NIST Industrial Impacts

A Sampling of Successful Partnerships

National Institute of
Standards and Technology
Technology Administration
U.S. Department of Commerce

A Note to U.S. Industry

The National Institute of Standards and Technology (NIST) has a mission to work in partnership with industry toward the shared goal of strengthening the nation's technological and economic bases. Here are a few examples of how we are fulfilling our mission:

- Crucible Compaction Metals, a company in Oakdale, Pa., wanted technical assistance in honing a new way to make high-performance metal parts. They turned to NIST where they joined a handful of companies with similar goals in a research consortium that taps into a variety of NIST specialists and advanced equipment. The company ended up increasing productivity by 40 percent.
- SDL Inc. of San Jose, Calif., wanted to develop a high-risk laser technology, but the risk was too great for them to bear alone. So they, too, turned to NIST, which administers the Advanced Technology Program to share costs with industry for developing high-risk, enabling technologies with commercial payoff. With unexpected swiftness after the start of their project, SDL had three spin-offs on their hands—and on the market.
- Thomson Berry Farms of Duluth, Minn., wanted to automate the way they make jams, syrups, dressings, and vinegars. They contacted NIST's Upper Midwest Manufacturing Technology Center, which is part of a growing nationwide network of assistance centers managed by NIST. The advice they received helped the company increase their productivity by 50 percent while almost quadrupling their manufacturing capacity.
- Ames Rubber Corp. in Hamburg, N.J., made the NIST connection in the form of a coveted Malcolm Baldrige National Quality Award. This award, which was established by Congress in 1987, is the most visible outcome of a program designed to promote and recognize quality in the business sector. The stringent criteria to qualify for the prestigious award are playing an increasing role in the way Ames and many businesses run.

This booklet briefly chronicles these and other recent cases in which U.S. companies and NIST have crossed paths to their mutual benefit. We hope that they will encourage you to explore how you too can take advantage of the opportunities for collaboration with a technology agency that's designed to work with industry.

Hoping to hear from you,

Arati Prabhakar

Arati Prabhakar, Director

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NIST at a Glance

The National Institute of Standards and Technology has a primary mission to promote U.S. economic growth by working with industry to develop and apply technology, measurements, and standards. NIST, a non-regulatory agency of the U.S. Department of Commerce's Technology Administration, carries out this mission through a portfolio of four major programs.

- The Advanced Technology Program is a rigorously competitive cost-sharing program designed to help industry pursue high-risk, enabling technologies with significant commercial potential. The program, which seeks to build bridges between basic research and product development, provides multiyear funding to single companies or industry-led joint ventures. Beginning in 1994, the bulk of ATP funding was applied to focused program areas targeted at specific, well-defined technology and business goals. The focused programs—each identified and defined from industry input—support multiple projects that complement and reinforce each other.
- The Manufacturing Extension Partnership (MEP) is a grassroots effort to improve the competitiveness of smaller manufacturers by providing access to the information and expertise that allow them to improve their operations through the use of appropriate technologies. These smaller companies are assisted through MEP's growing nationwide network of affiliated manufacturing extension centers run by local, state, and non-profit groups.
- The oldest component of NIST's portfolio resides in its laboratories—electronics and electrical engineering, manufacturing engineering, chemical science and technology, physics, materials science and engineering, building and fire research, computer systems, and computing and applied mathematics. These labs maintain world-class expertise in measurements, standards, data evaluation, and test methods with specific efforts planned and implemented in coordination with industry.
- The Baldrige National Quality Program is a quality outreach effort that recognizes and promotes quality improvement by U.S. manufacturers and service companies. The Malcolm Baldrige National Quality Award has become both the U.S. standard of quality achievement in industry and a comprehensive guide to quality improvement.

There are many specific mechanisms by which the private sector interacts with NIST's 3,200 scientists, engineers, technicians, and support personnel either in Gaithersburg, Md., or Boulder, Colo. They range from shot-in-the-dark problem-solving phone calls to more formal and long-term collaborations, including cooperative R&D agreements, R&D contracts, workshops, guest researcher agreements, patent licenses, and research consortia involving several companies and NIST. Direct assistance is available to smaller manufacturers from the NIST manufacturing extension centers around the country.

Organizational Contacts

General Inquiries
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Advanced Technology Program
(800) ATP-FUND
email: atp@micf.nist.gov

Manufacturing Extension Partnership
(301) 975-3593
email: mepinfo@micf.nist.gov

Baldrige National Quality Program
(301) 975-2036
email: oqp@micf.nist.gov

Laboratory Programs:

Electronics and Electrical Engineering
(301) 975-2220

Manufacturing Engineering
(301) 975-3400

Chemical Science and Technology
(301) 975-3145

Physics
(301) 975-4200

Materials Science and Engineering
(301) 975-5658

Building and Fire Research
(301) 975-5900

Computer Systems
(301) 975-2822

Computing and Applied Mathematics
(301) 975-2728

Technology Services:

Standards Information Center
(301) 975-4040

Weights and Measures
(301) 975-4004

Laboratory Accreditation
(301) 975-4016

Technology Commercialization
(301) 975-3084

Standard Reference Data
(301) 975-2208

Standard Reference Materials
(301) 975-6776

Calibrations
(301) 975-2002

Technology Evaluation
(301) 975-5500

Advanced Technology Program Impacts

NIST Industrial Impact

Company:

Accuwave
Santa Monica, California

Business:

Fiber-optic telecommunications

Number of Employees:

10

"As magnificent as they are, today's optical-fiber networks are still very primitive," muses Accuwave CEO Neven Karlovac. They are reminiscent of the early days of radio—a transmitter, a receiver, and you turn the signal on and off. Radio has come a long way. Tight, efficient use of the available spectrum has made possible a multiplicity of closely spaced AM, FM, and cellular phone channels. Fiber-optic networks have a way to go.

Karlovac's company has a way to get there. The small (10-person) Santa Monica company was a high-tech start-up in 1990, with a nifty technology in search of useful applications. Accuwave could use holograms "written" in the interior of thick, photorefractive crystals to separate a mixed beam of light into separate wavelengths. It seemed the basis for a very compact, discriminating "multiplexing" technique to allow many separate channels to share a single optical fiber simultaneously.

Commercial systems have been able to multiplex a few channels on a fiber, but Accuwave had demonstrated techniques that—in principle—could do 10 times better. Multiwavelength light entering one end of an Accuwave "volume holography" crystal would encounter a series of holographic gratings, each tuned to reflect a specific wavelength while passing all others with minimal loss.

What Accuwave didn't have was the in-house resources to develop their technology to the point where they could plausibly enter the huge, highly competitive communications market. In particular, they wanted to extend their technology, developed for visible light, to the infrared wavelengths more commonly used for long-distance telecommunications. Their entrée was a 1992 NIST Advanced Technology Program award for $2 million. "As a small company, we couldn't have entered the telecommunications market with the resources to develop a product without the ATP award," says Karlovac. "The award enabled us to take our technology and develop a prototype and make it real."

"The ATP award enabled us to take our technology and develop a prototype and make it real."

Very real. Although the ATP project is still under way, Accuwave has spun off some early results as new products. "As an offshoot of that work we have focused on a particular market need for wavelength standards," explains Karlovac. Just as every radio transmitter has a crystal to tune it to a specific wavelength, multichannel fiber-optic networks need a "crystal" to define specific wavelengths for each channel. Such a wavelength reference is necessary to control the transmitter wavelengths and important for networking monitoring equipment to ensure that you have the correct channel on each wavelength.

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At a July 1994 conference on optical networks, the company unveiled three new products based on early results of their research program: an optical network monitor, a wavelength standard, and a wavelength "locker" to allow tighter control of laser wavelengths on optical networks. "As far as we know," says Karlovac, "these are unique products. They've created a category of their own. To get the same functionality, you'd need a benchtop of lab equipment costing tens of thousands of dollars. The Accuwave units are less than 2 cubic inches each, designed for mass production and use in networks. They're low-cost, compact, and rugged."

"Our entry into the telecommunications market has largely been as a result of the ATP."

The announcement was particularly well received, Karlovac recalls, because it by chance followed an invited paper from AT&T that singled out the need for accurate and ubiquitous wavelength standards as the number-one issue for optical networks. "We've had outstanding response. In fact, we already have a commitment from five companies to go through beta testing with us and we're working on that right now," he says, "Of course the road to success and profitability still is a long one—the telecom marketplace has a long gestation period, and quite a few things need to happen. From the business point of view, we intend to serve the communications R&D market for the next couple of years, so these won't be in your home right away."

But, he says, the Advanced Technology Program played a key role in getting them this far: "Our entry into the telecommunications market has largely been as a result of the ATP."

NIST Industrial Impact

Company:
Aphios
Woburn, Massachusetts

Business:
Technologies that inactivate viral contaminants in biological and biotechnological products

Number of Employees:
20

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Trevor Castor has it out for viruses. Not only that, since 1988 when he founded a company now known as Aphios, the Trinidad-born mechanical and chemical engineer has aimed to make it his business to protect the nation's supply of blood and blood products from viruses, whether they be well-known viruses like the ones that cause AIDS and hepatitis or less familiar threats such as the deadly Ebola virus.

Laudable as that aim is, the virus-killing technology that he and Arthur Lander, a physician and biology professor at the Massachusetts Institute of Technology, had invented for this purpose was too unconventional and untested to readily attract the venture capital needed to usher their laboratory successes toward commercial virus-clearing systems. Castor, who is president and CEO of Aphios (Greek for "without viruses"), recalls wryly that in 1991, "I hit the road running hard, contacting about 100 venture capital companies and all of the human plasma processing companies.... Nine months later, I came up empty—physically, emotionally, and financially exhausted."

Even as Castor was chalking up rejections, a new federal technology initiative, the Advanced Technology Program (ATP), was getting into gear. As Castor saw it, the point of the National Institute of Standards and Technology's ATP was to help companies like his test the mettle of new and promising technology leads through cost-shared research and development agreements whose primary goal was to reduce the risks enough for the private sector to take the development baton all the way to a commercial end.

As it turns out, his 1992 application to the ATP was successful. It was a critical boost for him and Aphios, which at the time had only three employees. Under the two-year agreement, the federal government contributes a total of $2 million while Aphios kicks in $500,000. The five-year-old ATP was forged with provisions for financial arrangements like this one to encourage innovative companies like Aphios to enter ATP competitions.

"As a result of winning the ATP cost-sharing grant, we have been able to assemble a crack team of scientists."

"As a result of winning the ATP cost-sharing grant," Castor says, "we have been able to assemble a crack team of scientists." Now, among the 20 or so Aphios employees are virologists, molecular and cell biologists, protein chemists, and a veterinarian as well as biomedical, chemical, and mechanical engineers—an assemblage of scientific and technical talent essential for developing and ultimately commercializing the biotechnology Castor and Lander invented. "Before ATP we had tested one virus, now we have examined a dozen," Castor adds. Moreover, he credits the ATP with allowing him and colleagues "to demonstrate the technology to a level where we can attract collaborators from large and significant companies" in the blood products industry. Preferring not to reveal the partners, he notes "we have four agreements and six in the works." Just in time, too. After the ATP agreement ends this year, Castor estimates it will take an additional $5 million to get their technology to the commercial phase. "This will have to come from the venture community or from these partnership agreements," he says.

The technology that is the focus of these actual and hoped-for R&D agreements is called "critical fluid inactivation." Castor believes this technology could provide a generic means of inactivating all or most viruses, known or unknown, that might be present in protein-rich media such as blood and biotechnologically produced drugs. It will do this, he says, without affecting the proteins—such as the clotting factor used by hemophiliacs—in the same media.

Procedures involving heat treatments and detergents have proven effective against viral contaminants and are in use, but Castor says these fall short of the mark for the emerging biotechnology community. Heat treatments can simultaneously destroy the function of the very proteins that the treatment is intended to protect. In Castor's words, "You don't want to make scrambled eggs of the protein." As for detergents, they can leave behind traces of themselves, and they only work on viruses coated with oily molecules known as lipids. That includes such menaces as HIV, but the uncoated hepatitis A virus, for example, would slip by these detergents.

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Critical fluid inactivation hits the mark, Castor believes, with the same principle that incapacitates deep sea divers who surface too quickly. Such divers will suffer a painful and sometimes lethal condition, called the bends (caisson disease), when nitrogen that had dissolved in their blood and tissues at the higher pressures of deep water boils out again as the divers return to shallower, lower pressure water. The viral version of the bends starts when blood and other virus-containing products enter a treatment chamber loaded with a gas, say, carbon dioxide. The chamber's temperature and pressure are then adjusted to levels at which the gas becomes a so-called critical fluid, which means that its physical properties and state hover somewhere between those of a gas and a liquid. In this form, the carbon dioxide infiltrates the viral particles to create a pressure-triggered time bomb. When the chamber pressure is reduced, the carbon dioxide inside the virus reverts unambiguously to a gas and expands explosively, apparently taking with it much of the virus's genetic material.

Although no one yet knows exactly how the technique works, the Aphios scientists know that the viruses they have subjected to this treatment emerge stripped of their abilities to cause infection. Moreover, proteins in the same media often glide through the procedure either unscathed, or they revert to their functional forms after undergoing a temporary change. Teasing out the details of what happens to the viruses and proteins remains among the priorities for Aphios researchers, and plenty of work lies ahead before critical fluid inactivation will be ready to undergo its rite of passage through the Food and Drug Administration's approval process. Still, with prototype systems in hand, and with strategic collaborations in place or in the works, Castor is optimistic that by 1998 the technology will have the FDA go-ahead to become what he expects will be an important new tool for the medical, public health, and biotechnological communities.

NIST Industrial Impact

Company:

The Auto Body Consortium
APX International, Madison Heights, Michigan
ASC, Southgate, Michigan
Classic Design, Inc., Troy, Michigan
Detroit Center Tool, Inc., Detroit, Michigan
ISI Automation Products Group, Mt. Clemens, Michigan
Perceptron, Farmington Hills, Michigan
Modern Engineering, Troy, Michigan
Progressive Tool, Southfield, Michigan
Chrysler Corporation, Detroit, Michigan
General Motors Corporation, Warren, Michigan

Business:

Auto manufacturing

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When Toyota's "ball bearing" ad for its Lexus cars appeared during prime time, its message hit the U.S. car industry in the solar plexus. In the ad, a ball bearing rolls flawlessly along the car's virtually perfect seams. The manufacturing uniformity that is shown improves a car's quality, reduces company costs, and shortens time to market. It leads to tighter fitting doors, less wind noise, and fewer rattles and vibrations, all of which play pivotal roles in the decisions of car buyers. "The ad was a call to innovation," recalls Ernest Vahala, a 43-year retired veteran engineer at General Motors who now is president of the Auto Body Consortium (ABC). The group's goal is to help U.S. auto body manufacturers surpass the industry benchmark of product uniformity set and held by Toyota. The consortium was able to form, Vahala says, only because the National Institute of Standards and Technology's Advanced Technology Program provided an unprecedented framework for cooperative R&D even among arch rival companies.

"We were all skeptical when we first started this," recalls Dwight Carlson of Perceptron, an ABC member company that specializes in manufacturing sensor technology. The consortium's eight small technology suppliers work with the large auto makers as well as researchers at the University of Michigan and Wayne State University. "Now we know that this really works," Carlson says.

The industrial challenge has been clear enough: If domestic car makers are to continue competing in the global industry, they have to reduce car-to-car manufacturing variation from the typical 3 to 5 millimeters (on critical dimensions such as door openings) to 2 mm or less, or about the thickness of a nickel. Toyota has been the acknowledged "master of variation reduction," notes Carlson. Other auto makers in Europe and the Pacific Rim have been closing in.

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Meeting the challenge in the United States, however, would require an unprecedented collaboration among researchers in small companies, universities, and large auto makers. The millions of dollars required for the R&D also would be an issue, but it was the cultural hurdle of working across traditional lines of the R&D continuum that was the first barrier to clear. That is where the Advanced Technology Program came in like no other entity could have, say Carlson and Vahala.

"Prior to the NIST ATP program, there was no authorization which provided the necessary teaming structure and monetary support for auto companies, smaller suppliers, universities, and government to establish teams to improve the competitiveness of the domestic auto industry," according to ABC. Under the three-year ATP agreement, which ends in September 1995, the U.S. government contributes $4.8 million to the ABC's small members. Of the roughly $6.5 million of industry matching funds, GM and Chrysler kick in $2.25 million while the eight smaller partners ante up the rest. The ATP catalyzed the horizontal integration of small innovative suppliers and academic researchers as well as the vertical integration of these players with the Big 3 auto makers.

The fundamental manufacturing challenge rests in the fact that assembling car bodies is like assembling jigsaw puzzles. In both cases, each of many pieces must fit nearly flawlessly with its neighbors. Even minuscule misfits can accumulate into unappealing results. In only three years, the ATP 2 mm Program—as its participants call it—has yielded new valuable results. Among them are software and modeling tools for controlling and streamlining the manufacturing processes; laser-based sensing techniques for reducing variation occurring along the continuum from mathematically precise designs to manufacturing dies to production parts; and techniques of precision clamping to reduce tiny warps and deflections in sheet metal.

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Based on the results already in, auto makers have felt confident enough to invest additional resources to get the new technology on-line sooner than initially projected. The 2 mm goal is a reality already on several assembly lines whose products—including the Chrysler Grand Cherokee, Dodge Ram trucks, and GM 325 and 330 trucks—are rolling on the nation's roadways. At the GM Linden plant in New Jersey, variation levels now even run at a world-class 1.74 mm. These technology implementations have been accomplished in a way that promises a long-term competitive advantage, Carlson says. Similar to Toyota's approach, the ABC technique maximizes worker knowledge and contributions for each particular model. But the ABC approach also stresses manufacturing technologies that are more readily adaptable to many models, paving the way for a more agile brand of world-class manufacturing.

The unusually rapid transfer of technology from R&D stages to the plant floor is a natural outcome of the vertical integration among suppliers, researchers, and auto makers within the ATP framework, Vahala says. As soon as a technology or practice is proven, auto makers can make the investment in money and personnel to get that innovation into assembly lines. "This has a life of its own now," adds Carlson. There are 64 assembly plants making American cars in the United States and Canada, and ABC members say that all of them probably will adopt the innovations of the ATP 2 mm Program. With on-the-road proof that collaborative R&D really can work in the auto industry, many now seek to replicate the 2 mm project in other manufacturing steps, including metal stamping and welding.

The potential payoffs are enormous, the ABC says. The domestic auto industry accounts for one out of every seven jobs. It makes up 4 percent of the U.S. gross domestic product. Autos and auto parts make up two-thirds of the U.S. trade deficit. If the ATP 2 mm Program, and other collaborative efforts modeled after it, can help the U.S. auto industry to gain global market share, the U.S. economy as whole ought to benefit. That is no pipe dream, Vahala says. He proudly points out that the Truck of the Year according to *Motor Trend* magazine is made at a plant in Moraine, Ohio, where the innovations of the ATP project have been put into practice. In the end, it is quality like that that attracts buyers, earns market share, and determines which auto makers are at the top.

NIST Industrial Impact

Company:

Diamond Semiconductor Group
Gloucester, Massachusetts

Business:

Semiconductor equipment manufacturer

Number of Employees:

28

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"We're here now only because of the Advanced Technology Program. We'd tried all the other avenues —except for foreign investors." Risky ventures to replace an established technology don't fare well in a tight R&D market. Manny Sieradzki, president of Diamond Semiconductor Group Inc. (DSG), has firsthand experience.

Not that he was trying to sell an *unwelcome* technology. Sieradzki and his partner, DSG research director Nicholas White, hoped to develop a new type of ion implantation machine, one of the primary tools of the semiconductor industry. The new machine would be smaller, faster, cheaper, and more accurate than existing machines and accommodate larger wafers—all good things. But it would require a design breakthrough that was widely believed to be, if not impossible, certainly very difficult. And expensive. And times were tight.

Ion implantation is used widely to tailor the chemical composition of minute regions in a crystalline wafer of a substrate, such as silicon, as part of the process used to create integrated circuits. The new DSG machine is a *high-current* implanter, the type used to implant "source" and "drain" regions for microscopic transistors. In what might intuitively seem like a leap backwards, one of the principal features of the DSG machine is that it works on a single wafer at a time, in contrast to conventional high-current implanters that do a batch of 13 to 17 wafers at once.

Why? In part, explains Sieradzki, the advantage of his new machine is one of better process control. The vast majority of wafer-fabrication steps are done one wafer at a time, so a single-wafer implanter fits better in the process stream. You can better tweak the process for optimal results working on single wafers. And, were something to go wrong with the process, a single-wafer machine only trashes a *single* expensive wafer.

"We're here now only because of the ATP. We'd tried all the other avenues—except for foreign investors."

But perhaps more importantly, the existing technology for high-current ion implanters is being challenged by the demands of semiconductor manufacturers for ever larger wafer sizes. True, the size of individual *features* in integrated circuits is getting smaller and smaller, but the chips themselves are becoming larger and larger to accommodate greater complexity. Take a look at a state-of-the-art microprocessor. If you want to maintain the number of chips per wafer for each new generation, the wafers have to get bigger.

Which means all the processes have to be scaled up. Currently, the standard production wafer is 200 mm in diameter, but the industry wants to move to much larger 300-mm wafers —about the size of an LP record. To build a conventional ion-implanting machine that holds a dozen or more of these monsters ... whirling around at about 1,800 rpm ... in a vacuum ...

is a very expensive prospect loaded with engineering problems.

