouse also eliminated one of the semiconductor divisions that had supported Brody's work early on. This left no logical source of support within the company for Brody's activities. For Westinghouse, the choice was obvious: either invest in a pilot manufacturing facility, so that active-matrix displays could begin generating some revenue, or abandon the effort. In 1979, a committee of Westinghouse executives decided to kill the project.

Why would Westinghouse abandon such a promising new field after pumping millions into basic research and product development? In the words of Coates: "Every aspiration we had, every milestone we set, we missed. We missed timetables, and we missed cost."

In hindsight, Westinghouse could have teamed Brody's innovative group with others who had the managerial and manufacturing skills and experience to turn his ideas into products. This was never even considered. "At Westinghouse, we really didn't think like that," says an executive who was on the committee that canceled the project. "This was a management failure."

Fits and Start-Ups

Westinghouse's cancellation of the active-matrix-display project ignited Brody's entrepreneurial spirit. In 1979, he left the company and quickly moved to start his own firm to commercialize the technology. Over the next two years, he presented his ideas to more than 40 venture capitalists and electronics companies. Understandably, most wanted to know why Westinghouse had given up on the technology if it was so good. Some also feared competing against traditional picture tube or display technology and against established industrial giants.

One of the first firms Brody approached after splitting with Westinghouse was 3M, mainly because of its reputation for internal entrepreneurship and its record for marketing innovative products. 3M scientists liked the active matrix technology. But even though six of the company's operating divisions expressed interest in the project, none would commit to sponsoring it. Finally, after more than nine months, 3M reported that it was not interested.

Brody then got the attention of Wall Street venture capitalist Bruce K. Anderson of the venture capital fund of Welsh, Carson, Anderson and Stowe. Anderson suggested that one of his major limited partners might be willing to fund the outfit. That limited partner turned out to be 3M. Even after being told about the previous turndown, Anderson still decided to proceed.

In the brief interim since rejecting Brody's earlier proposal, 3M had restructured. A new vice-president now headed technology development, and the venture capital firm's proposal became his first opportunity to launch a visible new project. As a major producer of overhead projectors, 3M wanted to use active-matrix technology to make LCD overhead projector screens. The board of directors took only three weeks to approve an investment of $1.5 million.

In November 1980, the new company, called Panelvision, was launched. Panelvision bought equipment from Westinghouse's old thin-film transistor labs. By the summer of 1981, the firm had rented a building in a Pittsburgh suburb near the Westinghouse R&D center, and begun developing a process for manufacturing active-matrix display products. Seemingly on the verge of pilot production, the company got an additional infusion of venture capital, bringing total investment to almost $4 million. The venture capitalists, arguing that good management was more important than technology, brought in three new managers to help run the company Brody had founded.

Upon joining the company, two of the three new managers tried to stage a revolution to unseat Brody, urging the board to turn leadership of the company over to them. Their efforts were unsuccessful. The board fired the insurgents--but it also demoted Brody, whom they had concluded was not a good enough manager to safeguard their investment. In an effort to stabilize the company, the board promoted another of the recent hires, marketing vice-president Tom Maloney, to chief operating officer. Maloney had led an engineering group at Burroughs that had successfully commercialized early gas plasma displays. Maloney was close to Brody and was able to work well with him, even in such stressful circumstances.

Panelvision's location may have been a disadvantage. In the high-tech havens of Silicon Valley and Route 128, venture capitalists are accustomed to dealing with managerially naive scientists and engineers, and they treat palace revolutions as a fact of life. Moreover, they are close enough to the company to step in and take over in a crisis. And they can draw on a large pool of seasoned managers they have worked with before. In Pittsburgh, there was no outsider who could be rushed in to cope with Brody's foibles.

In the process of taking the helm, Maloney realized that Panelvision faced a more serious problem than the ill-fated coup. Its manufacturing process was not working as planned. The group began working with a sophisticated machine developed jointly by them and Westinghouse to produce thin-film circuits. The machine used a series of "shadow masks" that would deposit the various materials in a pattern directly on the substrate, eliminating the need for the multiple photolithographic steps used in conventional semiconductor technology.

But the displays the company was developing pushed the new mask technology beyond the state of the art. The mask machine had previously been used to produce circuit patterns with a resolution of 30 lines per inch; Brody was trying to push it to 50 or more. It became apparent that the equipment could not produce what Panelvision needed, and that a radical process change was required. The shadow mask problem forced the company back into a development mode, delaying the project by two years.

Again, Panelvision's isolated location in Pittsburgh worked against it. Its suppliers were all far away, in Silicon Valley, Route 128, and even Europe. This made interaction in designing and using equipment difficult.

