ADVANCED TECHNOLOGY PROGRAM

PERFORMANCE OF COMPLETED PROJECTS

STATUS REPORT NUMBER 1

WILLIAM F. LONG

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Contents

Certain trade names and products are mentioned in the text and tables of the report in order to adequately identify the commercial accomplishments to date deriving from completed ATP-funded research projects. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology.

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The opinions expressed in this report are those of the author, and do not necessarily express those of the Advanced Technology Program, the National Institute of Standards and Technology, the Technology Administration, or the Department of Commerce. And, of course, any errors as to factual information are the responsibility of the author.

Executive Summary

Innovations that reduce the costs and improve the outcomes of medical care, improve the clarity of wireless communications, and enhance the quality of manufactured products are among the many significant achievements supported by the Advanced Technology Program (ATP).

The First Group of Completed ATP Projects

This review of the first group of completed projects suggests that billions of dollars are likely to flow into the U.S. economy, greatly exceeding the ATP's investment. Thus, the ATP appears to be on track in fulfilling its mission to stimulate economic growth by helping American companies and their research partners overcome significant technical challenges to produce economically valuable new technologies. The details are contained in this report.

Background

During the period 1990 through 1998, the ATP — the nation's civilian technology program charged with improving the competitiveness of U.S. businesses — announced 431 multi-year research project awards as a result of 39 merit-based, peer-review competitions. These projects cost a total of approximately $2.8 billion, of which industry committed slightly more than half, and the ATP the remainder.

More than 1,000 participants are involved in the single-applicant and joint venture projects. For-profit companies, universities, non-profit laboratories, and federal laboratories serve as formal and informal partners and subcontractors.

ATP-funded projects are characterized by ambitious scientific and technological goals with strong potential to accelerate the development of technologies that offer substantial economic returns to the United States. The benefits to the nation are expected to extend well beyond the direct benefits to the ATP award recipients. The ATP is administered by the National Institute of Standards and Technology (NIST), which is part of the Department of Commerce's Technology Administration.

Report Objective, Scope and Approach

Policy makers and other observers are keenly interested in how ATP-funded research projects are turning out, what technologies have been developed thus far, whether these technologies have yet been embodied in commercial products and processes, and the impact that ATP-funded research has made on the U.S. economy. By the end of March 1997, 38 of all research projects then announced had been completed and 12 others had been terminated.

This report — which is just one element of the ATP's evaluation program — provides an assessment of the status of these projects. It contains a general analysis of the 38 projects as a group, touching on important technology and commercialization issues by looking at several across-the-board factors. It also provides a snapshot of each of the 38 completed projects, describing the context in which it unfolded, noting major accomplishments as of mid-1998, and highlighting the future outlook for continued progress. The 12 terminated projects are treated in Appendix B.

It is important to note that this set of completed projects constitutes only a portion of ATP's portfolio, and that it is not a representative sample but simply the first group to be completed at the time the report was initiated. Because the technology development efforts are for the most part still works in progress, this report is not expected to be the last word on their accomplishments. It remains the task of future studies to provide a more comprehensive assessment of their long-run impacts.

Overview of Completed Projects

The 38 completed projects were carried out by 34 single applicants — mostly small companies — and 4 joint venture teams. The 55 participants came from 21 states. The projects addressed technical challenges in 7 key industrial sectors: 15 projects involved research in electronics, 6 in computing, information, and communications, 5 in biotechnology, 4 in energy and environment, 4 in manufacturing, 3 in materials, and 1 in chemicals and chemical processing.

The median duration of these projects was 3 years. The ATP contributed a total of $64.6 million to the 38 projects, accounting for slightly less than half of the total costs of the projects, and project participants contributed $65.7 million. The ATP contributed another $9.4 million to the 12 projects that were terminated before completion, bringing the total ATP spending on these 50 projects to $74.0 million.

Projected Broad-Based Economic Benefits

Although it is beyond the scope of this status report to calculate the economic returns from each individual project, an "investment portfolio" approach can be used to evaluate ATP's investment across the group of funded projects, much as an investor in stocks and bonds might do.