The reason one would try at all is because it is extremely difficult to take a high-current ion beam and scan it—*uniformly*—across the face of a large semiconductor wafer. The catch is, you can't conveniently scan the beam as you would in a TV picture tube, because at the high beam current, it would simply tear itself apart. So conventional machines hold the beam more-or-less steady and move the wafers, whirling them around on a disk that slowly moves under the beam.

DSG's answer was a new design of ion-beam *optics* that produces a wide (about 350 mm), uniform, nearly parallel ion beam. By simply moving the wafer through this curtain of ions at a constant speed, 300-mm and larger wafers can be processed quickly and evenly. The new DSG optics make for a markedly simpler machine, so it should be much cheaper to build and maintain than a conventional ion-implantation machine.

But the concept wasn't an easy sell. "We spent a year and a half looking for funding, mostly from U.S. companies," recalls Sieradzki. "The concept was one that had been talked about for years," adds White, "but not everyone believed it was possible. It was definitely high risk. And the market had been in a slump, so there wasn't a lot of development money available anyway."

"Without the original ATP funding into the Diamond Semiconductor Group, there wouldn't have been enough 'existence proof' for Varian to go ahead with the technology, particularly since it was quite high risk."

One option was to look for overseas investors, but before trying that the partners decided to apply to the NIST Advanced Technology Program (ATP). Their project was one of 21 selected in 1992, and even before the final papers were signed, the fledgling company had attracted the attention of Varian Associates, one of the largest suppliers of ion-implantation equipment in the world.

"Winning the ATP award was absolutely crucial to us," says Sieradzki. "It's clear to us that without the ATP we wouldn't have secured domestic funding for this." Bruce Thayer, the Varian marketing manager dealing with DSG, frankly agrees, "Without the original ATP funding into the Diamond Semiconductor Group, there wouldn't have been enough 'existence proof' for Varian to go ahead with the technology, particularly since it was quite high risk."

Under the ATP award, DSG developed their concept and built a prototype machine. That was enough for Varian, which bought a worldwide license to manufacture, sell, and service DSG's ion implanter. And the company kicked in some funds to help with product development, an area not covered by the ATP.

DSG now has 28 full- and part-time employees and is looking to the next challenge—flat-panel displays. With its wide product capacity, the DSG implanter should be an ideal machine for making the large integrated devices that are the core of most flat-panel displays, but it will require a major marketing effort in the display industry, which isn't used to the concept of using ion implantation. To have picked that as their first market, says Sieradzki, would have meant trying to launch a radically new technology and a radically new application at the same time. His advice: "Don't do that." But now that the basic technology is well in hand and headed for the showroom ... .

The partners are understandably bullish about the company's future, but in a time of increasing commercial competition on an international scale, White has a cautionary moral to add: "We'd be a Japanese company right now," he says, "if it weren't for the ATP."

NIST Industrial Impact

Company:

Eagle-Picher Research Laboratory
Environmental Science & Technology Department
Miami, Oklahoma

Business:

Develops and manufactures electronic electro-optic and photonic materials and devices

Number of Employees:

202

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Physicist Jan Schetzina knows how to show-and-tell. In June 1994, at the end of a technical talk he was presenting at a meeting on semiconductor devices at the University of Colorado, he held up a little black box, his finger poised on a button. When he pressed it, a pencil-thin beam of bright green light from the box hit the back wall. He then swept the light like a beacon across the audience of several hundred. The next thing Schetzina remembers is that his ears were filled with a round of spontaneous applause.

Those gathered at the meeting—the Institute of Electrical and Electronics Engineers' Device Research Conference—knew what that light signified. It meant that Schetzina of the North Carolina State University (NCSU) and his colleagues had achieved a milestone toward the goal of making highly controlled semiconductor crystals that emit green or blue wavelengths of light. Schetzina's show-and-tell glory rests partly on his team's expertise with a crystal growing technique called molecular beam epitaxy (MBE), which allows them to build and vary crystal structures atomic layer by atomic layer.

The applause for Schetzina's demonstration was for more than skilled MBE work at NCSU. Also pivotal were a unique supply of pristine zinc selenide (ZnSe) crystals from Eagle-Picher Research Laboratory and what both Schetzina and Eagle-Picher representatives describe as a critical assist from the National Institute of Standards and Technology (NIST) in the form of an Advanced Technology Program grant.

There actually is nothing new about light-emitting diodes (LEDs), which were the kind of devices Schetzina was talking about. Nice bright ones have been shining for years inside CD players, or from the panels of consumer electronic products. But no one yet has made a true green or blue LED that lasts more than a few seconds. Those LEDs now marketed as "green" lack intensity and are actually a disappointing hue of yellow green, Schetzina says.

Also pivotal was a critical assist from NIST in the form of an Advanced Technology Program grant.

There is no shortage of technological carrots for green and blue LEDs and laser diodes, which emit a much narrower range of wavelengths than LEDs. For one, their availability would complete the basic spectrum of solid-state light-emitting devices and that could launch a new branch of the flat-panel display industry for TVs, computer monitors, control panels, and electronic games. Even more important, according to several key players in the field, is that their shorter wavelengths can pack more information than the redder ones now at the heart of optical communications. Moreover, those same shorter wavelengths could lead to data recording and storage systems with much greater capacities than today's best. Companies such as 3M, Xerox, and Sony in Japan, military planners, and academic researchers have been hot on the trail of this technology for years.

There have been plenty of dead ends. Schetzina and many other research teams around the world had made green LEDs by depositing II-VI semiconductors (so-named because they are made by mixing and matching elements from the second and sixth columns of the Periodic Table) atop a crystal of gallium arsenide (GaAs, a III-V compound). Anyone who has ever tried to make GaAs-ZnSe combos though has run into a show-stopping problem—the devices last only a short time, usually a few seconds, before their crystal structures become riddled with light-quenching defects.

The seeds for destruction probably are sown as soon as the first layers of ZnSe are deposited on the gallium arsenide since the respective spacing between the atoms in each layer are not quite matched. Like a plastic top forced onto a mismatched deli container, these differences elicit strains, which researchers think are the source of the structural defects that appear soon after any current courses into the crystals.

Like other semiconductor researchers, Schetzina suspected that the only way to grow durable ZnSe-based LEDs would be on top of ZnSe crystals, in which case there would be no mismatch between atomic spacings. That is a scenario much easier to imagine than make real. No one had ever succeeded in growing ZnSe crystals large enough to offer commercial promise, Schetzina says. Until 1991, that is. That is when researchers at Eagle-Picher, led by Gene Cantwell and William Harsch, announced that they had come up with a patented method to grow the coveted ZnSe crystals. Called seeded physical vapor transport, the method involves a heated tube that contains purified zinc selenide powder whose atoms boil off and then migrate toward seed crystals on either end of the heated tube on which large pristine crystals then grow. Harsch was confident that he and colleagues would be able to come up with the ZnSe crystal that others had given up on, but he wanted to take the crystal to the next step of technology development. So in 1991, Harsch gave Schetzina a call.

"Without the ATP, they would not have had the incentive or help that they needed at a very critical time... ."

Their subsequent collaboration already has yielded prototype LEDs that emit a deep emerald green light, which is more than 50 times brighter and more efficient than commercial yellow-green devices. Recently, the NCSU/Eagle-Picher team also has demonstrated bright blue LEDs, says Schetzina.

The timing of these successes was crucial. Eagle-Picher's original efforts to make ZnSe had been funded since the mid-1980s by a federal agency that shifted its emphasis entirely to gallium arsenide substrates in the early 1990s. The subsequent loss of government funds for ZnSe research led company management to seriously rethink the material's commercial potential. "I was told either to do something with the technology or to get out of the [ZnSe] business," Harsch recalls. Knowing "that the technology was too good to drop, though," the company applied for support from the Advanced Technology Program, Harsch says.

In late 1992, Eagle-Picher was awarded a 3-year ATP award totaling $1,759,000. "Without the ATP, they would not have had the incentive or help that they needed at a very critical time when they were about to make internal decisions," Schetzina says. Adds Harsch: "It gave our program credibility in the minds of our corporate people." The award also enabled the company to greatly leverage its own investment for a high-risk project with potentially high payoffs, just what ATP awards are chartered to do.

"This is turning into a textbook case of technology transfer," says Harsch. Since the award was granted, the Eagle-Picher group has been able to improve their success rate at growing usable ZnSe crystals from intermittent to nearly 100 percent, he says. By the fall of 1994, they expect to receive a production MBE system exactly like the one Schetzina's group uses at NCSU and the company plans to hire some graduates from Schetzina's lab. The hardware purchase was part of the ATP agreement. Says Harsch: "By the end of the year, we could be selling the world's brightest and most durable green LEDs."

NIST Industrial Impact

Company:

Engineering Animation Inc.
Ames, Iowa

Business:

Develops simulation, visualization, and animation software

Number of Employees:

96

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October 1994

One of the most successful and powerful inventions during the course of human evolution was imagination: the ability to picture mentally, to simulate, what might happen if this or that particular action is taken *before* taking the actual physical risk the actions entail. Beyond its critical role as a survival tool, imaginative simulation has been a veritable engine of scientific insight and technological innovation, one of the latest being the creation of artificial simulation tools that leverage human imagination into vast new territories.

In 1991, Engineering Animation Inc., a fledgling computer simulation company based in Ames, Iowa, was anxious to see how it might take its three-dimensional visualization and animation technology into new biomedical territories where company executives saw a big market. Others had been developing straightforward anatomic simulation tools, the sort of things that could supplant or complement anatomy books and medical school cadavers. But the founders of EAI, all of them mechanical engineers by training, were convinced they had a unique knowledge base and capability to add mechanically realistic motion to that otherwise static anatomy. Instead of offering a virtual cadaver, they had their sights on a "virtual human" that could walk, breathe, grasp objects, pump blood, sustain injury, undergo surgery, and simulate whatever else real people might do or that might befall them. Medical students, surgeons, ergonomic engineers (who worry about the way products and humans interact), as well as advertisers and entertainment professionals all looked like potential customers.

The problem was that the project was just too ambitious, risky, and expensive for the company to take on by itself. It would require the integration of massive amounts of anatomical, physiological, and biomechanical data into a computer visualization system that could manipulate and process those data at the enormous speeds required for producing computer images and animations. The company already had begun to make a name for itself among litigation lawyers, who were using the company's simulation products to make and break cases in which juries needed to visualize clearly details of complex events like car crashes and spreading plumes of underground pollution. The virtual human, though, was a leap beyond those simulations.

"We talked to venture capitalists, but the project seemed too far out for them."

"We talked to venture capitalists, but it seemed too far out for them," recalls EAI President and CEO Matthew Rizai. As he put it to a *Des Moines Register* reporter in April 1991, just a few anxious weeks before the company heard the verdict on a proposal it had submitted to the Department of Commerce's Advanced Technology Program (ATP), the goal was nothing less than "to represent every single millimeter of the body, inside and out." More than that, it had to render all of those data into images in such a way that the simulated parts would realistically move and respond to each other and to external forces.

In mid-April 1991, Rizai and his co-workers heard very good news from the managers of the ATP at the National Institute of Standards and Technology, a cost-sharing program designed especially to encourage companies like EAI that wanted to pursue high-risk technologies with high potential payoffs. More specifically, the company learned that over the next three years, it would receive nearly $2 million in its quest to develop the first tier of a virtual human, a high-fidelity musculoskeletal system. If Rizai and his colleagues could do that, they knew they could later hang the rest of a simulated human anatomy onto this framework, ultimately providing a tool by which users could peel back anatomical layers like an onion, zoom in to the cellular level, observe how a disease like osteoporosis erodes and weakens the labyrinthine mineral basis of bone, and assist their imaginations in ways impossible with books, cadavers, and even living breathing humans. Like any tool, much of its ultimate value would probably emerge unexpectedly from the people tinkering with it.

"We sincerely believe that push for us was the ATP award. Today we are a growing company adding high paying, highly skilled jobs."

Rizai unhesitatingly pegs the ATP award as *the* turning point for EAI, which in its five years has grown from five employees sharing a revenue of $35,000 to a rapidly growing company of 96 employees attracting $5 million in revenue. For every young company that becomes successful, Rizai surmises, "there is always something that pushes it, that launches it into a growth phase. We sincerely believe that push for us was the ATP award. Today we are a growing company adding high paying, highly skilled jobs."

Although the infusion of cash for research and development was a major part of that push, the award served up a less tangible and probably longer lasting value to the company, Rizai adds. "It built up our confidence. The ATP award put us on the map. We started getting noticed. People started calling us and it helped us network."

As for the project that won the company its ATP award, "we are right on time," Rizai says. "We are well into developing the final stages of a musculoskeletal system as a database" for visualization and animation products and services, he says. Moreover, with the alliances that the company has formed with biomechanical engineers at Johns Hopkins University and with computer hardware engineers at Silicon Graphics Inc., which specializes in powerful platforms for computer simulation, ambitions like creating a virtual human do not seem so far-fetched anymore.

NIST Industrial Impact

Company:

Illinois Superconductor Corporation
Evanston, Illinois

Business:

Start-up company that focuses on designing and building wireless communications components based on high-temperature superconductors

Number of Employees:

36

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January 1995

Cellular phones have changed the way tens of millions of people stay in touch, but the wireless technology underlying them metes out its share of headaches. All too often, cellular phone users find themselves cut off in mid-sentence, striving to listen through static, or diverted by uninvited voices from other conversations. Despite these problems, and the profit-eating tendency of users to "churn" between carriers in search of better service, revenues in the decade-old wireless communications industry have grown rapidly to an estimated $12 billion to $14 billion in 1994. With stakes like that, competition to provide better and more reliable services at attractive prices has become fierce.

That is what fuels the optimism of Ora Smith, president and CEO of Illinois Superconductor Corp. (ISC) in Evanston, Ill., and partly why his company was successful in its 1992 proposal for a three-year $3.5 million cost-shared proposal to the Department of Commerce's Advanced Technology Program. Smith, a lawyer and mechanical engineer by training, and his co-workers are betting that the high-risk road their company is taking in a bid to become a player in the ascent of wireless technology will pay off in a big way. The technical task for which they sought assistance has been to develop ways of preparing and depositing films of the high-temperature superconducting material—yttrium-barium-copper oxide, known by the acronym YBCO—onto metal and ceramic backings of various shapes and sizes. Getting this basic material processing capability under control, Smith expects, will lead to a variety of higher performance products for wireless mobile communications systems, including cellular phones and personal communication systems.

The first products to approach the commercialization stage, however, will be receiver filters that Smith says can greatly reduce the radio interference that causes many of the warts on cellular communication technology. He estimates that the potential market for these will be $750 million worldwide for retrofitting existing base stations with new filters, and about another $150 million per year for equipping new base stations. In the field, the filters that ISC is developing would be placed between the antennae and receivers at the cellular base stations that now punctuate the global landscape by the thousands. Current technology, such as "copper cavity filters," has worked well enough so far to facilitate the birth of cellular networks over a decade ago and the subsequent dramatic growth of the wireless industry. What is good

The technical task for which they sought assistance has been to develop ways of preparing and depositing films of the high-temperature superconducting material.

enough now, however, will not be good enough tomorrow, Smith notes.

That explains why ISC, a tiny company with 36 employees, thinks it is onto something big. The approach is a risky one since it depends upon high-temperature superconducting materials such as YBCO that have yet to prove their highly touted potential. In experimental filters, the materials' laboratory-proven property of being able to grab onto a very narrow range of frequencies amidst a noisy, frequency-filled background, however, means that whoever can develop an economic means of preparing and manipulating the ceramic materials could open themselves to some sizeable market niches.

ISC's approach, developed both in-house and through collaboration with the University of Birmingham in England, has been to first prepare slurries loaded with precursors of the YBCO material and then to "paint" the slurries onto ceramic or metal substrates of shapes and sizes matched to the communications frequencies the filters are supposed to control. Then, a heating step as well as exposure to oxygen converts the precursor coating into the superconducting material. The most time-consuming development challenge has been to find exact processing conditions that give reliable, repeatable results at acceptable costs.

"The ATP award gave us a lot of credibility," quickly attracting more venture capital.

The ATP has had multiple effects on this effort, Smith says, adding that his company's first ATP proposal in 1991 was turned down. ISC was barely a year old at the time, and it had not yet devised a strong business plan. To increase its chances with a second proposal, ISC sought out contacts, including one at AT&T Bell Laboratories in Murray Hill, N.J., who they knew could add expertise in integrating the new superconducting filters into real-world wireless communications systems while simultaneously strengthening the project's overall business focus. "The ATP competition provided a focus that attracted senior management at AT&T," Smith explains, which led to an agreement in which AT&T Bell Laboratories would work with ISC under a subcontract agreement, with ISC placing one of its engineers at AT&T.

ISC's second bid in 1992 for an ATP award was successful. In addition to paying for subcontractors, ISC hired four highly trained electrical engineers and materials scientists, thereby greatly accelerating the rate of progress, Smith says. "The ATP award also gave us a lot of credibility," quickly attracting more venture capital. Moreover, Smith adds, "because of the ATP, we were able to become a public company." During its initial stock offering in October 1993 on the NASDAQ stock exchange, the company raised some $15 million in capital.

This infusion of investor cash has enabled ISC to take another pivotal step in the perilous life of high-tech startups. The company has leased its first manufacturing facility, according to Sharon Trafford, ISC's contracts manager. Most startups never make it to this do-or-die transition from research to production. What's more, field tests of prototype YBCO-based filters begin this year on ISC's home turf in Chicago, on the west coast, and in the Pacific Rim. Although the ATP funds are devoted to preproduction research—and not to these more downstream steps of ISC's company development, "we attribute a major portion of what we are doing to the ATP program," Trafford says.

Smith expects these technical steps to be followed with what must be the most important business milestones for any new company. As he put it: "We hope we will get our first product revenue in 1995."

He believes in ISC's technology enough that he thinks the company would eventually have gotten to this point even without the ATP. But he credits the program with accelerating technical progress while helping to put their company on the radar screens of others in the wireless industry and financial community.

NIST Industrial Impact

Company:

National Center for Manufacturing Sciences
AlliedSignal Inc.
AT&T
International Business Machines Corporation
Texas Instruments Inc.
United Technologies/ Hamilton Standard Corporation
Sandia National Laboratories, U.S. Department of Energy

Business:

Suppliers, makers, and users of printed-wiring boards (PWBs)

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August 1994

Printed-wiring boards (PWBs) lack the glamour and romance of advanced microprocessors, flat-panel displays, or ultrahigh-density memory systems, but that doesn't mean they're unimportant. Perforated with tiny plated holes, embroidered with a lacework of copper lines, these thin composite boards form the backbone and nervous system of virtually every electronic product. In 1991, the world market for PWBs was estimated at $19 billion.

It is a market that U.S. companies have been losing. Ten years ago, the U.S. share of the PWB market was estimated at 42 percent. By 1991, it had fallen to 27 percent. Many relatively small firms are involved—of the estimated 725 independent PWB companies in the United States (excluding captive producers working for large manufacturers), roughly 80 percent have annual sales under $5 million.

To date, PWB technology has kept pace with the increasing complexity and speed of electronic devices, but it is approaching fundamental limits in both materials and processes. Because of the market size, relatively minor improvements in materials or manufacturing processes can result in sizable savings for the entire industry. By solving technology challenges, U.S. industry can rebuild its position in the PWB market —indeed, capture the high end.

With these thoughts in mind, the National Center for Manufacturing Sciences (NCMS) in Ann Arbor, Mich., assembled a team of member companies in 1990 to attack a broad array of fundamental technical issues in PWB manufacture with support from the NIST Advanced Technology Program (ATP). Now, in the last half of the 5-year project, member companies that include AlliedSignal, Inc.; AT&T; IBM; Texas Instruments; and United Technologies/Hamilton Standard Corp. already are benefiting.

In the last half of the 5-year project, member companies already are benefiting.

The research plan presented to the ATP envisioned a $28 million effort, more than half of which is coming from the private-sector partners. The Energy Department's Sandia National Laboratories later joined the venture, contributing $5.2 million.

Working from an initial industry study to determine just what PWB customers needed, the joint venture tackled a variety of often subtle problems. Where insulation requires two or three sheets of glass epoxy to be laminated together to get the desired thickness, for example, a couple of dollars could be saved on every sheet simply by using one thick sheet in place of two or three thin sheets. But can you do that and maintain the exacting tolerances required for the best PC boards? Some data suggest that drills tend to go askew when boring through thicker sheets, and the surface finish of thick materials tends to be rougher, which might interfere with the copper plating steps. For that matter, would thicker materials have the necessary dimensional stability? An evaluated database of numerous high-performance laminates and mathematical models to predict key technical issues—the dimensional stability of various laminates and the reliability of copper connections plated through holes—are three early achievements of the materials team.

But in addition to any benefits from the research program, participants in the NCMS/ATP project report that simple *cooperation* reaps substantial rewards. A study conducted in 1993 found that after 2 years, the project already had saved the participants about $13.5 million simply by avoiding redundant research and sharing facilities and information.

Bob Holmes, a research manager for AT&T noted, "We were quite insular, working in a large company, and weren't really aware of what other people in the industry were doing about this. The NCMS/ATP project opened a lot of windows and got us talking to a lot of other people. We saw that they had a lot of the same problems and sometimes had new insights on how to solve them."

Lee Parker, also with AT&T, worked on imidazole, an organic "solderability" preservative (OSP), as an inexpensive way to protect bare copper leads on a PWB from oxidizing without the use of tin-lead solder, an environmental hazard. He found that working with the NCMS/ATP project benefited his work in two ways. "One,

After 2 years, the project already had saved the participants about $13.5 million.

they went a long way toward making OSPs acceptable in the industry. Texas Instruments (TI), in particular, would present results of solderability studies using imidazole at conferences and impress people with the product. Two, the other members of the project helped us understand technically what was going on with the coating. As a result, imidazole is saving AT&T millions of dollars a year, and we now are working with Lea Ronal, a chemical supplier for the electronics industry, to market it internationally. The NCMS/ATP effort was very important in getting this to market so quickly."