Even so, Maloney was able to turn things around. Under his leadership, the company became reasonbly successful. Between 1979 and 1984, it raised roughly $13 million in six or seven rounds of financing from heavyweight venture capitalists such as Welsh, Carson, Anderson, and Stowe; Drexel Burnham; First Chicago's venture arm; and several Boston-area concerns. More significant, Panelvision became the first company to bring active-matrix display screens to market. In 1984, the firm began selling experimental products and lab prototypes. They soon had 80 customers in 12 industry segments.

But it was impossible to break even, much less turn a profit, selling on such small scale. The company needed to develop a real manufacturing process and high-volume production capability--and this required more capital. After squabbles between the board and management over how to do this, the board hired Panelvision's third president in three years, Tim DeSilva. Armed with a new business plan, the company aimed to raise $5 million and move into larger-volume production.

By this time the Japanese had entered the picture. Seiko introduced a color pocket television in the United States, infringing on the original Westinghouse patents for active-matrix displays, to which Panelvision held exclusive rights. The International Trade Commission encouraged Panelvision to bring suit. The company started this process in motion, alerting Seiko of a potential lawsuit.

Japan's entry sounded the death knell for Panelvision. Investors had already been hesitant about moving from R&D into volume production. Now they thought it utterly foolish to try to compete with the Japanese on their strong suit of manufacturing efficiency. The board of directors decided to recoup its investment by putting the firm up for sale. A team from 3M evaluated the firm and recommended taking it over, but top management declined. In 1985, Panelvision was sold to Litton Industries, which wanted to use the active-matrix technology in aircraft cockpit displays.

Brody left the company, now called Litton-Panelvision. Maloney stayed on for a time--serving as director of marketing--as did a number of other original Panelvision employees. Litton-Panelvision began to produce display products for its own defense avionics systems but never ventured into the commercial markets. And while Litton made some significant improvements, it was not in the business of advancing the technology. In April 1989, the parent company moved Litton-Panelvision to its main corporate facility in Toronto, where it continues to manufacture cockpit displays.

Thus, after 15 years of fighting corporate battles and braving the entrepreneurial wilderness, Brody seemed to have failed. But convinced of the value of his idea, he decided to try again.

The Second Time Around

In the mid-1980s, the time for Brody's active-matrix displays seemed to have come. Portable computers were becoming popular. Tiny, hand-held TV sets were appearing on the market. After a brief hiatus following the sale to Litton, Brody resumed his crusade. This time, it was the threat of Japanese competition that would prove his major obstacle.

Brody formed a consulting firm, Active Matrix Associates. In late 1985, he tried to get backing for a new start-up. He intended to pick up where Panelvision left off, especially since Litton had confined itself to cock-pit displays. But U.S. investors and venture capitalists were put off by Panelvision's inability to come up with a commercial product despite $13 million in investment.

Several major U.S. computer makers were excited by the possibilities offered by flat-panel displays. Apple, IBM, DEC, and Compaq each indicated that they would place big orders, but shrank from becoming involved in the extremely expensive undertaking of building a factory that could produce large volumes of flat-panel displays. They believed it was not the job of computer firms to create their own supplier base, especially since they could buy flat-panel displays from the Japanese.

The most receptive company was Apple, which was planning its Macintosh portable. Enthusiastic about active-matrix displays, Apple told Brody to bring back a proposal for a factory capable of producing 50,000 units a month. But Apple balked at the price tag. The company ultimately decided to buy screens for its portable Mac from a Japanese supplier.

Brody decided to rethink his strategy. The Japanese had been concentrating on small displays (10 to 14 inches across), for laptop computers. Brody decided to develop larger (20- to 40-inch) displays for use in military command-and-control systems and in corporate teleconferencing. Brody saw large displays as the key to the next big frontier--high-definition television. The idea was to create a large screen out of smaller active-matrix "tiles."

In 1987, Brody brought his new business plan to a Boston investment group whose advisory board was chaired by Jerome Wiesner, former science adviser to Presidents Kennedy and Johnson and past president of MIT. Wiesner, a strong believer in the need to strengthen and rebuild U.S. high-technology industry, was excited by the project. He touted its promise and importance, insisted that the investment group participate in the project, and said he would be willing to commit personal funds. The venture capitalists saw Brody's idea as a long shot and declined to invest, but Wiesner made good on his promise. He and close friend Richard Leghorn (the founder of Itek and a cable television entrepreneur) each committed $125,000 of their own money. The new company, called Magnascreen, attracted significant funding from individual investors close to Wiesner and Leghorn--including John Sculley of Apple and a former chairman of Xero--Xand from VenWest, the venture capital arm of Westinghouse. All told, the company raised $2.3 million in startup capital. Leghorn alone eventually put up more than $1 million.