Other economic studies have already projected future returns from three of the completed projects, as follows: from the **Auto Body Consortium** "2mm" project — at

least $3 billion from quality improvements in U.S.-produced automobiles and associated market share gains; and from two medical technologies still in clinical trials (**Aastrom Biosciences'** stem cell production system and **Tissue Engineering's** prothesis material) a projected return of several billions of dollars.

Based on these figures, the estimated economic benefits to the nation resulting from just these three projects would exceed the ATP's costs for all 38 completed projects as well as the 12 terminated projects — indeed, the estimated benefits would exceed the total costs of all projects funded to date by the ATP. Furthermore, the returns could be much higher, given the considerable evidence that some of the other projects will also provide substantial economic benefits to the nation.

New Technologies; Early Products and Processes

The research conducted in the 38 completed projects produced a number of scientific discoveries, contributed to the U.S. knowledge base, and produced a number of breakthrough technologies. Although the full benefits of the technical achievements of the ATP projects will not be realized until more time has passed, allowing for their wider diffusion, the creation of technical knowledge and its diffusion to date represent critical first steps in realizing real-world benefits for the nation.

For 24 of the projects the new technologies have already been incorporated in new or improved commercial products or processes through the commercialization efforts of the companies. These products and processes include applications envisioned in the original proposals submitted to the ATP as well as unanticipated early spin-offs which exploit opportunities arising in the serendipitous process of discovery. Early revenue generation is important, particularly to small companies which must keep a close eye on cash flow for solvency. This early commercialization of the new technologies represents another critical step in the delivery of practical national benefits.

A few examples, illustrative of the technology development and commercialization achievements to date, are given below.

Technology Development and Commercialization Examples

Engineering Animation, in Ames, Iowa, developed core algorithms to enable the creation of three-dimensional images from sets of two-dimensional cross-sectional images of human body parts, and to provide animation for selected organs. After an initial failure to commercialize a high-cost system that incorporated the technology, the company adapted the technology for three CD-ROMs and two print publications in 1995, and has more recently created CD-ROMs that are bundled with medical books and sold as a package.

The company is now active in a multiplicity of applications featuring three-dimensional animations which utilize computer visualization and computational dynamics, in sectors as diverse as medical education, manufacturing design, and entertainment. The company started receiving outside recognition for its technical progress in 1994, while it was working on the ATP project. Since the project ended in 1995, it has experienced outstanding growth as its technology has been applied to more and more fields, and it has been recently recognized by *Individual Investor*, *Business Week*, and *Forbes ASAP* magazines as one of the best technology companies in the country.

Illinois Superconductor, in Mount Prospect, Illinois, developed new processes for fabricating thick-film, high-temperature superconducting (HTS) materials and demonstrated their use in wireless communications. By finding a way to make HTS coatings on inexpensive substrates, the company overcame the substantial difficulties involved in making the large, geometrically complex components needed to handle the radio frequency spectrum.

Superconducting components lower costs and improve services by extending the range of signal transmission, increasing receiver sensitivity, and improving frequency stability, thereby extending the range of base stations and reducing the numbers of base stations needed. The new technologies have been incorporated into commercial products that are already being used in 12 cities.

The **Auto Body Consortium**, a Michigan-based joint venture — a group of small- and medium-sized auto tooling and engineering service suppliers, two universities and two auto manufacturers — solved an assortment of long-standing problems on assembly lines by developing new measurement and process control technologies that cut dimensional variation in auto body assembly down to a world-class standard of two millimeters and below. A tighter fit results in higher-quality vehicles and reduced costs.

The new technologies have been incorporated by suppliers in assembly line equipment and put to use in 6 of 10 Chrysler plants and 16 of 31 General Motors plants in the United States and Canada. Net production costs have been reduced by an estimated $10 to $25 per vehicle, translating into millions of dollars of savings per year in plants now using the new technologies. The project team has also published a manual on the new technologies to help extend their use throughout the supply chain and the aerospace, appliance, metal furniture, and other industries that use automation to assemble metal parts.