TI's Foster Gray has similar stories. Tools developed by the PWB surface-finish team, he says, allowed TI to halve the solder defect rate on boards for the HARM missile. Materials researchers with the PWB project also demonstrated that a board's coefficient of thermal expansion—a measure of dimensional stability—varied depending on where the board was cut from the original four-by-eight sheet. "It's a result none of us expected. Now that we know it's happening, we can control for it and get better process control overall."

Another PWB team, says Gray, turned up a useful *negative* result. The PWB industry was seriously considering an in-process test for gauging the solderability of boards, until the PWB team demonstrated that the technique had too much variation to be an accurate predictor of solderability. "That's difficult to quantify," observes Gray. "But you know it saved the whole industry a great deal of time and money that we would have spent putting in this equipment and trying to use it."

Participation in the PWB effort also gave TI access to a PWB test pattern developed by AT&T for monitoring production lines, according to Gray. "In the days gone by, we'd have had to develop that ourselves, instead we could use the AT&T test. We saved a cool million dollars right there."

In fact, says Tom Newton, manager of advanced programs for AlliedSignal Laminate Systems, industrial cooperation may be one of the biggest single advances to come out of the NCMS/ATP project. "The consortium concept is *not* natural in our industry," says Newton. "It takes a consortium-type effort of almost constant contact, working on specific problems, for people in our industry to really start talking. To get in there, do hands-on work together, that shows commitment. It was tough to do that, given our conceptions of how the PWB industry did business. The NCMS/ATP project created a structure to make it happen."

Could it have happened without the impetus from the ATP? "Well, I don't know," says TI's Gray. "But no one ever worked it out until they came along."

NIST Industrial Impact

Company:

Nonvolatile Electronics Inc.
Plymouth, Minnesota

Business:

Designs and manufactures memory and sensor devices using proprietary magnetic materials

Number of Employees:

23

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August 1994

In 1989, after a quarter century of work in the secure setting of major corporations, James Daughton took a leap into the unknown. In March of that year, his start-up company, Nonvolatile Electronics Inc., became a legal reality awaiting a human contingent to give it life. Three months later, Daughton left his post as vice president of Honeywell's Corporate Solid State Laboratory to lead NVE into the raging waters on which new startups sink or swim.

For Daughton, the decision to create NVE was a culmination of decades of work on magnetic materials, which he began as a graduate student in the early 1960s, and that remained a prominent theme throughout his subsequent work in electronics and sensor technology at IBM and then Honeywell. While he was at Honeywell he co-invented a computer memory technology—called magnetoresistive random access memory (MRAM)—that became the seed of NVE, which now licenses MRAM technology from Honeywell.

MRAM is a "nonvolatile" type of computer memory; it retains data even after a computer's power is turned off. NVE has been developing a range of memory and sensor products that marry MRAM components with more standard silicon-based circuitry. The company relies on established "chip foundries" to make the circuits; NVE engineers then pattern MRAM components onto the chips out of magnetic, insulating, and conducting materials.

Daughton is quick to admit that NVE has had its ups and downs. Having skirted ruin in its first 2 years, it has only begun the process of establishing a track record. In 1994, NVE even began selling a few copies of its first commercial product—a magnetic field sensor. Daughton hopes the sensor will infiltrate big markets, including anti-lock brake systems, pacemaker technology, and machine tool controls.

With big-name companies courting NVE and its technologies, and product revenue beginning to trickle in,

"Our company would not exist if it hadn't been for our ATP award."

Daughton sees reason for optimism. He says so with a sense of relief. From the get-go, the company has been surviving on government contracts and grants, including a cost-matching award of more than $1.7 million from the Advanced Technology Program, which is managed by the National Institute of Standards and Technology (NIST). "Our company would not exist if it hadn't been for our ATP award," which expired in the spring of 1994, Daughton says.

Besides helping the company expand and maintain a staff of more than 20 skilled researchers, the ATP award hastened several specific technological developments, Daughton says. "We came up with new architectures that enabled us to shrink the size [of MRAM chips] by at least 50 percent ... and we learned all kinds of techniques to overcome limitations in product reproducibility."

Ironically, the first NVE product to enter the marketplace, the so-called giant magnetoresistance (GMR) bridge sensor, is an unexpected spin-off of their MRAM development. These magnetic field sensors are based on a new type of thin-film material, first reported in 1988 by French researchers, whose sandwich-like structure comprises one or more alternating layers of magnetic and non-magnetic materials. The collective resistance changes dramatically in the presence of a magnetic field, which explains why the property is called giant magnetoresistance. NVE engineers happened onto a method of making their own GMR materials during efforts to improve the ability of their MRAM material to retain data.

The ATP award hastened several specific technological developments.

In addition to the ATP award, Daughton credits several NIST researchers with providing pivotal assistance ever since NVE was incorporated. One of them, surface scientist William Egelhoff, "has been there for us from the beginning, and still is," Daughton says. In August 1994, NVE researcher Eugene Chen wrote a letter of gratitude to Egelhoff for a recent technical tip to deposit a thin layer of "transition" oxide underneath their GMR material (a multilayer structure involving nickel, iron, and cobalt), an exercise that resulted in record-level responses of the GMR material to a magnetic field. "John Unguris," another NIST researcher, "helped us solve a yield problem," Daughton adds. The key here was data obtained using a specialized microscope that revealed the materials' microscopic magnetic structure responsible for its magnetic behavior. Yet a third assist came from John Moreland's group at NIST's Boulder facility. There, data from a magnetic-force microscope helped map out the details of the GMR materials' "magnetic microscopes."

"We now are healthy," Daughton says of his company. He is well aware that significant revenue from products remains a goal, for NVE, not yet a fact of business life. Meeting that goal, not government contracts, will soon become the basis of NVE's health.

NIST Industrial Impact

Companies:

SAGE Electrochromics Incorporated
Piscataway, New Jersey

3M
St. Paul, Minnesota

Business:

Electrochromic devices for tint-controllable windows intended for architectural glazing

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February 1995

Five years ago, chemical engineer John Van Dine knew that he and SAGE, his fledgling high-tech company in Piscataway, N. J., had plenty of challenges ahead in an ever more competitive international environment. He knew there could be no guarantees of success.

Today he is more confident than ever. A good part of his optimism comes from what started out as a disappointing failure in 1990. He previously had learned about the Department of Commerce's Advanced Technology Program (ATP), a cost-shared research and development initiative to help companies undertake high-risk, high-technology research harboring big commercial possibilities. SAGE fit the ATP profile exactly, Van Dine thought. The company's goal, after all, was to develop transparent "electrochromic" technology for manufacturing "smart windows"—panes of glass whose transmission of light can be electronically controlled in response to the amount of sunlight present, the time of day, the season, or simply the personal preferences of occupants. Though companies in Japan, France, and elsewhere have been working on the technology for years, none has yet found a way to manufacture smart windows at a cost that would open up the technology's biggest commercial niche—architectural glazing, which industry observers estimate at about $1 billion annually in the United States alone.

Basically, SAGE's electrochromic technology consists of a stack of thin and transparent layers of proprietary materials—which together are much thinner than a sheet of paper—that comprise an unusual courseway for electrons and ions. Two layers serve as positive and negative electrodes, enabling anyone with a power supply and a switch to control the window's tint. A small voltage (five volts, or so) sets electrons and lithium ions from other layers into motion. Some of the lithium ions end up traversing a central ion-conducting layer into a

The company's goal was to develop transparent "electrochromic" technology for manufacturing "smart windows."

tungsten oxide layer. As a result, the layer's optical properties change. In this case, it blocks more sunlight than before the lithium ions arrived. Upping the voltage sends in more lithium, resulting in more blocked light. Reversing the voltage draws the lithium ions back out of the tungsten oxide layer, allowing more light through.

The point of all of this, Van Dine says, is twofold. Smart windows with electrochromic tinting can reduce glare, which is becoming more problematic as more liquid crystal displays and computer monitors populate workplaces. Smart windows also can help increase a building's energy efficiency through the optimal use and control of the sun's light and heat content, thereby reducing the need for artificial light, heating, and cooling.

Despite the technology's cleverness, the company's first ATP proposal was turned down. Van Dine attributes the disappointment partly to the company's youth at the time and partly to the absence of a detailed business plan, which is a key criterion in the ATP. With those issues in mind, Van Dine realized his company needed partners. Within about a year, he had found them at the nearby Center for Ceramic Research of Rutgers University, and at 3M, a Fortune 500 company based in St. Paul, Minn. 3M already had experience in specialty window film (called privacy film) that uses the same principles underlying liquid crystal displays to toggle between transparent and opaque conditions.

In the partnership, SAGE would continue to provide the cutting-edge work in electrochromic materials and technology. The Rutgers connection would provide the company with access to additional materials experts and top-notch research facilities. And 3M's experience in developing commercially feasible manufacturing processes, its marketing expertise, and its own foray into switchable film technology would increase the chances that the entire project ultimately would move across the line that separates good technology ideas from products that sell.

"It enabled us to accelerate and expand our technology development and it put our company into a better internationally competitive position."

With renewed confidence, SAGE and 3M gave the ATP a second shot in 1992. This time the news was not disappointing. The National Institute of Standards and Technology, which administers the program, and the partnership would commit a total of approximately $7.3 million over three years to preproduct research and development. The goal, Van Dine says, is to develop materials and manufacturing methods suitable for justifying the additional "tens of millions of dollars" that he estimates would still be required for product development and designing and equipping large-scale manufacturing facilities.

Van Dine says the ATP experience clearly has put his company into a better competitive position. For one thing, he says, "it enabled us to accelerate and expand our technology development and it put our company into a better internationally competitive position." SAGE added four scientists and engineers to its previous staff of six. 3M's principal scientist on the project, Jim Billigmeier, says that his company's portion of the ATP now supports six full-time scientists on the project. Ironically, Van Dine adds, the company's initial failure at winning an ATP award may have created one of the most valuable returns of all: It served as the catalyst for linking SAGE and 3M into a more powerful partnership.

The marketplace—not research and development—will administer the critical commercial test of electrochromic windows. The initial test may not be that far off. Van Dine told *Popular Science* magazine (February 1995) that tint-control windows based on his electrochromic technology could be available for sale in about two years.

NIST Industrial Impact

Company:
SDL Inc.
San Jose, California

Business:
Producer of high-power semiconductor lasers and fiber optic components

Number of Employees:
180

Company:
Xerox Corporation
Palo Alto Research Center
Palo Alto, California

Business:
Manufacturer of document processing technologies

Number of Employees:
300

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February 1994

There are few substitutes for an annual infusion of, say, $1,400,000 for 5 years to ratchet up the research and development throttle. That is what happened to SDL Inc. and the Xerox Corp. beginning in September 1992, when their joint proposal to the Advanced Technology Program (ATP) for work on visible diode lasers and optical fiber components met with approval from a review panel at NIST, which runs the program for the Department of Commerce.

In less than 2 years since the ATP award, which is designed to support development of high-risk technologies that might enhance and spawn many other technologies, SDL has had three unexpectedly near-term spin-offs—new semiconductor-based laser products with wide-ranging applications that are now on the market, says Donald R. Scifres, SDL's president and CEO. The three products are laser diodes that emit red light directly at various powers without requiring a second laser for excitation, which is usually needed for high-power lasers. The company also is pushing forward to develop laser systems that can emit green and blue light, a much tougher technical challenge that is expected to open many more technological doors.

In the nearer term, applications for the red-laser products could range from surgery and an emerging light-based tumor treatment called photodynamic therapy to new laser-based cutting tools for manufacturers to high-speed color printing. It is that last possibility that provided the original impetus for SDL to join with Xerox Corp. and give the ATP a shot, and why green and blue lasers remain at the top of the to-do list. "We want to eventually use these types of lasers in high-speed color printing operations," says Neville Connell, director of the electronic materials lab at Xerox's Palo Alto Research Center.

The semiconductor laser market is as competitive as it gets. "If you don't accelerate your development, you fall behind your competition," Scifres says. The competition is getting stiffer now as high-technology firms around the world race for some of the newest trophies in the arena of optical components—those green and blue lasers. Together with the more mature technology of red lasers, these open up paths to higher capacity communications systems, new color displays, medical tools, and many other products.

In less than 2 years since the ATP award, SDL has had three unexpectedly near-term spin-offs.

The ATP awards are supposed to smooth the path from laboratory to marketplace and to post higher speed limits along the way. The program is designed so companies can leverage their own investment and commitment to higher risk, higher payoff technologies with partial support from the government. In the case of SDL and Xerox, the ATP ideal seems to be working. Says Connell:

"We now can get where we want to go twice as quickly." Secondly, he adds, the ATP competition "provided impetus to form an alliance with SDL and Stanford University," which is also contributing to the research effort. Scifres also credits the ATP award with strengthening his company's competitive position. "We were in catch-up mode and I think we have caught up and surpassed Europe and Japan," he says.

Scifres admits that his company probably would have developed one of the recently commercialized lasers without the ATP award.

As for the other two products, "they might never have happened without the ATP award."

Progress, however, would likely have been sluggish at best. As the funding started coming through, SDL hired four new people to their staff of 180, and as orders for the spin-off products came in, they hired even more for their production lines. As for the other two products, he says "they might never have happened without the ATP award."

Moreover, the three products are pure bonus for SDL since high-power lasers for printing are in the bull's-eye for the SDL/Xerox alliance. No complaints on this score, especially because the spin-offs keep spinning. In a letter last December to NIST Director Arati Prabhakar, Scifres noted that another company was considering one of these spin-off lasers for its own products. No final word on that yet, but if an order is placed, Scifres noted in the letter, "it would represent SDL's highest volume order."

NIST Industrial Impact

Company:

X-Ray Optical Systems Inc.
Albany, New York

Business:

Start-up company specializing in lenses that focus X-rays and neutrons into beams for use in research, medical imaging and treatment, and manufacturing.

Number of Employees:

8

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If Lilliputians in the high-technology arena think big enough, they can get a shot at the big time. Just ask David Gibson, president of X-Ray Optical Systems Inc., and one of eight employees at the 3-year-old start-up in Albany, N.Y. The company is not out of the woods yet, Gibson says, but the path ahead looks downright inviting, in large part because of new types of collaborations with the federal research infrastructure.

The prime movers of the company are two physicists—David Gibson's father, Walter Gibson of the State University of New York at Albany, and Muradin Kumakhov of the I.V. Kurchatov Institute of Atomic Energy in Moscow. They had known each other for decades as professional peers and collaborators. Kumakhov and colleagues in Russia had been finding that arrays of tiny glass capillaries, when carefully bundled, seemed capable of focusing X-rays and neutrons.

Most scientists had long assumed that the ability to focus these types of radiation was a great idea that the Muse of Physics would make both irresistible and unreachable. That ability could mean everything from uniquely fine probes into the structure of matter to more powerful medical treatments to the means for making next-generation microprocessors. But lens materials mostly absorb, rather than transmit these types of radiation, and can hardly bend whatever radiation does get through.

Kumakhov made an end run around this seeming impasse. By making tiny glass capillaries with smooth interiors that bend gradually, X-rays and neutrons entering them would repeatedly graze off the walls like a stone skipping on water. When bundled, such tubes could take a diverging weakening beam of X-rays or neutrons emanating from a radiation source and redirect them into parallel beams or onto small intense spots.

Gibson senior and Kumakhov were themselves convinced that the lenses had astounding scientific and technological potential. Kumakhov and Russian colleagues had done some experiments with prototype lenses that supported the concept. To go farther at more than a snail's pace, though, they had to convince other scientists in the United States that they were onto something, and they had to find financial support for development.

That ability could mean anything and everything from uniquely fine probes into the structure of matter to more powerful medical treatments to the means for making next-generation microprocessors.

To build an organization, they recruited David Gibson, an MIT educated mechanical engineer and business manager. He knew that nothing would happen unless external backing could be gotten and that the technology was too green to attract venture capital. So in the summer of 1990 when X-Ray Optical Systems (XOS) was being incorporated, he came across an article that mentioned the then fledgling Advanced Technology Program, administered by NIST. He read carefully. "My gut told me that this was a program designed for us," he recalls. "The Kumakhov lens was a high-risk nascent technology whose commercial payoff seemed very promising but that needed further development, just the kind of thing the ATP was created to support."

In 1991, they received word that their subsequent application for an ATP award had failed. Gibson surmises that the verdict followed naturally since the company did not yet have an infrastructure and its business strategy was incomplete. But the ATP experience had primed him to other possibilities in the government. The same year, XOS applied for and won two of the Department of Energy's Small Business Innovative Research grants. The momentum has only been building since.

A crucial part of that motion began also in early 1991 when the three-man company went on a 15-stop, cross-country dog-and-pony show to government labs equipped with accelerators, industrial users of X-rays, and academicians. Though they fielded some flak for their marketing bravado, they also turned some heads, including ones at NIST.

The series of government grants and collaborations have provided XOS with access to equipment and experts tailor made to assess, develop, and validate the new technology.

One payoff came through in December 1991, when XOS signed a Cooperative Research and Development Agreement (CRADA) with NIST. The goal of the CRADA is to develop neutron lenses that could help NIST in its mission of providing ever more accurate measurement capabilities for industry while helping XOS in its commercialization mission. A few months later, the company learned that its second try for an ATP had met with success and would receive $1,900,000 from the government in its part of a cost-sharing R&D agreement, in which XOS would have to come up with $350,000 for indirect costs. In June, just as the ATP money started coming in, the company began working with NIST researchers on another project to develop lenses that could form parallel beams of X-rays. In September of 1993, XOS began work on another collaboration with NIST in which it would provide lenses to NIST researchers for real world microanalysis of samples. In exchange, XOS would learn about what was necessary for the optics to be successful in that use.

In December 1993, as a result of progress made during the CRADA, XOS shipped its first commercial lens to a very familiar customer, scientists at NIST's research reactor. It has exceeded expectations in preliminary tests, notes NIST research chemist Gregory Downing, who expects the lens to dramatically enhance NIST's analysis abilities and services as well as its collaborative efforts with other U.S. companies including Intel, CIDTEC, Westinghouse, Texas Instruments, and a consortium of companies developing synthetic diamond products.

The series of government grants and collaborations have provided XOS with access to equipment and experts tailor made to assess, develop, and validate the new technology, David Gibson says. "It has allowed us to develop applications that we would otherwise not have addressed," he adds. The ATP award and NIST technical capabilities also enabled XOS to act like a bigger company with more resources and personnel without actually having to invest in these before the technical risks were overcome. That hurdle trips up many start ups. The ATP award had an important spinoff too. When news got out that XOS had been a winner in their second ATP competition, the company was finally able to convince private investors that the risk was reasonable. The foundations for success seem to be in place, Gibson says. XOS may not be in Lilliput for long.

Manufacturing Extension Partnership Impacts

NIST Industrial Impact

Company:
Clipper Diamond Tool Co. Inc.
Long Island City, New York

Business:
Manufacturer of precision superabrasive and diamond cutting tools and grinding wheels

Number of Employees:
38

Like the gem used in its product, the future once again looks bright and shiny for the Clipper Diamond Tool Co. Inc. This was not the case 3 years ago when company founder and president Joseph Klipper realized drastic moves were needed or the 50-year-old company would have to close its doors.

But after hooking up with the NIST New York Manufacturing Extension Partnership (MEP), the company has made a dramatic turnaround, improving productivity and morale and regaining customers.

When Klipper came to the United States from Belgium in 1940, he planned to set up a small manufacturing operation to provide gems for the jewelry industry. However, with America's growing involvement in World War II, he realized that both he and his newly adopted country could benefit if the company manufactured something more utilitarian than ornamental.

He turned his expertise to developing tools using industrial-grade diamonds to shape, size, and grind metal parts used for precision machining. During the war and for the next 40 years or so, business was good for the company. Sales were brisk, and the company counted among its customers numerous manufacturers such as Pratt & Whitney, Ford, and Chrysler.

But, during the 1980s things took a downturn. Rent for the Manhattan-based company was skyrocketing, and customers were turning to competitors in Japan and Germany.

"It's a story we hear quite a lot," says Phil Massaro, a field engineer with the New York MEP Industrial Technology Assistance Corp. (ITAC). "Mr. Klipper and others in the company recognized they were behind the times, that the company had stagnated, but they were not quite sure what steps to take to modernize."

After hooking up with the NIST New York Manufacturing Extension Partnership, the company has made a dramatic turnaround, improving productivity and morale and regaining customers.

Massaro worked with Klipper, company vice-president Steve Grossman, and others to find a wide range of city and state grant programs to help the company upgrade and modernize its operations. Most of the grants were matched with company funds, says Massaro.

For example, he says, "We worked with them to access a program offered by New York City that will help offset costs of moving if a company relocates within the city." Moving to a new facility in Queens not only reduced rent costs but set the stage for the next step, a total reorganization.

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June 1994

With the expert advice of Les James, an engineering consultant hired with New York MEP's assistance, a new modern layout was designed and the company began to automate both its manufacturing and office operations. "For example, we installed computer-aided design and manufacturing equipment and an automated accounting and inventory control system. Clipper employees now can electronically transfer drawings directly to customers, and soon, customers will have direct access to other data, such as information concerning purchase orders and invoices," says James.