Even with such an impressive list of independent investors, Magnascreen was able to garner support from only one traditional venture capital fund. Venture capitalists in New York, Boston, and Silicon Valley turned Brody down. Even the Pittsburgh CEO Venture Fund--where William Coates, Brody's old champion, was now a limited partner--declined to invest.

Venture capitalists were understandably fearful of the entry of the Japanese, who had announced plans to develop a 40-inch active-matrix display by 1995. Even though the Japanese had no products and were forecasting an eight-year time horizon (compared with Magnascreen's proposal for a prototype in two to four years), the looming threat was enough to deter the venture capitalists. Compounding this was the proliferation of Japanese active-matrix products in small consumer electronics, leading some to believe that they, not the Americans, had invented this technology.

Perhaps most troublesome of all, the task of developing large-screen flat-panel technology was simply too big for venture capital. According to Coates: "There aren't many venture capitalists who can shovel in money like that. With venture capital, you usually have a product, and it's a matter of refining or tweaking it, or gttting money for production or sales. You can't do the long-term research and development that you can in a large corporation." Once again, Brody found himself unable to move active-matrix technology across the divide from R&D to large-scale production.

Despite difficulty raising money, Brody launched Magnascreen in 1988. The company bought Panelvision's original Pittsburgh facility from Litton, and Brody rehired his old collaborator Tom Maloney. Magnascreen sought funding from the Defense Advanced Research Projects Agency to develop a 45-inch color display. At the time, DARPA was headed by Craig Fields, who strongly supported industrial policy--the idea that government should channel money to develop technologies key to the nation's competitiveness. Brody, naturally, became an ardent proponent of industrial policy, lobbying in Washington and writing letters to the popular press. Although Fields's outspokenness on industrial policy got him fired by the Bush administration, Brody's efforts paid off for Magnascreen. DARPA awarded the company a $7.8 million contract, of which it has so far provided $2 million.

In 1990, Brody once again found himself at odds with his board and his investors. The Magnascreen board wanted a hands-on chief executive who would focus all his attention on the company. Another major conflict centered on Brody's reluctance to accept Japanese investment.

Brody resigned as CEO, and was replaced by Leghorn, the biggest investor in the company. Maloney, who served as vice-president and general manager, assumed responsibility for day-to-day operations. The Magnascreen board and management are now developing a proposal to raise another $3.5 million. They are working on a new strategy for manufacturing large flat-panel displays for both military and commercial uses. The indefatigable Brody is trying to form a new company to produce small- and medium-sized active-matrix displays in Europe.

The Bigger Picture

Unfortunately, the experience of Magnascreen, Panelvision, and Westinghouse is not unique. Like Westinghouse, other big companies--RCA, GE, Burroughs, IBM, Raytheon, Zenith, Hughes, Texas Instruments, NCR, AT&T, and Exxon--incubated and then abandoned flat-screen display technologies. As with Panelvision and Magnascreen, the remnants of their efforts gave rise to a host of new companies: Plasma Graphics, a spinoff from Burroughs; Electro-Plasma, from Owens-Illinois; and a raft of others, most of which failed. None has developed high-volume production capability.

By failing to capitalize on a big initial advantage in a crucial technology, U.S. corporations have allowed foreign competitors to overtake them. Today, there are no significant active-matrix LCD factories in the United States. In the past few years, four Japanese corporations--Hitachi, Matsushita, Seiko Epson, and Sharp--have invested more than $100 million in such plants in their own country. Hoshiden makes screens for the Macintosh portable. Sharp builds screens for the new Texas Instruments notebook-size computer. IBM recently formed a joint venture with Toshiba, Display Technologies Inc., to produce 10-inch color active-matrix displays for its computers in Japan.

The situation is so serious that U.S. computer makers are siding with the Japanese against the U.S. display makers. Last July, a coalition of seven U.S. flat-screen producers accused 12 Japanese companies of "dumping" flat panel displays in the United States at prices well below those in Japan. But at a preliminary hearing before the International Trade Commission, IBM, Apple, Compaq, and Tandy testified against the U.S. display companies. The computer makers insist that they have no choice but to turn to Japanese vendors because domestic companies are unable to produce large volumes of displays. Even the Semiconductor Industry Association (SIA)--which has aggressively challenged "unfair" Japanese trade, and favors an industrial policy to rebuild U.S. consumer electronics--refused to get involved, perhaps fearing retaliation from U.S. computer firms.

In its initial ruling in February, the Commerce Department found no evidence of dumping by Hoshiden or Matsushita. It imposed small tariffs of 1.46 percent for Toshiba, 4.6 percent for Sharp, and 2.33 percent for the rest. The department was to make a final ruling in July following on-site investigations in Japan.