Peer Recognition of Technical Achievements

The technical achievements of some of the completed projects were honored by outside organizations, including trade associations and technical journals. In 1996 alone, the following six awards were given:

- *R&D* magazine — an R&D 100 award to **American Superconductor**, in Westborough, Massachusetts, for its development of CryoSaver current leads;
- *Industry Week* magazine — one of 25 Technology of the Year Awards to **American Superconductor**, for applications of superconducting wire;
- *Industry Week* magazine — one of 25 Technology of the Year Awards to **Engineering Animation**, in Ames, Iowa, for its interactive 3D visualization products used in the manufacturing sector for product development;
- *Discover* magazine — one of 36 finalists for Technology of the Year to **HelpMate Robotics**, in Danbury, Connecticut, for the HelpMate robot used in hospitals;
- *Microwave & RF* magazine — one of the Top Products of 1996 to **Illinois Superconductor**, in Mt. Prospect, Illinois, for cellular phone site filters and superconducting ceramics;
- *Computerworld* magazine — finalist for the Smithsonian Innovator Medal to **Molecular Simulations**, in San Diego, California, for advances in software to help scientists simulate and visualize complex molecules.

Dissemination of New Technical Knowledge

The new knowledge and technologies are being disseminated widely to promote broader application across the economy and further broad-based benefits. Dissemination takes place in several ways. For instance, inventions that are both novel and useful can be patented and licensed to others for their use. Of the 38 completed projects, 15 have been granted patents so far, and three projects produced at least 5 patents each. For some projects, patent applications have been filed but the patent has not yet been granted.

Products can be reverse engineered to determine the technology embedded in them. The substantial number of products thus far released to markets will further the dissemination of new technical knowledge. Other parties can not only use them but attempt to discover how they work by observation and testing.

Knowledge has also been shared through the numerous formal and informal arrangements with partners, intermediate customers, and end users, and through professional conferences and technical publications. Of the completed projects, 27 involved the sharing of technical information with a variety of collaborators: joint venture participants, subcontractors, and informal partners. Of the completed projects, 16 led to publications in technical and professional journals, and many awardees reported multiple publications — more than 20 in several cases.

Small Company Growth and Attraction of Capital

Besides the sales of products and processes incorporating ATP-funded advances, other signals also reveal that a company possesses valuable technology and is probably on the path toward commercialization. These signals include company growth and initial public offerings (IPOs) of stock.

Of the 27 small single-applicant awardees, 22 experienced some growth in employment, and 16 of these have at least doubled in size since the start of the ATP project. One company reported a 19-fold increase in staff. Of the 21 single-applicant awardees that were privately held at the beginning of their ATP projects, five companies raised capital for growth by conducting IPOs during the project, and a sixth did so afterwards.

Why ATP?

The ATP either made research and commercialization possible, or significantly accelerated it, according to company interviews. For 32 completed projects, 21 would not have been undertaken at all without ATP funding, and 11 would have begun at a later date and proceeded at a slower pace. (Personnel changes, severe company financial distress, or lack of clarity in responses to interview questions made it impossible to include six of the 38 projects in this tabulation.)

In addition, ATP funding significantly accelerated the time-to-market for the new technologies, according to the project participants. Of the 32 projects, 13 awardees said the ATP funding helped them raise additional capital, and 23 said it boosted their ability to find partners to pursue continued development and commercialization.

Examples of company comments about the role of the ATP include:

- **Torrent Systems** — It is doubtful that the technology could have been successfully developed at all; venture capital funding had been sought but was unavailable.
- **AlliedSignal** — The company would have needed another five years to reach this stage of development.
- **Diamond Semiconductor Group** — The company would have been unable to do the research or survive as a company; its only other alternative then was to become part of a foreign company.
- **Nonvolatile Electronics** — ATP funding enabled the project to be done, prevented the company from failing, and improved the company's ability to attract capital from other sources.
- **FSI International** — The award enabled FSI to collaborate with Massachusetts Institute of Technology researchers.
- **Light Age** — The visibility generated by winning the ATP award helped Light Age establish agreements with research partners and, coupled with the success of the ATP project, enabled it to secure additional funding from private investors.
- **Thomas Electronics** — Without the ATP award, the company would have struggled along with its conventional CRT technology and would have stood virtually no chance of competing with other display-component suppliers, all of which are foreign companies.