Also, with New York state grants facilitated by ITAC, James set up employee training programs in subjects such as statistical process control, quality management, and English-As-a-Second-Language.

"Our company has been revitalized," says Klipper. "We are once again able to compete both here in the United States and around the world."

The changes have resulted in marked improvements. For example, just 6 months after implementing a quality improvement program, Clipper earned Ford Motor Co.'s Q-101 rating—its highest quality ranking for vendors.

Statistics down the line look good: For 1992 and 1993, productivity was up 3 to 4 percent. Ninety-eight percent of all orders are sent out within 2 weeks, up from 90 percent. Cycle time for some products has been shortened to 7 days. Prior to the improvements, the shortest cycle time was 28 days. In addition, the number of orders leaving the factory on time has improved by 20 percent. The company currently exports 15 to 20 percent of its products to Europe, South America, Israel, and Mexico and hopes to increase that number as well. "The task before us now is to capture the opportunity for growth that the renewed market interest has offered," says Grossman.

"Our company has been revitalized," says Klipper. "We are once again able to compete both here in the United States and around the world. If it had not been for this help, Clipper Diamond Tool would not be around today," he says.

NIST Industrial Impact

Company:

Dee Inc.
Crookston, Minnesota

Business

Aluminum foundry and machining company

Number of Employees:

185

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August 1994

As an aluminum foundry and machining company, Dee Inc. makes parts for snowmobiles, personal watercraft, oil and air filtration equipment, and other products. The company employs 185 and has annual sales of more than $8 million.

Even though Dee Inc. increased sales between 1991 and 1992, the company wasn't seeing a corresponding relationship in profitability, according to company President Jim Ellinger. At the same time, Dee recognized the need to emphasize process controls beyond meeting its shipping goals.

Dee manufactures aluminum-alloy, sand- and permanent-mold castings. In addition, Dee offers machining and engineering services, which account for almost one-third of sales. Some of Dee's products ultimately are used by John Deere, Caterpillar and Ford—companies that, as part of their quality improvement processes, have set stringent standards for their suppliers to meet.

"That got us to look at what being a qualified supplier really means," Ellinger says. Dee decided it needed more control over its processes and requested a needs analysis by the NIST Upper Midwest Manufacturing Technology Center (UMMTC), managed by Minnesota Technology. The review provided an operational "snapshot" of Dee and pointed to some steps the company might take to improve things.

As a result, UMMTC assisted Dee in choosing and buying manufacturing software and management information system (MIS) software and hardware, in establishing a cost-based pricing system, and in securing the services of a metallurgist to help the company refine its foundry processes.

The most important step Dee took, Ellinger says, was to initiate a "Total Quality" philosophy stressing employee empowerment. Dee had discovered that its decision making was top-down. "That's not the future," Ellinger says. "So we embarked on a path to see that trend reversed."

Dee decided it needed more control over its processes and requested a needs analysis by the NIST Upper Midwest Manufacturing Technology Center (UMMTC).

Through the UMMTC, Dee found a facilitator to conduct on-site employee training to open up lines of communication. As a result, "we saw the evolution of the team approach," Ellinger says. It's an approach that Dee successfully tested when it implemented a management information system.

"If our people are going to be empowered to set goals and standards, they're definitely going to need information," Ellinger says. So Dee bought bar-coding hardware and software that provides "real-time" information on what's happening in the plant. More importantly, Ellinger says, "the people that selected the new (system) are the people using it."

As a result of employee involvement, "worker frustration has notably diminished," Ellinger says. "We're also seeing increased efficiency and reduced scrap."

Of the NIST center's role, Ellinger says, "They bolstered the knowledge we already had. They also helped us in terms of technical expertise, in finding a facilitator, and in finding a metallurgical engineer. They

"... The NIST center provided an outside opinion as to our weaknesses and strengths... ."

provided an outside opinion as to our weaknesses and strengths, which offered a reinforcement for directions we were interested in taking."

As a result of its improvements, Dee's sales have increased and the company is developing new markets. In addition, the company has reduced both foundry and machining set-up times. Ellinger says the company is now achieving the type of profitability it needs to stay competitive for the future. Subsequently, employment has increased from an average of 103 in 1991, to 169 in 1992. Most importantly, Ellinger says, Dee is more competitive. "If you're more efficient and make a more value-added product, your potential for gaining more market share increases."

NIST Industrial Impact

Company:
Dyna Mow, Inc.
Cushing, Oklahoma

Business:
Manufacturer of commercial lawn mowers

Number of Employees:
16

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March 1995

When Ronald and Jean Good purchased T&M Technologies in 1993, they took a risky move from being oil-field service entrepreneurs to manufacturers of a commercial lawn mower used in the landscaping industry. The company, since renamed Dyna Mow, Inc., had a winning product—but was in organizational chaos.

After tapping into the resources of the NIST Oklahoma Alliance for Manufacturing Excellence, Inc., the Goods were able to turn the company into a rapidly growing business that is making a name for itself worldwide and is spinning off other businesses to support it.

Before buying Dyna Mow, located in Cushing—halfway between Tulsa and Oklahoma City, the Goods had owned a number of other businesses, mainly in the oil-field service industry. Dyna Mow, however, is their first experience running a manufacturing company.

Ronald Good knew the inventor of the mower, a low-maintenance, all-hydraulic riding mower model controlled by a single joystick. After a three-hour test, Good was convinced that the hard-working device had market potential, and over time decided to purchase the company. "When we took over, the internal paperwork was a shambles—they didn't really know how much it cost to manufacture each mower," Good says.

Knowing they needed help, the Goods contacted the Oklahoma Department of Commerce and the Oklahoma Department of Vo-tech. A meeting was arranged that included Sandy Conner, broker/agent for the Oklahoma Alliance for Manufacturing Excellence.

Unlike many of the centers affiliated with the NIST Manufacturing Extension Partnership, the Alliance is independent of the state's higher education system and other state agencies, says Edmund Farrell, the organization's executive director.

After tapping into the resources of the NIST Oklahoma Alliance for Manufacturing Excellence, Inc., the Goods were able to turn the company into a rapidly growing business... .

The Alliance's network of broker/agents work directly with companies to help them identify consultants and other resources in both the public and private sectors to solve their problems. The manufacturers pay the Alliance no fee for its services but have to pay the private consultants for theirs.

"The help I provided the Goods was multidimensional," says Conner. The new owners requested marketing assistance, help with plant layout and process design, help in locating a larger building, help in finding new technologies to use in their mowers, and even help in modernizing the firm's computer system. In all cases, the Goods were put in touch with consultants—such as industrial engineers and marketing and finance experts—who were able to help in specific areas.

One result of this help is that the city of Cushing is in the process of constructing a 2,789 square-meter (30,000-square-foot) building that Dyna Mow will lease-to-buy as a replacement for its existing 1,486 square-meter (16,000-square-foot) plant. That plant, a former truck line service building, has become increasingly cramped as production of mowers grew from about 20 a year in 1993 to 120 a year by the end of 1994. Last November the company celebrated the shipping of its 100th machine in 1994.

The Alliance continues to help Dyna Mow, Conner says. Most recently, the Alliance assisted them in getting a U.S. General Services Administration listing as an approved supplier.

Without the help provided by the Alliance, the success of Dyna Mow would not have been possible.

Good is proud that since he took over the company, it has launched a second mower line and is about to begin producing a third, smaller line. Sales are booming, and employment has gone from six to 16—and is expected to double again as orders continue to increase.

"We have dealers talking to us about ordering 100 at a time," says Good. "And three major mower manufacturers have approached us to do private label manufacturing for them." In addition, Dyna Mow has been able to break into the European market and recently shipped several mowers to customers in Israel.

The success of Dyna Mow is breeding success for other small firms in Oklahoma. Two of the company's original employees left, with Good's help, to start up shops to build the metal frames and fiberglass bodies for Dyna Mow products. Other parts manufacture has been farmed out to small manufacturers and job shops in the region, he says.

"It's been tough, but it's turning around," says Good. Without the help provided by the Alliance, the success of Dyna Mow would not have been possible, he says.

NIST Industrial Impact

Company:

HJE Co. Inc.
Watervliet, New York

Business:

Manufacturer of gas atomization systems and metal powders

Number of Employees:

4

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June 1994

As one of only four companies of its kind in the world, and the only one in the United States, HJE Co. Inc. is a big fish in a very, very small pond. And company president Joe Strauss likes it that way.

Strauss's company manufactures gas atomization systems specially designed to produce ultrafine metal powders from molten metal. These powders are used, for example, in solder and braze pastes and dental alloys. The particles also are used to coat base metal such as jet turbine blades. HJE also produces and sells the metal powders.

HJE is now a thriving business with sales in the United States, Europe, Asia, and the Middle East. But it started almost as a hobby, says Strauss, and may not have developed at all without some assistance from the NIST New York Manufacturing Extension Partnership (MEP).

A materials engineer with a Ph.D. from Rensselaer Polytechnic Institute, Strauss first seriously considered the gas atomization technology as a money-making venture after attending a seminar in 1987 and realizing that no one was commercializing it. "Many people, including myself, were interested in the 'gee whiz' aspect of turning liquid metal into a powder as fine as talcum powder. But very few people were manufacturing equipment that could do this or exploring ways to use the powder," says Strauss.

Although still a student at the time, the idea stuck and eventually Strauss started designing equipment to produce very fine powder. In particular, he had an idea for a special nozzle design that can handle high temperatures and a very reliable control system.

But he was having difficulty translating what was in his head to mechanical drawings that could be understood by a parts manufacturer. "I was spending lots of time, money, and energy and still not getting it quite right," he says.

What he found was a gold mine of manufacturing equipment, ideas, and expertise.

After struggling for several months, he eventually heard about the NIST New York MEP. "I wasn't quite sure what they had to offer and, to be honest, if I had found a good drafting shop along the way I probably never would have made it to their door," says Strauss.

But he did, and what he found was a gold mine of manufacturing equipment, ideas, and expertise. "I was like a kid in a candy store," says Strauss.

The NIST New York MEP and its Manufacturing Technology Resource Facility (MTRF) provided Strauss the opportunity to learn about modern manufacturing technology, explore "hands-on" a variety of computer-aided design and manufacturing equipment and software, and get tips from experts. "When Joe first came to us he had lots of good ideas and some sketches and rough drawings," says Sam

Chiappone, manager of the MTRF. "But he did not have the basic set of blueprints that he needed to get parts machined," he says.

Chiappone and others at the MTRF did more than help Strauss figure out how to design the equipment he needed. "They also made sure that what I was designing was practical to manufacture and helped me find machine shops to make the parts," says Strauss.

Strauss spent about 6 months at the MTRF and eventually purchased his own computer-aided design and manufacturing equipment and software. "The people at the MTRF were extremely helpful and patient," he says. "With the information I gained I was able to dramatically streamline my operations and improve the quality of my product as well."

"The people at the MTRF were extremely helpful and patient," he says. "With the information I gained I was able to dramatically streamline my operations and improve the quality of my product as well."

Strauss still occasionally seeks some guidance and vice versa. "They often call on me when they need a materials expert," says Strauss.

Today, Strauss is looking for a larger facility and is trying to market his gas atomization technique to a new industry—jewelry manufacturing. "They are not comfortable, yet, using a powder to make jewelry, but I'm working on it," says Strauss. And, if he does decide to jump into a larger pond and needs some assistance, he knows he can turn to the NIST New York Manufacturing Extension Partnership.

NIST Industrial Impact

Company:
Spartanburg Steel Products Inc.
Spartanburg, South Carolina

Business:
Manufacturer of stamped metal parts

Number of Employees:
600

Company:
Coastal Technologies Inc.
Varnville, South Carolina

Business:
Manufacturer of mist eliminators

Number of Employees:
15

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March 1994

Through the NIST Southeast Manufacturing Technology Center (MTC), manufacturers of products ranging from fishing rods and baseboard heaters to parts for cars and pressure vessels for geothermal power plants are taking advantage of computer-aided techniques that can speed product design and development.

One satisfied customer is the engineering department at Spartanburg Steel Products Inc., a South Carolina supplier of stamped automobile parts that employs about 600 people. With a technical assist from the Southeast MTC's Computer-Aided Design Laboratory, Spartanburg Steel successfully responded to a challenge by one of its major customers and thereby strengthened their relationship.

Specifically, Spartanburg Steel faced the task of developing a lighter, lower-cost alternative to the metal brace used to secure the dashboard to the frame of an automobile made by the customer. The company developed a new design, but, then, its engineers hit a snag: Because of the part's complex geometry, conventional, manual methods of stress analysis were not a practical, cost-effective option for determining whether the design would satisfy the load conditions and other structural-integrity requirements specified by the customer.

A possible solution emerged when Spartanburg Steel engineers attended a "CEO breakfast" on predictive engineering technology, which was arranged by the Greenville Technical College, an affiliate of the Columbia-based Southeast MTC. Recognizing that the technology might serve its needs, the company requested an in-depth seminar on a particular technique, known as finite-element analysis.

Presented with the challenge facing the company's engineers, senior specialists from the Southeast MTC proposed a computer-based approach that could be used to conduct the essential stress and weight analyses. Using the center's coordinate measuring machine, the specialists measured 10,000 different points on the surface of the part supplied by Spartanburg Steel. The digital data were used to create a graphic model, permitting reliable simulations of stress tests with the finite-element-analysis technique. The analysis of the new design revealed the distribution of stresses over the surface of the part.

With a technical assist from the Southeast MTC's Computer-Aided Design Laboratory, the company successfully responded to a challenge by one of its major customers.

The findings confirmed that a part based on the new design, which would reduce the weight of the brace by nearly a pound, would satisfy the customer's structural requirements.

Now in full production, the part is being used daily in a popular, high-volume vehicle.

Curtis Rhodes, one of the Southeast MTC specialists who worked with Spartanburg Steel, says that finite-element analysis is a valuable tool for evaluating designs. But, he adds, most small and medium-sized companies cannot justify investing in the technology and in training a staff member to apply it.

"Companies will have only an occasional need for finite-element analysis," Rhodes explains. "When you need the technology, it's more efficient to go outside the company and acquire this capability as a service."

Most small and medium-sized companies cannot justify investing in the technology and in training a staff member to apply it.

Rhodes and his colleagues have a steady stream of customers who are doing just that. For example, Coastal Technologies, of Varnville, S.C., recently used the Southeast MTC's service during the design phase of an ongoing project to build a 40-foot-tall pressure vessel, or cyclone separator, that will be packaged with one of Coastal's mist eliminators, the company's main product. When completed, the equipment will be supplied to a Japanese construction company building a geothermal power plant in Asia. It will be used to remove potentially destructive particles from underground steam that will drive the plant's turbines.

Harry Wechsler, president of the 15-employee firm, explains that, because of an unusual feature specified by the customer and unaddressed by engineering codes, Coastal was required to do a thorough mechanical analysis of the design. "We didn't have the resources—hardware, software, or expertise—but we knew the MTC did," he says, noting that Coastal has used the center's services on several occasions. "Our relationship with the MTC has been very beneficial. We make use of them whenever we think they can help us."

NIST Industrial Impact

Company:
Thomson Berry Farms
Duluth, Minnesota

Business:
Manufacturer of jams, syrups, dressings, and vinegars

Number of Employees:
20

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February 1994

In less than 2 years, the business outlook for Thomson Berry Farms, a Duluth, Minn., manufacturer of jams, syrups, dressings, and vinegars, has changed from glum to glowing. A 50-percent increase in productivity and an anticipated 100-percent increase in sales can lead to that kind of transformation.

And, in turn, a boom in business can save jobs. To keep up with increasing demand, Thomson's management has retained all 20 positions in the company.

Some of the credit for the change in fortune goes to the NIST Upper Midwest Manufacturing Technology Center (MTC), which linked Thomson Berry Farms with the manufacturing expertise it needed and then served as technical adviser as the company revamped its processing operations.

Thomson's new management, which took over the company in 1992, recognized market opportunities for the company's specialty products, but it lacked experience in automated manufacturing. "My background is wholesale and retail food distribution," explains Paul Leonidas, Thomson's chairman and chief executive officer. "The only thing I knew about jam was that you put it on your toast in the morning."

By hooking up with a regional office of the Upper Midwest MTC, Thomson's management remedied this shortcoming. Using the services of an engineering consultant secured with the assistance of the MTC, the small company began to automate manual processes that drove up production costs and, in effect, were forcing Thomson to price its products out of the market. The engineering consultant designed a new plant layout, helped the company draft equipment specifications, and then located sources of that equipment.

"Our changes allowed us to cut our labor costs in half," without eliminating any jobs, explains Leonidas.

The answers to Thomson's manufacturing needs already existed—in the form of used equipment. For an investment of $32,000, the company secured jar-cooling equipment, conveyers, and a filling machine, all of which were incorporated into the new plant layout. The company estimates that, within a year, waste reduction and other cost savings will pay for the entire investment.

"Our changes allowed us to cut our labor costs in half," without eliminating any jobs, explains Leonidas. "They also helped us go out and seek more business. We have almost quadrupled the production capabilities of the plant"—to more than 3.5 million units a year.

"Plant improvements, together with tighter controls, have turned our company—in 1 year—into a profitable enterprise," he says.

In the year since it was established in August 1992, the Upper Midwest MTC, which is based in Minneapolis, provided services to nearly 1,100 small and medium-sized manufacturers. Though the center's principal customers are firms in the computer, machinery, metal fabrication, and plastics and composites industries, the MTC serves a diverse clientele as the interaction with Thomson Berry Farms attests. And like Thomson, the vast majority (more than 80 percent) of Minnesota's 8,700 manufacturers employ fewer than 50 people.

"Small businesses like ours need the kind of help you [MTCs] provide," says Leonidas, "because we don't have the resources of the larger companies."

"Small businesses like ours need the kind of help you [MTCs] provide," says Leonidas, "because we don't have the resources of the larger companies."

Laboratory Impacts

NIST Industrial Impact

Industry:

Air-Conditioning and Refrigeration Institute
Arlington, Virginia

Business:

Designing, manufacturing, installing, and maintaining residential and industrial cooling and refrigeration equipment

Size:

$20 billion in shipments

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July 1994

In 1937, before a rapt crowd at a meeting of the American Chemical Society, Thomas Midgely, Jr., filled his lungs with vapors of dichlorofluoromethane, the world's first chlorofluorocarbon (CFC)-based refrigerant, and then extinguished a candle as he exhaled. He convinced the audience that this chemical, which he had come up with 7 years earlier at the Dayton Engineering Laboratories Co. (Delco), was neither flammable nor toxic. Had he tried the stunt with the standard refrigerants of the day—ammonia, methyl chloride, and sulfur dioxide—the outcome ultimately would have included some mix of choking, fire, burns, cancer, and death.

CFCs, which became well known under the DuPont trade name Freon, quickly grew into a massive commodity chemical used not only for refrigeration but also for industrial solvents and foaming agents for insulation, cushions, and packing material. When he died in 1944, Midgely had no idea that CFCs already had begun wending their way into the upper atmosphere where they were initiating the destruction of stratospheric ozone molecules, which shield life from dangerous ultraviolet portions of solar radiation. Nor did he know that four decades later the industrial world would agree to cease producing CFCs altogether by 1996 in an effort to stave off the ozone kill.

That dramatic multinational agreement has forced a number of CFC-dependent industries to enter an innovate-for-your-life phase in which they need to come up with CFC substitutes if they expect to remain in business in the next millennium. One of those industries is represented by the Air-Conditioning and Refrigeration Institute (ARI). "We had been using CFCs forever, and now we have to get rid of them on short order," says Mark Menzer, vice president of research and technology for ARI, noting that researchers at the National Institute of Standards and Technology (NIST) are playing a critical supportive role in this transition.

Researchers at NIST are playing a critical supportive role in this transition.

The challenge resides in the chemical virtuosity of CFCs, save for that fatal flaw of destroying stratospheric ozone molecules. Before that revelation, CFCs were wonder chemicals—safe, non-toxic, stable, easy to handle, inexpensive, and useful in many ways, including refrigeration. The refrigeration value resides in their ability to undergo countless cycles of volumetric expansion into a gaseous state—during which the CFC gas draws heat from its surroundings such as a refrigerator's interior—and condensation, during which a compressor forces the refrigerant back into the liquid state ready for the next cycle.

Any CFC replacement must come close to matching CFC's virtues while lacking its vices. "We have not found any drop-in replacements" that can simply take the place of CFCs like one cola for another, Menzer says. HCFCs, in which hydrogen atoms replace one or more of the chlorine atoms in CFCs, are excellent refrigerants but are not a long-term solution since they too can destroy ozone molecules; by 2010 at the latest, HCFCs also will be off limits in new equipment.

That has pushed air conditioning and refrigeration companies to look toward more complicated refrigerants, including blends of two or more components, an exercise that entails redesigning new cooling and refrigeration systems and testing blends for a long list of physical properties. "We knew we would need data, high-quality data, since small design errors based on the data can lead to big miscalculations" about a cooling unit's efficiency and cost, Menzer explains. Multiply each cooling unit by the many thousands that would be sold and the importance of good engineering data magnifies. That is where data generated and compiled by NIST researchers into a user-friendly personal computer program, called REFPROP, have been coming into the picture of ARI's members. "We have used NIST data and the REFPROP program as the standard," Menzer says.

"Without NIST, we would have gotten less detailed data, which would have meant a lot more expensive, time-consuming engineering work to produce hardware. It would have cost us millions more."

Soon after the 1987 signing of the Montreal Protocol, which provides for the phaseout of CFCs by 1996, researchers at NIST began a major effort to measure thermophysical properties of individual environmentally acceptable refrigerants and mixtures involving up to five components. Accurate information about these properties is critical for engineers who aim to design the most energy-efficient air conditioning and refrigeration systems.