While significantly higher tariffs are unlikely, even modest increases may force more U.S. manufacturers of laptop computers to move production to Japan, or convince Japanese display makers to move more production to this country. Sharp is already building a $30 million plant in Camas, Wash., where it expects to produce up to half a million portable-computer displays a year.

With little choice but to continue buying displays from Japan, U.S. computer makers are at the mercy of suppliers who are also their main competitors--microelectronics megacorporations such as Sharp, Matsushita, Toshiba, and Seiko. This is a very dangerous arrangement. The risk of supply shortages and cutoffs are high. And because the learning curve and other process advantages are in the hands of competitors, U.S. companies are no longer assured of getting the latest technology and thus are at a perpetual disadvantage.

A number of U.S. firms have begun forming alliances to try to regain some footing in active-matrix displays. Xerox, which developed the technology for use in its printers and scanners, has started a joint venture between its Palo Alto Research Center and Standish Industries of Wisconsin to make active-matrix products, and is looking for other partners. Harris has teamed with Sun Microsystems and the David Sarnoff Research Center, the former RCA research labs where much of this technology was first developed. Last year, a group of 10 small companies--Cherry Electrical Products, Coloray Display Corporation, Electro-plasma, Magnascreen, Optical Imaging Systems, Photonics, Planar Systems, Plasmaco, Standish Industries, and Tektroni--Xbanded together to form the Advanced Display Manufacturers of America Research Consortium (ADMARC) to develop flat-screen technology. In March, ADMARC received a $1.25 million grant under the National Institute of Standards and Technology's new Advanced Technology program.

While such consortia are a move in the right direction, they are not the answer for the U.S. display industry. Research consortia, by their nature, focus on high-end R&D or advanced development work--so-called generic or precompetitive technology. They have not had great success in manufacturing, where U.S. industry is weakest. Indeed, we may well see a repeat of the computer memory chip story. The Japanese developed high-volume production capability, then captured larger and larger market share that allowed them to drop their prices and corner the world market. When an industrywide consortium, U.S. Memories, was formed to rebuild U.S. capacity, the Japanese dropped their prices again and the consortium crumbled.

Lessons and Solutions

The failure of U.S. industry to commercialize active-matrix technology tells us that we cannot expect entrepreneurship to drive us forward in all areas of high technology. In this case, venture capitalists have proved less--not more--effective than big companies. They are interested in taking technologies that are almost ready for the market and quickly turning them into commercial home runs. If the market for a technology does not open in three to five years, venture capitalists will typically abandon it. If it requires huge capital investment to develop manufacturing capabilities, they generally will stay out altogether.

Venture capital is simply not the mechanism for providing the massive amounts of investment and process development to build state-of-the-art manufacturing. Venture capitalists underwrote this country's semiconductor and computer industries, but they may not again be able to muster the resources to support a high-technology manufacturing industry. The future of venture capital may well be in high-end, high-return markets such as semiconductor design and in non- manufacturing (or nontraditional manufacturing) industries like software--not in industries that require costly manufacturing capability.

The story of active-matrix technology also brings us face to face with U.S. industry's systemic weakness in scaling up a new technology for high-volume production, which is where the long-run economic payoff is. Our system is successful at producing revolutionary new technologies, but fails at developing and constantly improving the manufacturing process. Westinghouse, after all, pumped millions of dollars into its active-matrix display effort. But it abandoned the technology when bigger investments--on the order of $100#500 million--were needed for manufacturing. Says former Westinghouse executive Coates: "We consistently underestimated the difficulty with manufacturability and reliability--the things you've got to have to make it work."

Indeed, it may be too late to save the U.S. flat-panel display industry. We are now so far behind that it may be necessary to form joint ventures with Japanese companies. This should not be too difficult, because Japanese producers want to protect their access to the U.S. computer market and often see such joint ventures as being to their advantage.

How can industry assure that such pivotal inventions will not slip away again? The key is investment in manufacturing. Both Westinghouse and the venture capitalists happily funded Brody as long as he continued R&D. The money dried up at the critical moment when he needed to develop the manufacturing process required for commercial production.

U.S. investments in manufacturing must be coupled with deep organizational and management changes. The (mainly Japanese) companies that have succeeded in active-matrix technology have applied a basic formula: continuous process improvements on the factory floor. In these companies, R&D scientists and engineers work alongside factory workers to make sure the manufacturing process works. The factory is a center for innovation, change, and constant refinement. Such perseverance has, more than any other single factor, spelled success for the Japanese in active-matrix technology. This is where we failed and continue to fail.

This kind of industrial transformation must become a national cause. In the 1930s, when the U.S. economy broke down, American business, labor, and government pulled together to do what was needed to rebuild our economic and industrial might. Somehow we must recapture that kind of energy today.