Introduction

Industry has proposed 3,585 projects to the ATP since 1990, of which 431, or 12 percent, have been selected by the ATP for funding. Fifty of the 431 ATP projects were either completed or terminated as of March 1997, which is when this study began. Of the 50 projects, 38 were completed, and 12 were terminated before completion. This study focuses on these first 38 completed projects. A series of sequential studies will address additional ATP projects as they are completed or terminated.

Technology Development Proposals to the ATP

Projects are proposed to the ATP by U.S. companies. Proposals that score high in terms of their scientific/technical merit and their economic merit are selected for ATP cost-share awards. The reviews are carried out in rigorous peer-review competitions. All proposals are reviewed by government scientists and engineers who are expert in the relevant technology areas. They are also reviewed by business, industry, and economic experts who judge the potential of the proposed project to deliver broadly based economic benefits to the nation — including large benefits extending beyond the award recipient, i.e., "spillovers". The ATP issues a proposal preparation kit that presents and explains the selection criteria to prospective proposers and provides guidance on preparing proposals.[1]

ATP Project Evaluation

The Economic Assessment Office (EAO) of the ATP is charged with evaluating the performance of funded projects. One element of the EAO's evaluation plan[2] is to provide an interim assessment of the status of all completed ATP projects, this being the first status report. Another element is to conduct detailed economic case studies of selected projects, several of which are drawn upon and referenced in this study. Other evaluation activities of the EAO include database development, surveys, statistical and econometric studies, model development, and special issues studies.[3]

"Completed" and "Terminated" Projects Defined

For the purposes of this study, a "completed" project is defined as one for which a final report has been filed with the ATP, the financial and other paperwork required for close-out has been done, and the National Institute for Standards and Technology (NIST) Grants Office has notified the ATP that it considers the project completed. A "terminated" project is defined as one that either was selected in an ATP competition and announced but never officially started, or one that started but was closed for some reason before the completion date, with a substantial amount of the technical work still unfinished.

Sources of Information

Information contained in the individual project reports in Chapters 2-8 comes from several sources: documents filed by project participants; conversations with ATP staff familiar with the project; public documents, such as patent data from the U.S. Patent and Trademark Office, academic and other professional literature, trade and business literature, news reports, and filings at the Securities and Exchange Commission; previous EAO studies; and interviews with company project staff. Each of the individual project write-ups was reviewed for accuracy by the awardee and ATP staff.

Report Organization

Chapter 1 provides a summary overview of the 38 completed projects as a group. First, the portfolio is characterized in terms of technologies, company size, and other features. Then, the timing of the various stages of technology development and commercialization is discussed. Evidence of the gains in technical knowledge is covered, as is dissemination of the new knowledge, with special attention to the availability of products and processes that have been introduced to the market. The chapter closes with an overview of the broad-based benefits that this portfolio of projects is likely to produce.

The individual project reports are presented in Chapters 2-8, organized by technology group. For each completed project, major accomplishments and the outlook for continued progress are highlighted. A detailed account of how the project has unfolded is given, with attention to technical and commercial goals and achievements, information about technology diffusion, and views about the role played by ATP's funding.

Appendix A presents brief descriptions of technical and commercial achievements of the completed projects in tabular form. Appendix B provides a brief discussion of the 12 terminated projects.