"We have used this information for making important decisions," Menzer says. It has helped companies quickly zero in on blends worth testing in their engineering labs. "Without NIST, we would have gotten less detailed data, which would have meant a lot more expensive, time-consuming engineering work to produce hardware. It would have cost us millions more." Moreover, he adds, without NIST and REFPROP serving as a common source of data for the industry, each company probably would eventually make different choices about refrigerants, a scenario that would lead to a technical Tower of Babel for the maintenance and repair community. NIST has sold over 500 copies of REFPROP, whose latest version includes data for 38 refrigerants and many of their mixtures.

In a letter to R.F. Kayser, chief of the NIST Thermophysics Division, Donald Bivens, an engineering fellow in DuPont's Fluorochemicals Laboratory, echoed Menzer's assessment of NIST's contribution. "All of this work by NIST has permitted the U.S. refrigeration and air conditioning industry to accurately design equipment for the alternative fluorocarbons, resulting in efficient operations."

NIST Industrial Impact

Companies:

Amersham/MediPhysics, Illinois
Bristol-Myers Squibb, New Jersey
Du Pont Merck Pharmaceutical, Massachusetts
Mallinckrodt Medical, Missouri
Nordion International, Ontario, Canada
Packard Instruments, Illinois
Syncor International, California

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April 1994

Inventing ways to see inside bodies without cutting into them is one of the medical community's shining successes. Radioactive isotopes that can be injected safely into patients' bloodstreams and tissues get a lot of credit for that success. These so-called radiopharmaceuticals work like transient spies sending diagnostic signals from inside the body to external detectors and computers, which construct images of internal body structures from those signals. Like good spies too, the isotopes quickly disappear once their job is done, either by transforming into non-radioactive products or by passing out of the body.

If they know precisely how much radioactivity each dose harbors, doctors can confidently inject patients with radioactive drugs such as thallium-201 for heart scans. Determining the exact amount of radioactivity is an especially demanding measurement task, however, since radioactive isotopes are produced at private or government facilities, made into radiopharmaceutical preparations by a number of different companies, and then put to diagnostic use at thousands of hospitals. All the while, the radioactivity contents to be measured are changing. Unlike the weight of a pill, which remains constant from maker to patient, the activity of radiopharmaceuticals continually decreases over time.

Regardless of the challenges, each radiopharmaceutical handler must have a way of assuring that their own radioactivity measurements are accurate. Nuclear Regulatory Commission rules, for one, require such measurements. Good business and good medicine also critically depend on the quality of these measurements.

Assurance of that quality stems from the National Institute of Standards and Technology, remarks Tibor Schubert, manager of radiodiagnostics at Bristol-Myers Squibb. For the past 20 years, NIST and the Nuclear Energy Institute (formerly the United States Council for Energy Awareness), which represents the nuclear power and nuclear medicine industries, have collaborated to provide the industry with standards that everyone can use as benchmarks. "It helps make sure that everyone is on the same wavelength," says Schubert, who chairs a NIST/NEI steering group that sets the agenda for the collaboration. "It increases the confidence for everybody" who makes and uses radiopharmaceuticals, adds Michael S. Mosley, a quality control and government affairs specialist at Syncor International Corp., the country's fastest growing "nuclear pharmacy."

"It increases the confidence for everybody" who makes and uses radiopharmaceuticals.

That confidence level has contributed to the ascent of radiopharmaceuticals both as a standard part of medical practice and as big business, say Schubert, Mosley, and others in the industry. Each year, U.S. doctors perform over 7 million diagnostic procedures using radiopharmaceuticals. About one out of every four patients entering hospitals undergoes some form of radioactive diagnostic or therapeutic procedure. Many cardiac patients undergo the thallium-201 stress test, which allows doctors to image the damaged heart for guidance in treating heart patients. The market for radiopharmaceutical preparations now approaches $1 billion.

When the NIST/NEI collaboration began in 1973, there were no standards for three out of four radiopharmaceuticals then available, nor were there uniformly adopted protocols by which instruments in different places were calibrated even when standards were available. These and other measurement problems slowed Food and Drug Administration approval of new drugs and led to disputes between vendors and buyers of radiopharmaceuticals since prices are determined not by weight but by the amount of radioactivity sold.

"Participation in the program and having radiopharmaceuticals [whose activities are] traceable to NIST standards gives member companies a competitive advantage."

Out of the collaboration so far have come more than two dozen new Standard Reference Materials (SRMs), which are distributed as small sealed ampoules containing specific radiopharmaceuticals with NIST-certified amounts of radioactivity. Vendors and buyers use these to calibrate their own measurements. Among these SRMs, which are prepared and certified by three scientists at NIST who are supported by a fee paid by member companies, are standards for thallium-201; iodine-131, an agent for diagnosing and treating thyroid problems; and technetium-99m, which is used in procedures such as imaging brain tissue.

Besides the collaboration's intangible payoff in the form of product and industry confidence, the NIST-made SRMs have a more direct impact on companies' bottom lines. "If a company went out and developed these on its own, you are talking maybe $1 million," estimates Felix Killar, manager of Non-Utility Programs for NEI. "Participation in the program and having radiopharmaceuticals [whose activities are] traceable to NIST standards gives member companies a competitive advantage."

NIST Industrial Impact

Company:

Analogy Inc.
Beaverton, Oregon

Business:

Makers of simulation software tools for designers of electronic circuitry

Number of Employees:

120 worldwide

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May 1994

Using tools to make better tools has been standard practice since Paleolithic times. Now, engineers even use the silicon-based brains of computers as simulation tools for designing next-generation silicon chips, a practice that streamlines the costly trial-and-error cycle of making, testing, and redesigning actual prototypes. Problem: Simulation has yet to play a major role in the growing niche of "power electronics," which control voltages and currents in millions of appliance motors, automotive ignition systems, and electric vehicles that are often millions of times higher than the voltages and currents in integrated circuits.

That design limitation is in the midst of becoming history. A chain of events that began with a chance 1989 meeting between Allen Hefner, an electrical engineer at the National Institute of Standards and Technology, and Daniel Diebolt of Analogy Inc., an Oregon software company, led to new simulation tools that already are changing the way Motorola makes some of its electrical products and the way Ford Motor Co. makes cars. These tools are helping to bring power electronics technologies to larger U.S. markets and are putting the United States in a better competitive position in the global power electronics market, says Dan Artusi, director of operations for power transistors at Motorola's Power Products Division in Phoenix, Ariz.

One of the obstacles has been that power electronics are more difficult to simulate than standard microelectronics because the physics describing their operation is more complicated. That is partly because they generate much more heat, which in turn affects the electrical behavior of their components, notes Peter Decher, Analogy's director of modeling. Without reliable simulation tools, makers and users of power electronics have had no recourse but to make actual devices, test them, and then redesign them based on the test results—an expensive and uncertain process that

These tools are helping to bring power electronics technologies to larger U.S. markets and are putting the United States in a better competitive position... .

has limited the power electronics market. It also has meant that the power electronics now in use are not controlling the motors, engines, and other downstream components as well as they could.

The 5-year-old NIST/Analogy collaboration seems to be smoothing the way for power electronics. It began at a technical conference of electrical engineers where Diebolt heard Hefner give a talk on power electronics focusing on an important, relatively new component called an Insulated Gate Bipolar Transistor (IGBT). It struck a chord. Earlier, engineers working on ignition systems at Ford Motor Co. had told engineers at Motorola that new generations of semiconductor power electronics would be more than welcome since they could lead to cars that burned fuel more efficiently. That message naturally ended up reaching Analogy, since its Saber simulator, a software tool which is used mostly by large corporate chip designers, often was central to the design of Motorola's electronic systems.

Within months, Analogy and NIST drew up a Cooperative Research and Development Agreement. By the end of 1989, their collaboration had yielded a preliminary computer model that would clearly work as part of an upgraded Saber simulator. By mid-1991, the model had proven itself in principle for a variety of circuit design applications. Before the year was up, Alan Mantooth, a senior engineer at Analogy, had further developed the model to the point that the company could include it in its commercial simulation packages. In Hefner's words, "He bullet-proofed it in the Saber context," and it has become a standard part of the commercial program. Adds Decher: "We view this as a strategic collaboration, and we want to continue down this path."

The initial commercial payoff of the work was an upgrade in 1992 of Saber, Analogy's bread-and-butter simulation package. Now, in addition

By the end of 1989, the NIST/Analogy collaboration had yielded a preliminary computer model that would clearly work as part of an upgraded Saber simulator.

to simulating standard integrated circuits with low-voltage, low-current components, Saber incorporates an IGBT model. At the same time in 1992, Motorola, whose engineers used the Saber IGBT model, announced a new generation of automotive ignition coils that rely on an IGBT to control the electrical pulses going to a car's spark plugs. One good thing leads to another. In February 1994, Ford Motor Co. announced plans to use Motorola's IGBTs in ignition systems during the 1995 model year.

As Artusi sees it, that is just the beginning for Motorola. "We intend to establish a strong capability in power semiconductors in the United States," he says, adding that such technologies will be a key to higher efficiency machinery, appliances, lamps, and vehicles. That would cascade into the additional benefits of reduced energy needs and less pollution production. He credits Hefner's IGBT model as a springboard for such visions.

There's more than handwaving for arguing that such visions could become reality. In August 1993, Motorola's Semiconductor Products Sector and Analogy signed a $3 million, 3-year pact whose goal is something that Artusi calls "virtual prototyping." More specifically, the two companies aim to produce simulations of IGBT-based devices, which it will send to clients such as car companies who plug the models into their own simulated products to get an idea of how an actual power electronic component will behave. "This will allow customers to do a first-pass design very quickly, determine if the characteristics of the initial [modeled] device are correct, and give us high-quality feedback," Artusi told the trade publication *Electronic Engineering Times*.

Hefner is pleased by the steam that industry is getting out of his work. He also supplies free versions of the model that academic researchers can plug into SPICE (Simulation Program with Integrated Circuit Emphasis)—software developed in the early 1970s at the University of California at Berkeley—that has become a standard for simulating integrated circuits. As Hefner sees it, the more you increase the number of people thinking about power electronics the more innovation is bound to happen.

NIST Industrial Impact

Company:

The Automotive Composites Consortium:

Ford Motor Company
Dearborn, Michigan
General Motors Corporation
Detroit, Michigan
Chrysler Corporation
Highland Park, Michigan

Business:

Automotive manufacturers

Number of Employees:

Approximately 1,240,000

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March 1994

Pressure to substitute traditional materials with others that are cheaper, stronger, lighter, or better by some measure than the originals is a fundamental driver of technological change and adaptation. The risks and rewards are largest for industries like the car industry, which rely on vast amounts of materials.

The availability of inexpensive steel early in this century made mass production of cars more technologically and economically sensible. "It replaced wood in auto bodies and enabled [the car industry] to make larger, more reliable, higher performance products," says Carl Johnson, a product engineer at Ford's Scientific Research Laboratory in Dearborn, Mich. In 1991, the automotive industry used 10 million tons of steel.

The material virtues of strength, durability, and manufacturability that have made steel so critical to car makers may no longer be enough to offset a drawback—its heaviness—that has become a critical liability in today's ever more environmentally minded context. Every extra pound in a car translates into higher fuel consumption and pollution output. The search is on for lightweight, environmentally sound substitutes that can be integrated into the manufacturing process and provide the necessary strength, crash worthiness, and durability.

Composites, which are combinations of two different materials that each contribute desirable traits normally not found combined in any one material, are a leading candidate for substitution. That is why the big three automakers—Ford, General Motors, and Chrysler—joined forces in 1988 to form the Automotive Composites Consortium (ACC) and sought the assistance of the National Institute of Standards and Technology with their efforts.

Composites have a long history. One of the earliest examples still in use—straw mixed into a mud base—yields a building material that is stronger and more crack resistant than mud alone. The higher tech automotive composites now being developed through the ACC are made from polymers such as urethanes (the mud) and glass fibers (the straw), which are either pressed into random mats like the filters of home heating furnaces or woven or braided into fabric-like mats. Experimental

That is why the big three automakers—Ford, General Motors, and Chrysler—joined forces in 1988 to form the Automotive Composites Consortium and sought the assistance of the National Institute of Standards and Technology with their efforts.

composite parts weigh up to 40 percent less than their steel counterparts and could shave hundreds of pounds from each car.

The challenge for the ACC (in 1992 the ACC became part of US CAR, a broader based private-sector/government program with the goal of producing high-quality, high-efficiency cars) is to develop a practical, affordable composite technology that can meet some of the most demanding manufacturing specifications on the planet. For example, "the front rail of the car holds the engine up, takes all road loads, and must handle the crash energy" to meet specifications, points out Elio Eusebi, head of the polymers department at General Motors Research and Development Center in Warren, Mich.

The composite-forming method most likely to end up on production lines probably will go something like this: A fiber mat is placed into a two-part, heatable mold, which is then shut, imposing the shape of the car component onto the dry mat. Liquid resin, polymerization agents, and other ingredients then are injected or drawn into the closed mold where they permeate the mat like water through a dry sponge. The high temperature in the mold initiates a chemical curing process resulting in a fiber-reinforced polymeric part in the desired shape. All this has to take place reliably and nearly flawlessly in a matter of seconds. "I don't want to build a mold and discover that I can't get resin into the corner," Eusebi says.

"NIST has saved us the entire expense and time required to make accurate models, which is several man-years of work."

He, Johnson, and others working in the consortium say that the way to preempt the time and expense of that kind of unwelcome surprise is to create computer models that engineers can use to predict how variations in a part's shape and size will affect the composite-making process. The models ought to give engineers the power to quickly modify the process for each part, rather than having to go through a trial-and-error process each and every time to determine processing details such as how fast the liquid resin ought to be injected or what kind of fiber mat to use.

That's where researchers at NIST are making unique contributions to the composite R&D project, say industry consortium participants. Frederick Phelan, who was hired at NIST soon after the ACC began, has been developing computer models that predict critical process conditions such as how quickly liquid resin will flow into fiber mats in various shapes and the pressure generated during injection. To ensure that the models are realistic, Phelan's colleague, Richard Parnas, has developed protocols and materials, such as standardized fiber mats, that he and ACC members can use to measure the permeability into fiber mats under different conditions. "Without experimental permeability data, everything is hypothetical," Johnson says.

Though industry insiders are optimistic about composites, no one yet can say just how extensively the materials might substitute for steel. At the moment, the composites remain too expensive to design and manufacture. Also, their properties are still not understood with enough confidence, and recycling issues need to be resolved. NIST is helping with these problems, say industry researchers, by leveraging company research to demystify the material. "It is extending what we can do," says Douglas Denton at Chrysler's Materials Engineering facility in Auburn Hill, Mich. Adds GM's Eusebi: "NIST has saved us the entire expense and time required to make accurate models, which is several man-years of work." With input from all of this effort, it is likely that historical industrial decisions about millions of tons of steel and resin and about automotive design will be made.

Postscript: Aerospace companies, including Grumman and Boeing, which also see a future for strong, lightweight composites as substitute materials for heavier metallic alloys, have initiated collaborations with the same composites experts at NIST. The same kind of process understanding and predictive abilities that the ACC needs to make composites work in the automotive context is an absolute requirement in the aeronautics context, notes Lyle Schwartz, director of NIST's Materials Science and Engineering Laboratory.

NIST Industrial Impact

Company:

CEM Corporation
Matthews, North Carolina

Business:

Manufacturer of microwave-based analytical instrumentation

Number of Employees:

130

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February 1994

By the late 1970s, the CEM Corp. had begun earning a name for itself in the new arena of microwave-assisted chemical analysis. At the time, the standard way to analyze rugged, hard-to-dissolve metallic, soil, and other inorganic samples was to dump the samples into a strong mineral acid and heat it up on a hot plate. Then researchers would wait, and wait, and maybe wait some more, until the hot acid digested the sample enough for analysis by spectroscopy and other standard methods. Many jobs also required some kind of specific fiddling—maybe a stint on a shaker table or a more rigorous heating regimen. As a result, analysts had to know and use a variety of protocols that could take anywhere from hours to several days.

Word about CEM's apparently simpler microwave alternative spread quickly to companies in the oil, chemical, mining, and environmental monitoring industries where analysis of metal-containing soil and sludge, ceramic powders, and minerals was a daily need. With the microwave technique, the sample and acid go into a closed Teflon container, which is then heated in the microwave for a few minutes, 30 at the most. The sample comes out ready for analysis. "When people became aware of our microwave work, they came to us asking about it," recalls CEM CEO Michael Collins.

That was just fine, but Collins knew CEM (which stands for Chemistry, Electronics, and Mechanics—the disciplines that CEM's three founders brought into the company) could not yet offer customers a ready-to-go system. The specific microwave power, time, and other factors required for each type of sample could only be determined by a time-consuming, trial-and-error process. There was no recourse for a new user but to go through that process. Moreover, since no one knew exactly how microwave energy was digesting the samples, no one could say just how the method worked.

"When people became aware of our microwave work, they came to us asking about it," recalls CEM CEO Michael Collins.

Despite drawbacks of the traditional open-beaker, hot-plate methods, analysts understood them, knew they worked, and knew how to do them. It would be hard for CEM to break through into bigger markets unless the company could tell its customers both how the microwave methods worked and precisely which protocol worked for a given type of sample. "We didn't just want to ship our customers a box and then leave them on their own to make it work," Collins says.

With that goal on their minds, Collins received a fateful call in 1983 from NIST chemist Skip Kingston, now at Duquesne University. Kingston was doing some research on microwave-assisted chemistry and became convinced that the techniques had good potential to simplify many chemical procedures.

He wanted to learn more about the physical mechanisms underlying the process and to develop the kind of theoretical understanding that could add microwave chemistry to the generally accepted corpus of chemical knowledge and techniques.

Kingston knew that CEM had been selling microwave instrumentation for a few years so he gave them a call. Collins was interested. Within a month, he had spent a day in Kingston's Gaithersburg, Md., laboratory to discuss the possibilities in more depth. A collaboration seemed right for both parties. "Within a few months, we had set up and funded Lois Jassie as a research associate at NIST," Collins recalls. As part of this, Jassie enrolled in the Ph.D. program at the nearby American University, and this microwave work became the basis for her research and thesis. So, as CEM was finalizing the design of what would become production models of a microwave digester, the collaboration was developing application protocols for specific sample types as well as fundamental studies into the physics and chemistry of the process. In short order, these studies suggested to CEM that a sealable Teflon container would allow microwave energy to penetrate to the contained sample while enabling pressure to build up inside without exploding.

CEM found the NIST connection so valuable that the company kept Jassie on at NIST as a research associate until 1993, nearly a full decade.

By the end of 1984, CEM was selling a closed-vessel microwave system. Sales went up considerably following a seminal paper by Kingston and Jassie in the Oct. 12, 1986, issue of *Analytical Chemistry*. "That paper educated the technical community in microwave-assisted chemistry," Collins says. By 1990, the microwave digestion system had grown into CEM's major product, with sales to both domestic and foreign customers. The company now is the industry leader. "This year we expect to have $30 million in sales and 40 percent will come from our microwave digestion products," Collins says.

CEM found the NIST connection so valuable that the company kept Jassie on at NIST as a research associate until 1993, nearly a full decade. That human connection enabled CEM to benefit from NIST's strength in protocol development, and NIST researchers were able to keep abreast of what users and makers of microwave-based instruments were doing and what they needed.

The future still holds plenty of promise for the microwave-assisted chemistry that CEM and NIST helped shepherd into respectability and into instrumentation that analysts can buy. Says Collins: "We see this as an emerging field, which is still in its infancy."

NIST Industrial Impact

Company:

Corning Inc.
Corning, New York

Business:

Makers of consumer housewares and specialty materials including optical fibers

Company:

AT&T Bell Laboratories
Atlanta Works
Norcross, Georgia

Business:

Providers of communications services and products, computer systems, and network equipment including optical fibers

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As you read this, the world is becoming ever more wired with optical fibers. Growing networks of millions of kilometers of glass fibers cross continents and oceans linking millions of people and computers worldwide with pulses of information-laden light. Without optical fibers, any talk of a National Information Infrastructure would be little more than a pipe dream.

With all of this growth, the need for optical fiber makers and users to standardize products, manufacturing processes, and installation procedures becomes critical. Lacking that, technical incompatibilities that would stunt growth of these networks, hinder their maintenance and repair, and thereby erode the international competitiveness of the U.S. telecommunications industry could emerge. This challenge is a classic call to arms for researchers at the National Institute of Standards and Technology.

Since 1981, NIST has been working closely with the Telecommunications Industry Association to advance both standards and technology for the optical fiber industry. A 1992 report prepared for NIST by an independent economist estimated that NIST's aid in the development of standards and measurement protocols had by then been responsible for annual savings of $9.5 million in the optical fiber industry, which was more than four times the cumulative cost of the collaborative work throughout the entire 1980s.

A recent NIST contribution that has been getting particularly high praise from the industry goes by the unassuming name of SRM 2520. SRM stands for Standard Reference Material, and SRM 2520 is one of about a thousand different SRMs that NIST prepares for hundreds of industries that need reliable benchmarks by which they can calibrate their own tools, instruments, chemical analyses, and other measurement protocols.