Chapter 1

Overview of Completed Projects

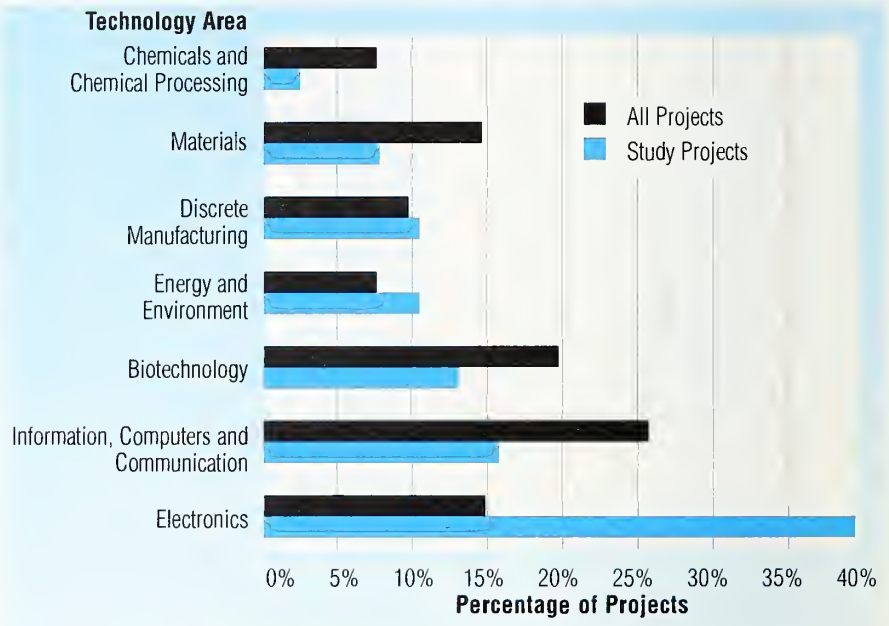
Characteristics of the Projects

The 38 completed projects within the ATP portfolio differ in many respects. They vary in terms of costs, duration, form (single applicant or joint venture), industry, size of company, public/private ownership status, type of participating organizations, research problems addressed, technology developed and the degree of progress made toward meeting technical and business goals.

Single Applicants and Joint Ventures

Thirty-four of the completed projects were proposed by single applicants, with the other four being proposed by joint ventures. For the majority of the first-completed projects to be single applicants was expected, since 285 of the 431 projects announced through 1998 were single-applicant projects, while 146 were joint ventures. Also single-applicant projects tend to be shorter in duration, completing sooner than most joint ventures. Thirty-three of the single applicants were for-profit companies, and one was a nonprofit institute.[1]

Figure 1. Distribution of Projects by Technology Area



Size of Companies

Among the thirty-three companies in single-applicant projects, 27 were small companies, where "small" is defined as having fewer than 500 employees. One was a medium-sized company, and the other five were large companies, as defined as Fortune 500 or equivalent firms. Small companies also participated in joint venture projects, but these are not separately identified here.

Public and Private Companies

Of the 27 single applicants that were small companies, 21 were privately held companies at the time their projects started. A number of these have since gone public, as discussed later in this chapter.

A Variety of Technologies

The 38 completed projects fall into seven different technology areas, as shown in Figure 1, where percentages of the 38 completed projects within the areas are shown in the lower of the two bars. The highest concentration, with 15 projects, is in Electronics, followed by Information, Computers and Communication, with six. The lowest is in Chemicals and Chemical Processing, with only one project. For comparison purposes, Figure 1, also shows, in the upper of the two bars, the distribution across the same seven technology areas for all 431 projects awarded through 1998. The Electronics area is much more strongly represented in the set of 38 completed projects reviewed in this study than in the portfolio of all ATP projects.

Table 1. Single-Applicant Project Cost

	ATP Share Total		(ATP + Industry)	
(millions)	Number of Projects	Percentage of Total Projects	Number of Projects	Percentage of Total Projects[2]
≤ $1	5	15%	2	6%
> $1, ≤ $2	29	85%	5	15%
> $2, ≤ $3			14	41%
> $3, ≤ $4			5	15%
> $4, ≤ $5			5	15%
> $5, ≤ $6			3	9%
Total	**34**		**34**	

Table 2. Joint Venture Project Cost

	ATP Share Total		(ATP + Industry)	
(millions)	Number of Projects	Percentage of Total Projects	Number of Projects	Percentage of Total Projects
≤ $5	3	75%	1	25%
> $5, ≤ $10	1	25%	1	25%
> $10, ≤ $15			2	50%
Total	**4**		**4**	

Duration of Projects

The 38 projects also varied in duration. The median length was three years, the maximum allowable length for single-applicant projects. Half of the projects lasted 33 to 36 months. Another group clustered around the two-year mark. The two projects that lasted longer than 36 months were joint venture projects, which can last a maximum of five years.

Differences in Costs of the Projects

The 38 projects varied significantly in terms of cost, as shown in Tables 1 and 2. Both the ATP share and the total cost (ATP share plus industry share) are tabulated. Joint venture projects, for which project costs are not capped, typically cost more than single-applicant projects, but even within the two groups, marked differences occur.

Rules concerning the share of project costs the ATP will contribute differ between single applicants and joint ventures. Single-applicant companies are required to cover all their indirect costs, and the ATP may cover up to 100 percent of direct project costs.[3] Since projects from small companies typically have smaller indirect costs relative to direct costs, it is likely that the ATP will contribute a larger percentage of total project costs for these projects than for others. The large percentage of single-applicants that are small companies (27 out of 34) accounts for the fact that ATP paid more than half the costs for many of these projects.

The cost-share rules affect the cost data presented in the 38 individual project reports (displayed project by project in Chapters 2-8). Tables 1 and 2 are based on those data. For the 34 single applicants, the industry contribution to their indirect costs is the amount given in the original ATP proposal, unless the company supplied a different amount for this study. None of these amounts was audited. For the remaining four projects, the industry contribution shown is the amount actually spent by project participants, as audited.

Among the 34 single-applicant projects, two had total costs (ATP + industry) of a million dollars or less. At the other end of the cost range, three projects had total costs between $5 million and $6 million. Altogether, approximately $98.4 million was spent for the 34 single-applicant projects, with an average total cost of about $2.9 million per project.

Cost data for the four joint ventures are summarized in Table 2. The smallest project, included in the first row, had a total cost (ATP + industry) of less than $2 million. The largest, included in the third row, had a total cost of almost $14 million. Altogether, approximately $31.9 million was spent on the four projects. The average total cost per joint venture project was about $7.9 million.

The ATP contributed $64.6 million to the 38 projects, providing slightly less than half the total funds. It contributed more than 50 percent of the total cost for 19 projects and less than 50 percent for 19. In the case of the joint ventures, the ATP's contribution was always less than half of total costs.

Timeline of Expected ATP Project Activities and Impacts

The ultimate success of the ATP projects is determined by activities and impacts that occur within the award-recipient companies and in the larger economy before, during and after each project.