At the heart of each SRM 2520, which companies can purchase from NIST for about $1,000, is an optical fiber whose diameter has been more accurately measured and certified than any other fiber in the world. To certify each standard, NIST metrology expert Ted Doiron designed and built an exquisitely sensitive and accurate micrometer that could measure fiber

NIST's aid in the development of standards and measurement protocols had by then been responsible for annual savings of $9.5 million in the optical fiber industry.

diameters with an uncertainty of about 50 nanometers or the width of about 100 molecular layers of the glass. In the hands of the engineers at an optical fiber plant, an SRM 2520 serves as the most reliably calibrated ruler by which they can monitor the uniformity of their own commercial fibers, explains Matt Young, who developed SRM 2520 with Steve Mechels, Paul Hale, and other NIST researchers.

SRM 2520 has become a necessary tool in the production of optical fibers even though the standard only became available in 1993, according to Jan H. Suwinski, an executive vice president of Corning Inc. At the center of the standard fiber is a glass core about 10 micrometers in diameter surrounded by a thicker glass cladding whose outer diameter is about 125 micrometers, or about two hair-widths. (The cladding is coated with a tough polymer to protect the glass from environmental degradation and breakage.)

The particular value of SRM 2520 is emerging as optical fibers reach from major optical cables to individual buildings, homes, and offices. This phase of network growth entails massive amounts of splicing and matching of fibers, which can be more expensive than stringing fibers longer distances, a procedure requiring fewer splices. Industry experts say that variation in fiber diameters would be calamitous because, if the diameters differ, the inner cores probably would fail to align precisely when joined, resulting in degraded light signals. And that spells "disaster" for an industry whose raison d'être is transmitting signals reliably and clearly. By using SRM 2520 to calibrate the fiber-making process, the optical fiber industry can increase the likelihood that its fibers will align. According to Department of Commerce statistics, the U.S. optical fiber market amounted to $2.1 billion in 1992, which was 40 percent of the world total. That translates into a lot of splicing.

"The opportunity to work with NIST on this project gave Corning and other American fiber manufacturers a clear competitive advantage."

"Another industry-wide study found that the main problem in controlling the cladding diameter was having a reference," notes William Gardner, who specializes in fiber measurement standards at AT&T's optical fiber plant in Norcross, Ga. With SRM 2520, he says, uncertainty in the measurements of fiber diameters now vary within about one-tenth of a micrometer (about the width of a cell nucleus), which is about one-tenth of the uncertainty that was typical before SRM 2520 became available. Both AT&T and Corning now use SRM 2520 routinely for quality control.

In a letter to Judson French, director of NIST's Electronics and Electrical Engineering Laboratory, Corning's Suwinski wrote that "the opportunity to work with NIST on this project gave Corning and other American fiber manufacturers a clear competitive advantage."

For NIST, that kind of industry feedback translates into a mission accomplished. But not completed, notes Young. NIST and the optical fiber industry now are planning to work on other standards, including one for measuring the tiny diameters of ceramic ferrules that are used to connect fibers into continuous pathways of light.

NIST Industrial Impact

Company:
Crucible Compaction Metals
Oakdale, Pennsylvania

Business:
Producer of high-performance materials and parts for aerospace and other applications

Number of Employees:
65

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The inside of a working jet engine is a hellish place. Hour after hour, day after day, hot, corrosive combustion gases flow over its internal parts at hundreds of miles per hour. Many of these parts also rotate hundreds or thousands of times per minute, creating internal strains that would shred most materials in short order. Yet those parts have to withstand the punishment. There are no shoulders for repairs in the jet stream.

William Eisen thinks about these facts with more gravity than most people. He is president of Crucible Compaction Metals (CCM), an Oakdale, Pa., company, one of the few manufacturers of metal disks that rotate at high speed at elevated temperature to move gas through the jet engines on military and civilian aircraft. Given their hostile venues, these disks and other parts that Crucible makes have to be made of the toughest, strongest, most reliable, and most temperature-tolerant material that his company can make at a price that jet engine makers are willing to pay. Moreover, with global competition in both the aerospace and advanced metals business on a rapid ascent, Eisen can never afford to coast on the quality and efficiency of today's manufacturing processes.

Crucible's process starts with molten metal of the proper chemistry that will produce an alloy with the desired materials properties. But, instead of casting these parts by pouring molten metal into molds, or first forming billets that are shaped and processed later, CCM converts the liquid metal into fine powder using the so-called inert gas atomization process. This powder is then loaded into metal containers (molds) and consolidated into solid parts by hot isostatic pressing. Very little machining and finishing work is required afterward.

"You can make materials this way that you can't forge or roll or make in any other way," notes long-time NIST metallurgist John Manning, director of NIST's in-house powder metallurgy research group, which operates a powder making facility rigged with sophisticated sensors and valves that can monitor and control exactly what occurs as metal powders are made. It was a setup that no company had in place or could afford.

The disks and other parts that Crucible makes have to be made of the toughest, strongest, most reliable, and most temperature-tolerant material.

For Crucible, the complex process yields engine parts that fit the bill, Eisen says, but its efficiency was disappointing. NIST was soon to become part of the solution. The problem had to do with the particles in the metal powder. To create parts with the range of properties needed for jet engines, the particles have to start out very small—with a maximum size about 0.076 millimeter (0.003 inch) in diameter—and extremely uniform. The small sizes of the particles help produce uniform properties in the finished parts and also reduce the sizes of voids or other imperfections, which are the seeds of material failure. If the company could reduce the amount of oversize powder produced, the process would become more efficient, operating expenses would decrease, and the company would become more competitive.

With that chain of events never far from Eisen's mind, he was especially receptive in 1982 when he heard about, and subsequently attended, a powder metallurgy conference in Gaithersburg, Md., at the National Institute of Standards and Technology (then called the National Bureau of Standards). "I had no idea of the extent of work going on there," Eisen recalls, adding that he hadn't previously thought of NIST as a place for getting answers to industrial process problems.

After the meeting, he remained in touch intermittently with the metallurgy group. In 1986, Crucible was invited to join a research consortium with NIST and other powder metallurgy companies. The consortium's goal would be to develop more detailed knowledge about how metal powders form and to use this knowledge for making the process more of a science. In 1987, Crucible, General Electric Corp., and Hoeganaes Corp. joined NIST to form the consortium. It was renewed in 1991 with two of the old partners and four new players and will end after 6 years in 1994.

The computer model guided the company in the redesign of its gas delivery system, thereby increasing "the percentage of usable powder produced during the atomization process by over 40 percent."

The half-decade involvement paid off for Crucible in higher efficiency and lower costs. One crucial part of this gain was a computer model developed by the NIST fluid flow group. It enabled Crucible engineers to simulate accurately what was happening as particles formed rather than having to guess what happened by examining finished particles. The model had a lot to consider. The powders are made in an atomization process by letting the molten metal fall through a nozzle at the end of which a high-velocity stream of inert gas blows the liquid metal stream into a fine mist of tiny spherical droplets. These cool and solidify almost instantaneously and are collected downstream.

"We suspected that if we could understand the gas dynamics, we could control our process more successfully," Eisen says. They were right. The model, which the fluid flow group was able to develop using data obtained from NIST's supersonic inert gas metal atomizer, was designed to help CCM and other consortium members optimize their processes without having to tell each competitive details. "We now use this model the way other manufacturers rely on computer-aided design," Eisen says.

In a 1992 letter to Lyle Schwartz, director of NIST's Materials Science and Engineering Laboratory, Eisen noted that the computer model guided his company in the redesign of its gas delivery system, thereby increasing "the percentage of usable powder produced during the atomization process by over 40 percent." Efficiency gains of just a few percent usually are enough to get congratulatory memos flying around. At the same time, Eisen added, the new process consumes less argon gas, "helping to decrease Crucible's operating costs." That's just good business.

NIST Industrial Impact

Company:

Gas Processors Association
Tulsa, Oklahoma

Business:

Represents member companies who produce, process, and distribute natural gas and natural gas products

Size:

Approximately 60 member companies

When Kepler came to the startling conclusion that planets rotate around the sun in elliptical orbits, not circular ones as everyone had believed, he owed plenty of thanks to his employer Tycho Brahe. Brahe had spent years measuring planetary positions with unprecedented precision. Had that precision been a fraction of a percent less, Kepler almost certainly would have failed to discern the unexpected orbital shape.

Now, there are countless down-to-earth reminders of how important precision can be, including one that has brought the Gas Processors Association's (GPA) member companies into alliance with researchers at the National Institute of Standards and Technology (NIST). The collaboration, which began in 1989, goes by the descriptive title of Volume Correction Factors Project.

The industrial problem that brought the two organizations together originated with disagreements between the companies that sell so-called liquid natural gas products such as ethane, propane, butane, pentane, isohexane, and their blends (which condense into liquid when extracted from natural gas) and those who purchase often huge amounts of these to use as fuel or chemical feedstocks. Says Dale Embry, a senior engineering specialist with Phillips Petroleum Co. in Bartlesville, Okla., and GPA liaison on the project: "The settlement of disagreements between the buyers, sellers, and regulators were tying up resources that could be better spent on other projects." By the late 1980s, the problem was getting expensive enough to move the GPA into action.

The technical basis of the discrepancy resides in calculations used to determine the quantity of the liquid product, which for practical reasons is always metered by volume, rather than mass. But since the density of liquids varies with the temperature, which means that a gallon of the same product packs a different mass of product on a hot day than it does

The financial consequences are great because the quantities of material produced and sold are so

on a cold day, the metered volumes need to be corrected to a standard set of conditions that everyone agrees to. Though actual corrections are relatively small, the financial consequences are great because the quantities of material produced and sold are so large.

Members of the GPA decided they needed to re-evaluate the correction tables they had been using since the 1950s when they were compiled by an engineer at Gulf Oil Co. Doing that meant preparing liquid product samples of precisely known compositions and then carefully measuring their volumes and masses in the range of temperatures at which these liquids might be pumped into a buyer's tanker. In the late 1980s, when they contacted NIST, they believed the corrections carried a 1 percent uncertainty. To halve that uncertainty, they needed measurement experts, which they

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knew they could find at NIST. Moreover, since many GPA member companies are multinational, they wanted to develop correction standards that would stand up to the scrutiny of foreign standards organizations. "This was another crucial reason to work with NIST," Embry says.

Beginning in 1989, the company contracted with a team of researchers at NIST's Boulder, Colo., facility to measure the density of liquid natural gas components and their mixtures. Collaborators at the Colorado School of Mines have used the detailed data, which even account for the portion of material that vaporizes into the free space of a tank, to generate sophisticated

The data "have resolved many discrepancies in the [previously] available data."

mathematical models that GPA members can use to calculate corrections with a maximum uncertainty of 0.5 percent. That is a factor of two to four improvement when compared to the previous methods. The new lower uncertainty translates into annual savings of tens of millions of dollars due to reduced claims tracking and settlement, Embry says.

In a letter to W. Mickey Haynes, a NIST researcher who had worked on the project since its inception, Embry wrote that "we have gotten a bargain from your laboratory in terms of the quantity of data measured for the money that we have contributed." In the letter, he points out that the data "have resolved many discrepancies in the [previously] available data." Moreover, he says, the improved data and correction calculations even have allowed companies to keep open some operating stations that would have required costly upgrades in metering systems to improve measurement accuracy. "With the new data, we will be able to continue to use less expensive metrology with reduced uncertainty," Embry says.

Precise measurement, it seems, is the key to discovering the cosmic paths of planets, cost-saving methods for major industries, and, undoubtedly, a few other things in between.

NIST Industrial Impact

Company:
Hewlett Packard Company
Greeley Hardcopy Division
Greeley, Colorado

Business:
Manufacturer of high-tech measurement, research, and business instruments

Number of Employees:
750

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In January 1992, engineers at Hewlett Packard (HP) Co.'s Greeley Hardcopy Division detected some disturbing signs in one of their product lines. Five months earlier, they had stunned the electronic communications community with a new and uncommonly affordable color scanner, an instrument that could convert a color image, or regular text, into a digital format. Once digitized, images or texts can be fed into electronic publishing software, multimedia packages, or whatever else the electronic communications moguls might come up with.

"This kind of product had been available for $30,000 to $50,000, and we brought it down to the $2,000 range," notes Virgil L. Laing, manager of reliability engineering in Greeley's Hardcopy Division. Moreover, HP was then, and still is, the only U.S. company to have successfully entered the scanner market, which had been totally dominated by companies in Japan and Singapore.

HP's role as the lone Western player in the field only amplified the unnerving news trickling in from a small proportion of scanner customers. After several months of trouble-free operation, one or two out of a hundred users found that the copyboard glass—the pane of glass on which scanned material is placed like a page to be photocopied—suddenly cracked, from one corner to the corner diagonally across.

The news—both alarming and puzzling—was a call to action to Laing and a colleague who took on the unexpected challenge full time.

"At first we thought our packaging might have been inadequate and that the cracks were occurring in shipping," Laing recalls. The natural inclination to wishful thinking, in this case, that a simple packaging fix was the solution, helped favor this hypothesis. But it also was reasonable

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because it just wasn't easy to break the copyboard glass. "We dropped it and we shocked it, but we didn't see any breaks," Laing says. "We literally couldn't break the glass unless we treated it so badly that it shattered."

Developing and evaluating the next tier of hypotheses took the special knowledge of a mechanical engineer especially familiar with glass and that meant going outside the group that had designed the scanner. The company hired a consultant in nearby Boulder who had designed spacecraft windows, which have to be as rugged and fracture resistant as glass can get. The consultant didn't solve the problem, but he suggested they call Harry McHenry, chief of the NIST Materials Reliability Division. They did. McHenry listened to the problem and then connected Laing with Robert Walsh, a specialist in materials fracture at the NIST lab.

On March 12, 1992, Laing, two other HP engineers, and a few scanners traveled to Walsh's laboratory where James Dally, a mechanical engineer on sabbatical from the University of Maryland, happened to be working as a guest researcher. In less than a day, the ad-hoc trouble-shooting caucus found the root of the problem.

Measurements with strain gauges indicated that the design of the top, which has to secure the glass in the machine, unexpectedly had introduced damaging levels of stress into the glass. Instead of a safe level of 200 pounds per square inch (psi), some parts of the glass were under 2000 psi. With that information in hand, "we did more research, got engineering manuals from Dow Corning [a glass manufacturer], and checked with Dally some more," Laing recalls.

In little more than a month after the NIST visit, the designers at HP learned what gremlin had caused the cracking. The original design included a molded plastic part that

He estimates that their visit to the NIST lab and access to top experts in the field of fracture mechanics saved them 4 months of time and expense.

put pressure on the corners of the glass to secure it in place. It seemed a reasonable way to meet the company's stringent shock and vibration specifications to prevent damage during shipping or intermittent rough treatment by users.

A consequence of this design decision, though, was to set the stage for a subtle kind of failure mechanism in glass that begins with what engineers call "static fatigue." At the corners of the copyboard, the extra pressure designed into the machine elicited microscopic cracks that, over time, merged into a single crack that ultimately sliced across the copyboard. The result: glass that breaks slowly rather than shattering instantaneously.

The solution was simple, clear, and inexpensive. "We redesigned the cover plastic, and the problem went away," Laing says. He estimates that their visit to the NIST lab and access to top experts in the field of fracture mechanics saved them 4 months of time and expense. Luckily, the fracture problem only affected a small percentage of the machines. But the scanners were selling well enough that Laing estimates the 4-month head start on the solution saved the company at least $500,000. The static fatigue flaw was an unexpected difficulty, but it is the type of problem likely to arise as companies develop more sophisticated and complicated instruments that demand more and more of the materials used to make them. The key to success, Laing says, rides both on preempting problems before they happen and, if that fails, on finding good solutions quickly.

NIST Industrial Impact

Company:

HYPRES Inc.
Elmsford, New York

Custom Microwave
Longmont, Colorado

High Precision Device Inc.
Boulder, Colorado

RMC Inc.
Tucson, Arizona

Business:

Makers and users of high-precision electrical calibration equipment and standards

In early 1962 at Cambridge University, Brian Josephson made an arcane prediction that would earn his name a permanent spot in the scientific lexicon. By 1983, HYPRES, Inc., a small company in Elmsford, N.Y., was building a business around Josephson's prescience, and in 1990, RMC Inc., in Tucson, did the same. And they're only a sampling of what Josephson's prediction has wrought.

Josephson started it all when he predicted that a tiny electrical current would alternate back and forth between two patches of superconductive material separated by a thin layer of insulating material. All it should take, he suggested, was some electrical incentive in the form of a small voltage across the sandwich structure, which is now known as a Josephson junction. Also, according to Josephson's quantum mechanical calculations, the voltage across the junction ought to be precisely controllable by subjecting the structure to an external alternating current. It is. That controllability attracted electricity researchers at the National Institute of Standards and Technology like moths to light since it presumably would provide them with a means for building the world's most precise voltage standards. It did.

The seed for RMC and HYPRES's commercial entry into the Josephson junction voltage standards business was first sown in the early 1980s at NIST's facility in Boulder, Colo. There, Richard Kautz, together with researchers from Germany's counterpart to NIST, the Physikalisch-Technische-Bundesanstalt, adapted microfabrication techniques from the electronics industry to link thousands of Josephson junctions into miniaturized arrays. "By putting thousands of junctions together, we made a device that produced voltage at practical levels," Kautz says.

Once word got out, the world came knocking at the NIST researchers' door. Perfecting the device for widespread use was taken up by Clark

The seed for RMC and HYPRES's commercial entry into the Josephson junction voltage standards business was first sown in the early 1980s at NIST.

Hamilton, who now has been working on the project for a decade. "In the beginning we gave away devices to learn from others' experience with them," Hamilton recalls. These so-called Josephson Junction Voltage Array Standards now serve as the world's most precise voltage standards by which all other electrical equipment ultimately is calibrated. By the late 1980s, NIST had begun selling them; by 1994, it had shipped nearly 40 to standards facilities around the world, businesses, and several military facilities. As flattered as Hamilton, Kautz, and their colleagues were that their voltage standard was in demand, they never perceived their mission as a manufacturer and supplier of the standard. This is where RMC and HYPRES come in.

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RMC was the first to pick up the baton. Starting with NIST-developed chips, the company commercialized a voltage standard system, which includes cryogenic components for cooling the chip to nearly absolute zero, an instrument for monitoring the chip's electrical behavior, and a computer to control the system and record data. Since 1990, RMC has sold about $2 million worth of voltage standard systems and components—about 10 percent of the company's total revenue during that time—to both foreign and domestic buyers, according to David L. Swartz, founder and CEO of the company. "This is a case of technology transfer that has gone very well," Swartz says.

Elie Track, president and CEO of HYPRES Inc., in Elmsford, N.Y., says the same thing. "We took NIST's design, which was completely optimized, adapted it to our fabrication processes, and the outcome has been some of the best voltage standard chips that anyone has ever produced," Track states proudly.

To actually make their voltage standard chips, HYPRES engineers use microlithographic techniques, which they had developed specifically for working with superconductive niobium metal, to create tiny arrays of 3,600 or 20,208 Josephson junctions for their 1-volt and 10-volt standards, respectively. When chilled with frigid liquid helium and driven with microwave radiation (the external source for an alternating current), the chips generate specific voltages accurate to one-billionth of a volt.

"This is a case of technology transfer that has gone very well."

Track assesses his company's achievement so far as an "excellent technical success." HYPRES has sold about 10 voltage standard chips, mostly to foreign metrology labs, for a total gross revenue of roughly $150,000. A portion of this comes from RMC, which now buys the standard chips from HYPRES instead of NIST. Track says that commercial success for his 11-year-old company now hinges on penetrating larger markets. The most likely, he adds, will involve the U.S. Army, which provided funding and research support to develop the standard.

The Army's precision weaponry and other state-of-the-art instrumentation need to be precisely and confidently calibrated since uncertainties can translate into a missed target, inaccurate transmission of data, or a failure to detect threats. The Army now has its own Josephson voltage standard (manufactured by RMC) in Alabama, which means that all of its secondary voltage standards in the field must be periodically taken to Alabama for calibration. "Instead of having to take all of those secondary standards to Alabama, they envision installing primary standards into their equipment to begin with," Track says. The Army estimates an easy-to-use standard system could save them $3 million per year.

Other companies also have been feeling some commercial energy coming from Hamilton's lab. After High Precision Devices Inc. of Boulder had built a cryoprobe (a component that holds and shuttles the chips into the refrigeration system) for Hamilton's group, the company won similar contracts from a handful of clients including TRW, IBM, and HYPRES. In a June 1994 letter to Hamilton, the company's president Bill Hollander wrote that "This family of products has become a significant portion of our business." Astro Endyne Co., also in Boulder, and Custom Microwave in Longmont, Colo., wrote Hamilton with similar expressions of gratitude.

Josephson may have been able to predict a remarkable property in superconducting materials, but he probably had no inkling of the technological and commercial consequences that would unfold from its application.

NIST Industrial Impact

Company:
Intel Supercomputer Systems Division
Beaverton, Oregon

Business:
Develops and sells supercomputers

Number of Employees:
Several hundred

People who use supercomputers are speed freaks. When a program runs more slowly than they think it should, they quickly want to uncover and overcome the computational bottlenecks. Is the problem in the way the software is written? Or is the hardware simply pushed to its limits? Answers to questions like these are at the heart of business decisions such as whether to buy new computers or invest in software engineers.

Sniffing out the source of a computer's performance snags is especially tricky when it comes to parallel processing supercomputers, says Wayne Smith, a software designer working at Intel's Supercomputer Systems Division in Beaverton, Ore. To help its customers through the thicket, Intel began shipping its new line of Paragon parallel supercomputers in 1993 with a built-in "performance monitor" based on work by researchers at the National Institute of Standards and Technology (NIST). Says Smith: "Without the NIST effort, we wouldn't have had this in our machines so soon."

Measuring performance in a conventional serial processing computer such as a PC is relatively straightforward. These computers usually have a single microprocessor that takes one line of a program at a time and does what that line commands—retrieve data from memory or plug data into a mathematical expression, for example—before moving on to the next program line. If operators want to speed things up, they might find the computational slow points by checking the computer clock from time to time and noting how the computation is proceeding. They might learn, for example, that the computer is not getting data out of memory as fast as the processor can work on the data. If they can't circumvent the problem by doctoring the program to shunt data around more efficiently, then they would have to decide between patience and purchasing a new computer with faster retrieval from memory.

"Without the NIST effort, we wouldn't have had this in our machines so soon."

When it comes to parallel processing supercomputers, uncovering bottlenecks is much more difficult. Instead of the neat linear process going on inside of a serial supercomputer, a dizzying computational orchestration unfolds when a parallel computer runs programs. Each of dozens, hundreds, or even more processors simultaneously receives input from other processors or from memory, transforms data in accordance with the part of the overall program it happens to be running, and sends output to different processors, memory, and other components. This frenetic activity might cycle an indefinite number of times. Moreover, these events often do not occur during the same time intervals in each processor.

In this far more complicated arena, finding out where bottlenecks arise

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has been virtually impossible, Smith says, partly because no single clock was available that was universally applicable to all of the processors as a program ran. That is why he saw good prospects in the "MultiKron Project" of Alan Mink and colleagues at NIST. The MultiKron is a chip (or system of chips) that collects performance data as directed by processors as they compute and shunt data around. One of its functions is a universal clock that can effectively track program progress and compare performance of all processors in a computer. Says Smith: "You need global counters and time stamps to know when and where things are occurring" in a parallel processing computer.

NIST has been developing MultiKron technology at relatively low manufacturing cost by relying on small batches of prototypes made on a nationwide chip fabrication resource known as MOSIS, which enables chip designers to pool the cost of manufacturing if each participant can live with only a few dozen copies of its respective chip.

That's where the design concepts behind NIST's MultiKron may well come into his company's maiden product.

That wouldn't work for Intel, which would need many chips for each of its Paragon supercomputers. Intel found that the lowest cost way to provide the MultiKron functions they desired in the high volumes that they needed was to hire a contractor to adapt an off-the-shelf programmable chip. "Now all new machines [Paragon supercomputers] have a performance monitor."

Newcomers to the parallel supercomputing field also have their eyes on the NIST MultiKron Project. Tera Computer Co. in Seattle expects to launch its own supercomputer late in 1994, says Tera systems designer Allan Porterfield. "We believe that to make the impact on the market that we would like, we have to make it easy to program our machine," Porterfield says. That's where the design concepts behind NIST's MultiKron, if not actual MultiKron chips, may well come into his company's maiden product. That companies so far seem to be opting for the brainwork behind MultiKron rather than the chip itself is just fine to Mink, who continues to develop MultiKron concepts with input from computer scientists at universities as well as companies. It's getting out there and seems to be helping the parallel supercomputing industry. And that is precisely the kind of technology transfer we like, he says.

NIST Industrial Impact

Company:
Intelsat
Washington, D.C.

Business:
International communication satellite organization

Number of Employees:
133 member countries

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To spacecraft designers, any visible amount of unidentified gunk showing up in development and testing phases has a knack for sending blood pressures to orbital heights while keeping would-be satellites down to earth. Better to get to the bottom of the problem when the spacecraft is in reach instead of anxiously wondering, perhaps for years, if the same dirt-making process will eventually turn a multimillion dollar spacecraft into a useless assemblage of high technology.

That is why engineers at Intelsat, an international organization with 133 member countries and 21 communications spacecraft in orbit, were mightily concerned when they noticed a brownish contamination on "reaction thrusters" of a few yet-to-be launched spacecraft. Flight controllers fire these small thrusters to fine tune the orbital orientation of deployed spacecraft. Without working thrusters, the spacecraft's communications performance could be impaired at least or entirely muted at worst.

The problem surfaced in ground tests as a "brown goo" corrosive to steel valves on the thrusters. The corrosion, in turn, was causing volatile propellant to leak around the thrusters' Teflon seals, says Andrew Dunnet, a principal scientist at Intelsat. Before the problem was noticed, one satellite was launched into orbit, which means it may have contaminated valves. "We have seen no problems as yet," he notes, adding that his organization now wants to learn as much as possible about the contamination to help them predict what the orbiting satellite might do in the future and to help their engineers prevent future contamination problems.

This is no easy task since the amount of the brown goo is small despite the potentially catastrophic scenarios it elicits for those who depend on the spacecraft. To help out, Intelsat hired Tom Kirkendall, an independent consultant with decades of experience in spacecraft materials. He knew about NIST's sophisticated instrumentation and expertise in analytical techniques (partly because he used to work for COMSAT, which is a short distance up the road from NIST's Gaithersburg headquarters) and suspected that researchers there could help decipher the nature and cause of the contamination.

The data proved quite instrumental in the making of engineering and management decisions which materially affected the reliability of many spacecraft.

In mid-April 1994, he met with Edgar Etz and Robert Fletcher of NIST's Surface and Microanalysis Science Division and Bruce Benner of the Organic Analytical Research Division. Within a month, these researchers had supplied Kirkendall with a number of preliminary results.

The data proved quite instrumental in the making of engineering and management decisions which materially affected the reliability of many spacecraft, Kirkendall says.

Based on 30-year-old reports in the scientific literature about similar contamination on spacecraft materials, Kirkendall suspected that the brown goo might form from chemical reactions between the thruster fuel (mono-methyl hydrazine) and a chlorofluorocarbon (CFC) that the manufacturer of the thruster had been using to clean out the thruster assemblies after test firing them. To test the theory, Kirkendall needed data. He had some, but not enough.

Intelsat previously had hired commercial analytical laboratories to help determine the source and effect of contamination on other thrusters. While those analyses revealed the elemental composition of contaminants, they did not pinpoint the specific corrosive species or reactions at work on the thrusters. Intelsat needed more detailed information to decide if they could use the existing thrusters after cleaning them or if they needed to replace them with never-contaminated versions.

Models of the chemistry occurring at a CFC-cleaned valve suggested that both hydrogen fluoride and hydrazones, which contain carbon atoms that are bonded to nitrogen atoms, likely would form on the steel surfaces. The chemistry perpetrated by these molecular species is thought to be capable of corroding some steel alloys. Without data to back them up though, such models do not impress aerospace engineers in charge of keeping real satellites healthy for their projected 17-year lifetimes.

"With NIST as part of the effort, we were able to decide that we had to change attitude thrusters and we were able to do that in a minimum of time."

Getting that data is where Kirkendall hoped the NIST team could came in. "I don't know where else I could have turned," he says. In one analytical technique known as laser microprobe mass analysis (LAMMA), Robert Fletcher repeatedly blasts micrometer-sized samples with a finely focused laser beam, each time creating a miniature plume of material. The molecular debris is then swept after each blast into an instrument that measures the masses of each molecular fragment by measuring how long the fragments take to reach a detector.

In another technique, infrared microspectroscopy, data about the types of chemical bonds present in the goo were collected without even having to remove sample particles from the contaminated thruster components.

"We now have information on the chemical groups present and these data have essentially confirmed our hypothesis" that residual CFC and propellant react to form the brown goo, Kirkendall says. "With NIST as part of the effort, we were able to decide that we had to change attitude thrusters and we were able to do that in a minimum of time," Dunnet notes. Moreover, the thruster manufacturer no longer uses the CFC to clean components after test firings, he notes. Now, Kirkendall and Dunnet hope that the NIST analysts can help answer more specific questions about exactly what chemical compounds are present and whether this type of corrosion process will continue in a space environment, or if it requires oxygen.

"Contamination is always a nightmare" in the space industry, Dunnet says. It would seem that NIST has gotten into the business of helping some members of the space industry sleep a little better.

NIST Industrial Impact

Company:
Lake Shore Cryotronics Inc.
Westerville, Ohio

Business:
Manufacturer of measurement and control instruments for research, medicine, and industry

Number of Employees:
90

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In 1987, the term superconductivity became part of the household lexicon. Coming in by radio, newspaper, and television were visions of a new technological era ushered in by breakthrough materials called high-temperature superconductors. If these strange ceramic materials could be developed into forms such as wires and coils, they just might supersede and surpass the copper and silicon-based electrical and electronic technologies that have come to characterize these times.

Insiders knew even then that the new materials were far from a sure bet, and realistic projections had scientists and engineers taking a decade or two before any part of the technovision stood a chance. Still, no company that had the potential to be involved could afford not to pay attention. Lake Shore Cryotronics (LSC), a small firm in Westerville, Ohio, that makes and sells a variety of sensors and specialty electronic components, was one of them.

Right in the middle of those heady days in 1987, company employees Jeff Bergen and Warren Pierce were setting out on a multistop trip to find new and future markets relevant to LSC's strengths. That's also when LSC president John Swartz received a call from a colleague at the Massachusetts Institute of Technology suggesting that the trip itinerary include Fred Fickett's research group at the NIST Boulder facility. It turned out to be a key stop.

When the LSC team got into the laboratory, they saw an experimental instrument that the NIST group was using to measure electrical and magnetic properties in the new superconducting materials, recalls Bergen. Nothing came of the visit immediately, though Bergen and his colleagues cataloged the instrument in their memories since they knew that superconductivity, and sensors for studying the phenomenon, were probably going to be growth fields.

A few months later during a phone conversation between LSC and NIST scientists, the commercial possibilities of the instrument that the LSC troupe had seen, called an AC susceptometer, came up. The NIST group was finding their instrument so useful in their experiments that they suspected others studying and developing the new superconducting ceramics would feel the same way. Moreover, a number of groups, mostly in Europe, were already putting their own homemade AC susceptometers to work. The instrument uses an alternating electrical current (AC) to impose a magnetic field on a sample while monitoring how the sample responds to, and interacts

The NIST group was finding their instrument so useful in their experiments that they suspected others studying and developing the new superconducting ceramics would feel the same way.

with, the field. The data from these experiments reveal electrical and magnetic features of the sample, including its superconducting and non-superconducting properties.

After studying the possibilities, and drawing heavily on the experience of the NIST group, the LSC staff concluded that AC susceptometers "could be built and sold at more accessible prices than anyone could build themselves in the laboratory," Bergen says. LSC scientists and engineers conferred with the NIST group regularly and within 1 year—by mid-1988—LSC had built and sold the first commercially manufactured AC susceptometer. "We turned it into a turn-key instrument," Bergen says. The company followed that in 1991 by unveiling an AC susceptometer combined with a DC magnetometer, a related instrument that the U.S. research community is more familiar with.

LSC scientists and engineers conferred with the NIST group regularly and within 1 year, LSC had built and sold the first commercially manufactured AC susceptometer.

These instruments since have been sold to many labs around the world and have contributed greatly to the rapid growth of Lake Shore's magnetic measurements product lines, Bergen notes.

As it turns out, the more sober projections for high-temperature superconductivity remain on target, Bergen says. A few small applications of the materials in products such as magnetic field sensors (superconducting quantum interference devices, or SQUIDS for short) for oil prospecting and medical imaging could emerge before 1997 comes around, but widespread and large-scale use remains uncertain. That uncertainty has changed the business context for LSC, notes Bergen. "The cryogenic market [for instruments that work at extremely frigid temperatures] is having a lesser rate of return," Bergen notes.

"We are now looking beyond traditional markets," Swartz adds. It is that kind of adaptive behavior that could well transform business uncertainty into opportunity.

NIST Industrial Impact

Company:
Lockheed Missiles & Space Company Inc.
Sunnyvale, California

Business:
Designers of aerospace technologies and vehicles

Number of Employees:
15,600

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August 1994

Sometimes researchers at the National Institute of Standards and Technology (NIST) get letters fit for their mothers' refrigerators. Charles Tilford, an expert in measuring extremely low pressures, and his vacuum metrology group received such a letter in May 1994 from a team of measurement specialists at Lockheed Missiles & Space Co. Inc. in Sunnyvale, Calif.

The company has wanted to develop a confident in-house means of certifying ultralow pressure measurements of their vacuum chambers in which they routinely observe and test components, even entire spacecraft, under pressure conditions similar to what the hardware would encounter in orbit and outer space—about 1 ten-billionth the pressure on Earth.

To make sure the readings of their hundreds of pressure gauges are accurate (the gauges read the correct pressure) and precise (the variation range from measurement to measurement is very small), Lockheed has a strictly enforced policy to send their in-house calibration instrumentation to the vacuum group's laboratory at NIST's Gaithersburg facility twice each year where *it* can be calibrated with unsurpassable confidence.

For Lockheed, an aerospace company, the initial push for in-house pressure standards, which would enable more frequent and convenient calibrations, arises mostly from design and engineering requirements imposed by the National Aeronautics and Space Administration for certifying space station components. But calls for ever more reliable pressure measurements also are coming from several other industrial sectors, including the vast microelectronics industry, notes Klaus Jaeger, manager of metrology for Lockheed.

The technical challenge is to develop a standard source of low pressure, which then can serve to calibrate the gauges used to monitor the tiny amount of gas in the company's

Calls for ever more reliable pressure measurements also are coming from several other industrial sectors, including the vast microelectronics industry.

vacuum chambers. The strategy is similar to a company that makes rulers. To make sure the marks on the ruler actually correspond to centimeters or inches, the manufacturer relies on length standards that ultimately are traceable to standards maintained at national standards facilities such as NIST.

The vacuum metrology group developed its pressure standards by designing and building devices that deliver precisely known flows of gas through apertures of known area. Under proper conditions, the pressure throughout each chamber becomes equal to the pressure at the aperture, which is calculated by dividing the measured flow rate by the known area. Researchers at Lockheed and elsewhere regularly send vacuum gauges to the vacuum group. Flight hardware now in place aboard the Hubble Space Telescope, communications satellites, and other spacecraft have been certified in vacuum chambers whose pressures were measured with gauges whose calibrations are traceable to the NIST standard.

Now, Lockheed is about to wean itself from this ultimate reliance on NIST. In a letter to Tilford dated May 9, 1994, Jaeger and two Lockheed co-authors, Paul Levine and L. Kasturi Rangan, reveal that their company is now poised to cut the umbilical cord and in a way that could well open up important new business for them.

"Lockheed is in the process of commissioning an ultrahigh vacuum primary calibration system, designed after the NIST system," they wrote in the letter. "Without the drawings, technical specifications, and details of the process used to fabricate critical components provided by your [Tilford's] group, our system could not have come together and reached testing phase in the relatively short time it has taken." Many of the important details, which never show up in written documentation for any high technology, were transferred during visits to NIST and multiple off-the-cuff calls. "Chuck [Charles Tilford] was always more than willing to give me advice," Levine notes. Lockheed engineers working on the project "have always received a warm welcome, in-depth help and advice, and cooperation as though we are all partners in the same business," the letter states.

"The entire vacuum group is a jewel in the U.S. crown."

Indeed, the company foresees several business benefits emerging from all of this interaction. Since their new calibration system can serve as a means of "primary calibration," the Lockheed engineers no longer will have to send their vacuum gauges to NIST's Gaithersburg facility every 6 months. That will amount to an annual savings of $40,000 for the company, notes Levine.

That cost saving could well become incidental to a much larger benefit that the engineers expect from their in-house calibration system. "It will afford us the capability of providing calibrations of [ultralow] vacuum gauges on a commercial basis," Levine says. Such certifiable measurements are important not only for aerospace companies but also for chip makers and others who deposit thin layers of materials under highly controlled temperatures in vacuum chambers. "This will put us in an enhanced competitive position," says Jaeger.

Tilford notes that the microelectronics industry also is getting much more serious about accurately measuring the conditions in their manufacturing processes. These processes can involve hundreds of steps to produce chip-filled wafers, each of which represents tens of thousands of dollars of presale investment. When problems arise, many wafers are discarded before the solutions are found, and that costs plenty. Getting more understanding and control over the process steps, many of which are at low pressures, is a route to fewer losses, less downtime, and better products. Tilford is not surprised that much of his team's efforts now focus on helping chip companies develop more sophisticated pressure-monitoring protocols.

"The entire vacuum group is a jewel in the U.S. crown," Jaeger says. Adds Levine: "I cannot say enough good things about them." That's definitely commentary fit for the fridge.

NIST Industrial Impact

Company:
Maxtor Corporation
Longmont, Colorado

Business:
Specializes in producing data recording products

Number of Employees:
6,200

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July 1994

Virtually every byte of data in all of the computers in all of the homes, offices, laboratories, and manufacturing floors in the world is stored on exquisitely thin magnetic films. These films most often are frosted atop palm-sized aluminum disks that subsequently become the organs of memory in computer hard drives. In 1992, the hard disk drive market amounted to $24.5 billion, according to statistics from the Department of Commerce.

Since an individual byte on a typical disk resides on an area roughly the size of a red blood cell, any manufacturing defect big enough to be seen with the naked eye is a red flag to anyone in the business of selling the disks. And that is just what happened in early 1993 to engineer Michael Montemorra of Maxtor Corp., one of the country's "Big 5" producers of hard disk drives. While visiting the company's facility in Singapore where disks, heads, and other components are assembled into "plug-and-play" hard drives, he learned that some of the disks arriving at the factory from suppliers had clearly visible ring-shaped defects circling through the disk's data storage areas. The disks should have appeared perfectly smooth and shiny.

Though the problem was neither widespread nor catastrophic, "it gave us a small yield problem," notes Montemorra. It was a glitch familiar in the industry and one that had been insidiously eating into profits. Montemorra decided to get to the bottom of the problem and hopefully solve it. First he questioned the disk suppliers, but they couldn't pinpoint where the problem resided. So when he got back to Maxtor engineering offices in Longmont, Colo., Montemorra and co-workers began examining defective disks with conventional analytical tools, including scanning electron microscopy for looking closely at surface texture of the disks and electron diffraction for examining the crystal structure of the magnetic films. Still, nothing obvious was showing up.

At about the same time, Jim Lytton, a senior materials scientist at Maxtor, had established a research agreement with a group of researchers at the National Institute of Standards and Technology, just 32 kilometers (20 miles) down the road in Boulder. He and others at Maxtor had known about NIST for awhile, but when

Maxtor would get access to new tools for quality control and basic research that could help them to improve the quality of their products and to remain competitive.

Lytton heard that NIST mechanical engineer Paul Rice was using an atomic-force microscope (AFM) for looking at magnetic materials, he decided the time was right to initiate a collaboration. Maxtor would get access to new tools for quality control and basic research that could help them to improve the quality of their products and to remain competitive.

At the same time, NIST researchers would learn more about the technical problems of data storage technology and could better assist U.S. players in an important global industry.

Montemorra hoped that access to an AFM and to an expert user might help solve the defect problem. The AFM held that kind of promise because it can create renditions of sample surfaces down to the atomic scale. It does this by dragging an extremely fine stylus across the surfaces like a blind man sweeping a cane back and forth to determine the lay of the land. In the NIST AFM, a laser beam trained on a flat reflective plate on the back of the stylus deflects into a detector as the stylus follows the microscopic hills and valleys on the sample surface. From those deflections, a computer constructs an image of the surface. None of the analytical techniques in Maxtor's own labs could reveal the surface structure with as much detail as the AFM.

"We asked them [Rice and NIST colleague John Moreland] if they could see anything funny about the defective disks with their AFM," Montemorra recalls. In short order,

The AFM images that Rice produced at NIST's Boulder facility were pivotal in helping Maxtor's suppliers uncover where their processes had been falling short.

Rice produced revealing AFM images of the defective disk surfaces. When Montemorra sent these to the suppliers who actually made the disks for Maxtor's Singapore factory, the defects soon began disappearing. "You had to go right to the people who were involved in the manufacturing process," Montemorra notes.

The problem, it turns out, resided in an intermittent failure to meet the specific conditions under which the magnetic films are deposited onto the nickel-plated aluminum disks. The deposition occurs inside a vacuum chamber. There, a strong electromagnetic field transforms a cloud of gas atoms into minuscule bullets that slam into a piece of metal whose composition is the same as the magnetic alloy needed to coat the disks. The sputtered metal atoms then reassemble onto the blanks in thin magnetic films that can store data when a magnetic field is applied to them.

Getting the process to work consistently as part of a commercial manufacturing process begins as a maddening empirical exercise of varying the chamber temperature, the strength of the electromagnetic field, and other conditions until good magnetic films are produced. Once found, that hard-won set of conditions then serves as the key to the manufacture of high-quality magnetic films. In Maxtor's case, those films translate into millions of dollars worth of disk drives each year. Montemorra and Lytton say that the AFM images that Rice produced at NIST's Boulder facility were pivotal in helping Maxtor's suppliers uncover where their processes had been falling short.

With that win in the track record, Maxtor engineers say they are looking forward to continuing work with NIST. The NIST researchers also have plenty of experience with a magnetic-force microscope (MFM), which they have been using for an even longer time than their AFM. The MFM can image a material's magnetic landscape on the same fine scales that the AFM can image a material's topography. With these dual windows on magnetic materials, NIST researchers believe there are prospects for additional payoffs for Maxtor and other companies.

NIST Industrial Impact

Company:

Optical E.T.C. Inc.
Huntsville, Alabama

Business:

Developer of infrared-based technologies for military and commercial applications

Number of Employees:

5

Networking works, sometimes when you're not even trying. R. Barry Johnson, a former professor of electrical engineering who now calls himself an infrared technologist, can tell you so. The results so far from an unexpected collaboration with researchers at the National Institute of Standards and Technology, he says, are accelerated progress for his company's R&D and $3 million of research funding from the Navy.

What Johnson and his main NIST collaborator, Michael Gaitan, are developing might be thought of as minuscule stoves having hundreds of burners and made out of tiny silicon chips, aluminum, and a few other ingredients. Their experimental models today consist of square arrays of "microheating elements," together with microcircuitry that controls the pattern and intensity of heating, all on a chip about the size of a telephone number button. Johnson, Gaitan, and other collaborators expect to make much larger arrays involving more than 16,000 individually controllable heating elements. The tiny devices are made by adapting mature microfabrication techniques developed originally by the microelectronics community.

The initial goal of all of this microstovery, Johnson explains, is to develop an inexpensive, versatile, and reliable technology for "dynamic thermal scene simulation," which is the art of emulating the thermal energy emissions of objects or even complex scenes like tanks on patches of desert. The Department of Defense, which has supported both Johnson and Gaitan's work for years, is moving more and more toward simulation and emulation technologies like this one as a hopefully cheaper and less risky means of testing equipment and training personnel.

Johnson and Gaitan both envision using their microfabrication skills for non-military uses as well— sensors built into wings, bridges, and even shipping crates that monitor, locate, and record damaging vibrations; chip-sized sensors that simultaneously sense the presence and amounts of many different pollutants in the air; or accelerometers for mechanisms that control and trigger air bags in cars.

These possibilities are accelerating along the R&D process faster than would have been possible had they not been networked several years ago.

Gaitan and Johnson say these possibilities are accelerating along the R&D process faster than would have been possible had they not been networked several years ago by an Army contract officer working at Redstone Arsenal, Ala. The Army happened to be supporting both researchers for different projects. When Gaitan traveled to Alabama to discuss his project, the Army contract officer arranged for Gaitan to meet Johnson, intuiting that the two might cook up good ideas relevant to the Army's needs. Who could predict what

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could emerge by mixing people with expertise in infrared optics, electrical engineering, and microfabrication?

Plenty, it seems. For the first 2 years after their initial meeting, Johnson and Gaitan maintained informal contact by phone, e-mail, occasional visits, and the like. It was during that time that they began developing and testing their ideas for mass-produced, microfabricated thermal arrays. In 1992, Johnson and NIST made their connection somewhat more formal by signing a Cooperative Research and Development Agreement (CRADA), which Johnson and Gaitan say has led to several tangible benefits. As a result of their joint work on thermal displays, NIST is in the process of applying for a patent, an involved and tedious process that Johnson says he and his company, Optical E.T.C., would not have pursued on its own. Moreover, Johnson credits his association with Gaitan as a major factor in a Navy decision to fund a project in which the two are co-principal investigators in an effort to take their thermal-imaging prototypes to the next stage of development. The funding will span 3 years beginning in FY 1995 and will amount to about $3 million. Johnson notes that his company already has an agreement with a California company, Santa Barbara Infrared, to distribute commercial products that may come out of the collaboration.

"This relationship is in principle what Congress intended" with its legislation to make the federal government's research assets more accessible to private companies, Johnson notes.

"This relationship is in principle what Congress intended" with its legislation to make the federal government's research assets more accessible to private companies, Johnson notes. "With this type of assistance and motivation, I think we will have a much stronger country."

NIST Industrial Impact

Company:

Rolf Jensen and Associates
Deerfield, Illinois

State Fire Marshal
St. Paul, Minnesota

Donald Belles and Associates
Madison, Tennessee

Business:

Fire protection

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Every year fire wages war on the United States. In 1992 alone, nearly 2 million fires killed 4,730 people and injured 28,700. The National Fire Protection Association (NFPA), which releases grim statistics like those each year, estimates the property damage caused by these 1992 fires at well over $8 billion.

Yet these numbers only hint at the full cost of fire. Business interruptions and closings, insurance and litigation, fire protection and fighting, adhering to construction and manufacturing codes and standards, and disaster recovery sum into a national cost that one recent government-commissioned report estimates to be over $100 billion each year.

That is a compelling incentive for fire researchers and fire protection engineers to develop tools for predicting the outcome of fires, says Tom Brace, Minnesota's State Fire Marshal. He says that predictive tools, if used properly, can save lives, save money by giving more latitude to building designers, and save businesses millions of dollars in liability suits, which are traditionally hard to defend against.

One of the tools that Brace uses more and more is called Hazard I, a fire simulation program developed by researchers at the National Institute of Standards and Technology (NIST). Into the model go data about a building's design, materials, furnishings, occupancy, and the nature of the fire. Out come predictions about the temperature, smoke and toxic gas concentrations in each room, and the likely loss of life and injuries. The development team even included a psychologist to help with the human behavior components of the model. Since 1988 when the original version of Hazard I was released, over 500 copies have been sold to fire marshals, engineering firms, consultants, and others in the fire research, litigation, prevention, and fire fighting communities. The program—now sold in its second upgrade—never will replace the judgment and experience of human beings, Brace stresses. But he adds that programs like Hazard I and FPEtool, another NIST production, have become important components of big decisions that influence court settlements, liability claims, and even entire state economies.

Programs like Hazard I and FPEtool ... have become important components of big decisions that influence court settlements, liability claims, and even entire state economies.

One high profile case in point is the new and enormous Mall of America in Bloomington, Minn., which opened in 1992. According to the mall's publicity office, more people will visit the Mall of America each year than Disney World, and it is expected to be a major source of revenue for the state. Since tens of millions of people will be visiting the facility each year, Brace wanted to be extra sure that everything about the mall was as safe as possible and complied with regulations. That is why in late 1993 he sought out Jack Snell, deputy director of the NIST Building and Fire Research Laboratory, at an NFPA meeting in Phoenix. Brace needed an objective second opinion on the calculations and simulations used by Rolf Jensen and Associates (RJA) of Deerfield, Ill., whose fire protection engineers worked on the design and fire modeling of the Mall of America. Snell asked Richard Bukowski, a fire protection engineer at NIST, former firefighter, and co-author of Hazard I, to help out.

A key question for Brace was whether people on the mall's fourth level, which hosts a 16-screen cinema and many large restaurants, would have enough time to evacuate the building if a fire began, say, on the second level. From their analyses using the NIST prediction tools, RJA was confident that the answer was yes, but Brace wanted to make sure that the assumptions and data RJA engineers put into their computer models were appropriate and that RJA's interpretations were sound. He also wanted to check out a few more scenarios without having to do full-scale smoke tests in the mall, which Brace says are "pretty disruptive and may not be an accurate indicator anyway." The models helped Brace to validate RJA's work and deem the Mall of America fit to be occupied.

NIST predictive models are helping the company capture big jobs on high-rise buildings in Singapore, Hong Kong, and Jakarta.

"I didn't base my decision on the model, but it was a key element that had to come up positive."

As for RJA, the prediction and analysis tools are helping the company capture big jobs on high-rise buildings in Singapore, Hong Kong, and Jakarta where Bukowski says "designers, owners, and regulatory officials recognize the fire safety record of U.S. high-rise buildings." RJA engineer Bill Webb concurs. "Anyone [in the building engineering and design] business who wants to claim they are current with design technology would have to have a knowledge of these tools."

The NIST fire prediction tools also are changing the context of product liability litigation stemming from fires. Claims that a particular product or material present at a fire scene contributed to an injury or death, for example, are difficult to confirm or refute based on investigations that rely entirely on human judgment. The NIST fire models have made it possible "to assess the relative role of a specific material or product in the loss, freeing those whose product had no impact and limiting the liability for those whose role was small compared to other factors," Bukowski says.

Several small carpet firms that had been caught up in such suits owe their continued existence in part to Hazard I and FPEtool, claims Donald Belles, a fire protection consultant in Madison, Tenn. He says he has successfully absolved several carpet mills from liability using NIST's predictive models. The models have become an integral part of the way Belles does business.

Jon Nisja, one of Brace's deputies, points to yet another important role that predictive tools are beginning to play. Safety officials are slowly moving away from rigid, prescriptive building codes that stipulate in detail precisely where electrical outlets, lighting fixtures, vents, and other building components have to be placed during construction. Better, Nisja says, are the more flexible "performance- based codes" that consider the hazards unique to each building. This approach ought to lead to buildings that are safer, less expensive to build, and make more sense for their occupants and users. It also requires more skilled analysis by code and safety officials since they no longer can simply pull out a book of specifications. "This is where models developed primarily by NIST have a great deal of advantage for code officials," Nisja notes. What's more, when he has problems with the program he knows where to turn for help. "NIST is extremely customer oriented," Nisja notes. "I have called for help on numerous occasions and my experience has always been very positive."

NIST Industrial Impact

Business:
The steel industry

Number of Employees:
180,000

The National Institute of Standards and Technology is an agency of the U.S. Department of Commerce's Technology Administration. NIST promotes U.S. economic growth by working with industry to develop and apply technology, measurements, and standards.

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Steel. It is the strength and stability of skyscrapers and bridges spanning miles. It is the stuff of machine tools and mass manufacturing. It is the material of this century's two gargantuan war efforts. It is big, big business. In 1991, the U.S. steel industry sold $27.3 billion worth of material and, even after dramatically paring back its workforce, employed over 180,000 at 83 companies that shipped 78.8 million tons of steel.

From the early years of the century, the National Institute of Standards and Technology (known as the National Bureau of Standards until 1988) has been woven intimately into the evolutionary process by which steel has become one of the most reliable, most used, and most important materials of the age. Basic steel is made from iron whose normal carbon content of 4 percent or so by weight is reduced to usually less than 1 percent and whose properties are extremely sensitive to precise differences in composition. Special alloys depend on specific additions of other elements such as chromium for stainless steel, or chromium, tungsten, and vanadium for particularly hard tool steels. The central challenge of the industry is to produce the desired amount of steel with the specified properties with the greatest possible efficiency.

To some industry representatives, the most consistent and crucial kind of assistance that NIST has lent comes in the form of Standard Reference Materials, or SRMs as they are known in the trade. NIST ships over 125 steel-related SRMs that manufacturers use for calibrating instruments and validating in-house measurements of their products' chemical composition and physical properties such as hardness and electrical resistivity. Most of the steel-related SRMs are chips, disks, powders, or rods of steel alloys whose chemical composition has been measured with exceptional precision and accuracy.

In 1993 alone, NIST shipped 5,963 SRMs related to the chemical composition of steel alloys. These SRMs are as central to a steel company's operations as a tape measure is to a carpenter. "We use these things [SRMs] every day," says Thomas Dulski, a senior analytical chemist at Carpenter Technologies Corp., a century-old specialty steel company in Reading, Pa., which

> **"It would be a different and lesser industry if it had not been for NIST."**

supplied steel cables to the Wright Brothers and now specializes in high-end steel alloys for such things as surgical implants and parts for air bag systems. "I have worked in the industry for 30 years and I could not imagine the last 30 years without [SRMs and] interaction with NIST. It would be a different and lesser industry if it had not been for NIST."

Makers of huge volumes of basic steel rely just as heavily on NIST's SRMs, notes Dulski, who also is chairman of the steel analysis committee of ASTM (American Society for Testing and Materials), a voluntary standards organization through which industries develop consensus on technical issues such as manufacturing and testing practices. "Without those SRMs, their operations would be virtually impossible," Dulski notes.

The NIST connection with the steel industry reaches nearly as far back as NIST's creation by Congress in 1901 when the steel industry was still maturing from its industrial roots a few decades earlier.

At the time, railroad accidents were occurring at a rate of over 4,000 each year, causing an annual average of almost 13,000 deaths and injuries between 1902 and 1912. The blame, it seemed, rested with broken rails, wheels, flanges, and axles pushed to failure by a combination of excessive loads, inadequate maintenance, and

> **The steel industry now regularly interacts with NIST via cooperative research arrangements, consortia, workshops, trouble-shooting sessions, and other collaborative mechanisms.**

inferior iron and steel. Besides subjecting specimens from railroad disasters to chemical, mechanical, and microscopic investigations to uncover the bases for good and bad metal, NIST began supplying the steel industry with some of the first "standard materials," which companies used to better control the properties of their products. That was the start of an extended relationship between NIST and the steel industry, which Dulski says only becomes more critical and diverse today. Besides using SRMs, the steel industry now regularly interacts with NIST via cooperative research arrangements, consortia, workshops, trouble-shooting sessions, and other collaborative mechanisms whose common goal is to improve existing technologies and to develop new ones. It would seem that this NIST-industry connection is as strong as steel.

NIST Industrial Impact

Company:
U.S. industry

Business:
Everything from steel making to ice cream production

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Do not let the title fool you. *Temperature-Electromotive Force Reference Functions and Tables for the Letter-designated Thermocouple Types based on the ITS-90*—also mercifully dubbed "Monograph 175"—is near, if not always dear, to the hearts of most industries in the United States and, for that matter, the world.

Produced by a multidisciplinary team of engineers, physicists, and mathematicians at the National Institute of Standards and Technology, it is a Rosetta stone by which sense is made of literally billions of electrically based temperature measurements carried out every year using a ubiquitous type of thermometer known as a thermocouple. The technical data and formulas in Monograph 175 are to thermocouples what graduation lines are to an archetypal mercury-filled glass thermometer. Without these guideposts, neither type of measuring instrument would be able to provide precise and reliable measures of temperatures.

"Monograph 175 is the global authority" for those who make and use thermocouples, says Richard Park, chief engineer of Marlin Manufacturing Corp., a company in Cleveland, Ohio, that makes and sells several million dollars worth of thermocouples each year. Published in the fall of 1993, Monograph 175 replaces the previous version, Monograph 125, printed in 1974. The new tome incorporates an updated technical definition of the volt that renders the data more accurate. Also, it is based on the new International Temperature Scale of 1990, or ITS-90.

What are thermocouples that they need such attention by a federal laboratory? For one thing, they constitute big business. Nothing is more basic and critical for many industries than accurate measurements of the temperature of their processes, materials, instruments, and machinery. According to estimates cited by industry members, each year in the United States alone, up to 100 million new thermocouples begin service in venues as disparate as metallurgical furnaces, residential kitchen ovens, food processing vats, jet engines, chemical plants, medical clinics, and the many fabrication chambers of the microelectronics industry. The annual U.S. thermocouple market alone extends into the hundreds of millions of dollars range; its reach is much wider.

"Monograph 175 is the global authority" for those who make and use thermocouples.

Thermocouples serve the same function as glass thermometers, but they cover a far greater range—from a frigid –270 °C to a searing 1820 °C. Rather than relying on ups and downs of a mercury column, a thermocouple responds to temperature by producing a voltage across its metallic components. At the core of every thermocouple is a couple of wires or strips, each made of a different metal. Platinum and platinum/rhodium alloys are expensive materials well suited for measuring the temperature of molten steel in a steel-making furnace. Another example, a copper/copper-nickel alloy thermocouple, is less expensive and better for lower temperature venues such as a medical freezer.

The physical principle underlying a thermocouple's thermometric talent is that a temperature-dependent voltage forms between dissimilar metals that are touching each other if a temperature gradient exists. As the temperature changes, so too does the voltage. To make a practical device, manufacturers join the two metals to form the basic couple and then encase the assembly in a housing, such as a small tube of steel or within a ceramic matrix. Leads from the couple then feed into a voltmeter and from there into other electronic components that process the thermocouple's raw voltage signals into easily interpretable temperature readings.

Therein lies the connection between thermocouples and Monograph 175. Reading a thermocouple in the field requires prior knowledge of precisely what temperature each measured voltage of the working thermocouple ought to correspond to. It has been NIST's responsibility for decades to make the required series of voltage and temperature measurements to determine these correlations for each of eight standard types of thermocouple. This validation exercise is too time consuming, technically difficult, and expensive for most individual companies to afford.

"The service your group provides is invaluable to the quality of our industry and its continuous pursuit of consistently reliable and more accurate temperature sensing devices."

From the resulting data come look-up tables as well as mathematical formulas that enable users to translate and interpret the signals from their thermocouples and to recognize and diagnose problems in the instruments when they do arise. The data in Monograph 175 also serve as the ultimate standards for the metal suppliers and thermocouple makers whose materials and products need to perform within accepted tolerances of the values.

Monograph 175's authority is global, as Park pointed out, but he and others in the U.S. thermocouple industry say that they feel its value most right at home. Frank L. Johnson, president of the temperature measurement company JMS Southeast, Inc., of Statesville, N.C., expressed his company's view in a letter to George Burns, one of the lead NIST scientists on the project. He put it this way: "The service your group provides is invaluable to the quality of our industry and its continuous pursuit of consistently reliable and more accurate temperature sensing devices."

Metallurgist B. Forrest Hall, director of Research and Development at Hoskins Manufacturing Co. in Hamburg, Mich., says his company derives another value from the thermometry efforts at NIST. The 90-year-old company has been a dominant U.S. player in the business of making the metal wires for thermocouples—a task that requires precise metallurgical control. Hoskins traditionally has sold its metal components to other companies that assemble them into thermocouples. In May of 1994, however, Hoskins launched a new thermocouple product of its own. Prior to the launch, the company sent a prototype to NIST where members of the thermometry group subjected it to a 1,000-hour, high-temperature stability test. It remained within specifications cited in the monograph. "These data are key for us in introducing this product," says Hall.

Monograph 175 need never become a household reference, but in its own hidden way, it is very much that.

Baldrige National Quality Program Impacts

NIST Industrial Impact

Baldrige National Quality Program

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By the 1980s, many industry and government leaders in the United States firmly believed that a renewed emphasis on quality was no longer an option for American companies but a necessity. An ever growing world market was, and is, demanding quality goods and services. But many American businesses either didn't believe quality mattered for them or didn't know where to begin.

To accelerate a small, slowly growing U.S. quality movement, the Malcolm Baldrige National Quality Award was established by Congress in 1987 to promote quality awareness, to recognize quality achievements of U.S. companies, and to publicize successful quality strategies.

The Baldrige National Quality Program, developed and managed by NIST with the cooperation and financial support of the private sector, has proven to be a highly successful government and industry team effort. Over the past 6 years, the award program has encouraged thousands of U.S. companies to adopt quality improvement strategies. According to a recent report by the Conference Board, a private business membership organization, "A majority of large U.S. firms have used the criteria of the Malcolm Baldrige National Quality Award for self-improvement, and the evidence suggests a long-term link between use of the Baldrige criteria and improved business performance."

While quality management cannot guarantee success, the Baldrige award winning companies and many others believe that investing in quality can lead to outstanding returns, both for individual companies and the country.

For example, Thomas N. Kennedy, an executive with Solectron Corp., says, "We embraced the Baldrige criteria in 1989 and continue to use it as a template for process improvement as well as for driving leadership and employee involvement in all aspects of quality. As a result, annual revenue has increased over threefold in the last 4 years, from $130 million to $407 million. ... Net income has increased from $4.3 million to $14.5 million ... jobs have increased from 1,500 to over 3,700 and Solectron's customer satisfaction index grew to 93 percent." Based in California, Solectron, a 1991 Baldrige Award winner, provides manufacturing services to the electronics industry.

"The evidence suggests a long-term link between use of the Baldrige criteria and improved business performance."

In the early 1980s, senior management at Ames Rubber Corp., a 1993 Baldrige Award winner, realized that the international marketplace was changing dramatically. The New Jersey company of about 450 employees produces rubber rollers for office machines and highly specialized automotive parts. Even though the firm was doing well both in Europe and the United States, its customers were demanding products that met more exacting quality requirements at lower prices. Offshore competition was emerging, and it became evident that business as usual would not suffice.

With help from Xerox Corp., its prime customer, Ames Rubber instituted a new work process in 1987 based on quality management. Their success can be measured by a 3-year, 48-percent increase in productivity, a defect rate that has plummeted from 30,000 parts per million in 1989 to just 11, and savings from teammate ideas of over $1.2 million in 1993 alone.

Another 1993 Baldrige Award winner, Eastman Chemical Co., also looked to quality management as a way of getting back on track after losing market share of a major product in the late 1970s. Employing over 17,000, the company used the Baldrige Award criteria to help define its quality culture and regain its competitive edge.

Eastman Chemical is indeed competitive. For the past 4 years, over 70 percent of its worldwide customers have ranked Eastman as their number one supplier. Of the five factors customers believe are most important—product quality, product uniformity, supplier integrity, correct delivery, and reliability—Eastman has been rated outstanding for the past 7 years. And, quality management helped the company reduce the time to bring a new product to market by 50 percent since 1990.

The three publicly traded whole company Baldrige winners outperformed the Standard & Poor's 500 from the time they won through Sept. 30, 1993, by a factor of 8.6 to 1.

Says company president Earnie Deavenport, "Eastman, like other Baldrige winners, didn't apply the concepts of total quality management just to win an award. We did it to win customers. We did it to grow. We did it to prosper and to remain competitive in a world marketplace."

Other Baldrige winners have similar stories:

- At Federal Express Corp., a 1990 winner, ideas from Quality Action Teams have saved the company almost $29 million.
- At 1988 winner Globe Metallurgical, exports have grown from 2 percent to 20 percent of sales from 1988 to 1992, while overall sales grew by 24 percent.
- Customer accounts at Granite Rock Co., a 1992 winner, have increased 38 percent from 1989 through mid-1993.
- Since 1987, Motorola Inc., a 1988 winner, has increased its sales from $6.7 billion to $17 billion. In addition, the company has added 18,000 employees and productivity has increased 126 percent. Also, by reducing manufacturing defects, Motorola has saved $4.6 billion since 1987 in manufacturing costs.
- According to an article in the Oct. 18, 1993, *Business Week,* the three publicly traded whole company Baldrige winners outperformed the *Standard & Poor's* 500 from the time they won through Sept. 30, 1993, by a factor of 8.6 to 1.

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