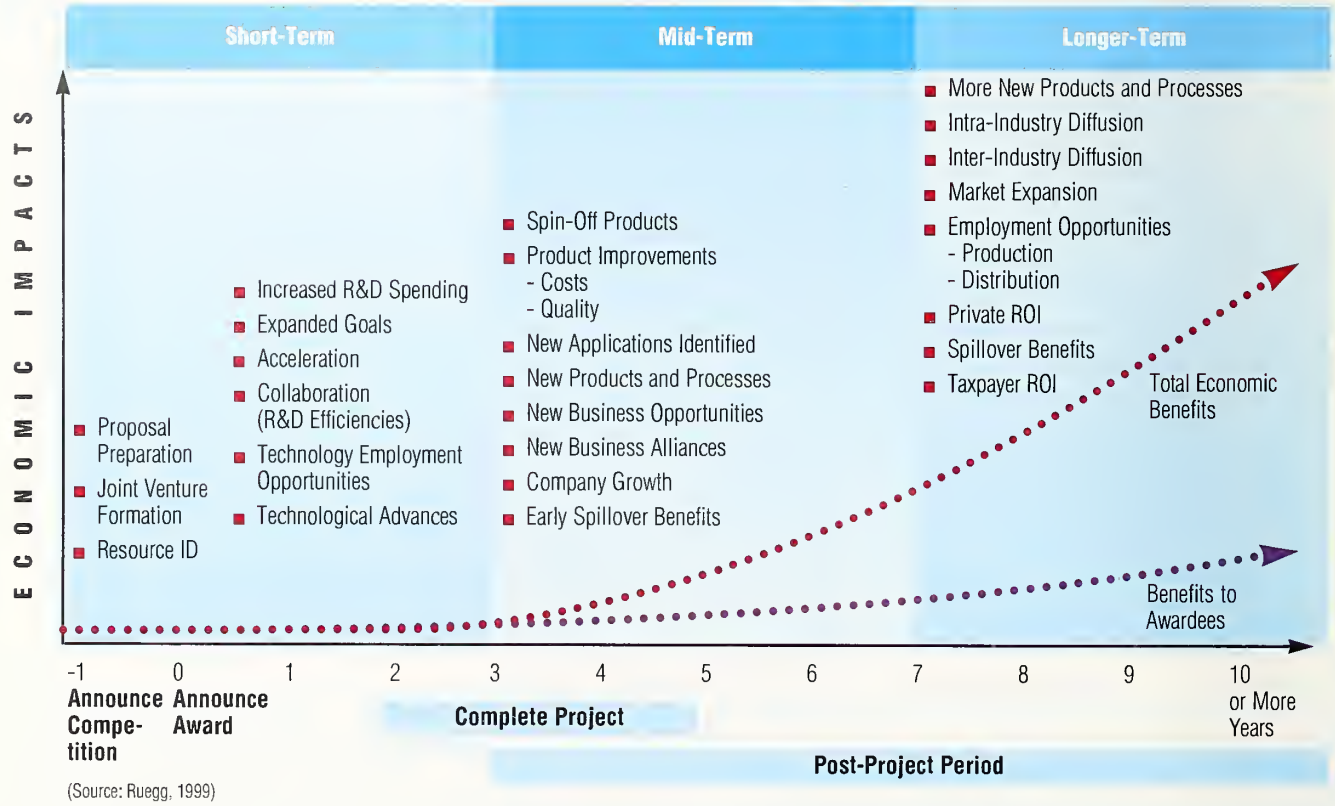
Activities and Impacts Within Firms

The following activities and impacts are related mainly to the award recipients: forming the initial idea; establishing collaborative research relationships; developing a research agenda; applying to the ATP for an award; carrying out the research; publishing results, filing for patents, and licensing the technology to others; conducting further post-ATP project research; attracting other sources of funding; conducting marketing studies and other precommercialization activities; forming new alliances for commercialization; developing products and processes that use the new technology; producing, selling and distributing the new goods or services; generating revenue; and building the business.[4]

Activities and Impacts in the Broader Economy

Activities and impacts that occur in the broader economy — outside the immediate influence of ATP award recipients — include receipt of benefits by purchasers of the new products or users of the new processes[5] in the course of their business operations, receipt of benefits by other companies that are able to imitate the technology or benefit in other ways from knowledge derived from the technology, and receipt of benefits by ultimate consumers of goods and services embodying the technologies.

Figure 2: Conceptual Timeline of ATP's Expected Impacts



(Source: Ruegg, 1999)

Timing of Activities and Impacts — A Conceptual Picture

Technology area, market conditions and the regulatory environment vary significantly across ATP-funded projects, and these differences can substantially affect the time path for the activities listed above. Hence, the time required for technology development, commercialization and diffusion varies greatly among the projects, even when they stay on track.

Figure 2 illustrates in concept how the time path of a successful project might unfold, starting with the announcement of a competition by the ATP.[6] On this conceptual chart, economic impacts are depicted on the vertical scale, and time on the horizontal scale. The lower of the two curves, rising from left to right, shows returns to the project innovators increasing over time as they commercialize it. The upper curve shows returns to the economy at large increasing as the technology diffuses into wider use. The difference between the two curves reflects benefits that "spill over" to those outside the project.

The chart is annotated with events that may lead, or contribute, to the generation of economic benefits during three time periods designated by the shading. Upon announcement of a competition by ATP, companies begin to prepare their proposal, form collaborative relationships, and identify resources. If they receive an ATP award, they tend to increase R&D spending, expand goals, accelerate research, hire scientists and engineers, and make technical progress.[7] These developments occur in the short-term, shown here as extending through to the approximate average project length of three years.

As a successful ATP project ends, the pace of commercialization activity surrounding the technology generally will pick up as depicted in the "mid-term" stage. Then, in the longer-term, wider diffusion of the technology — within the initially targeted industry and, for multi-use technologies, across industry sectors — is expected to occur as it is incorporated into new products and processes.

Two Specific Timelines — Differences and Similarities

Figure 3, on the next two pages, illustrates the specific time paths for two of the 38 projects. One project does not yet have a product or process on the market, the other does. One requires regulatory approval, the other does not. One company is publicly traded, the other is privately held. One is in biotechnology, the other is in computer software. Still, as shown in Figure 3, many activities appear in both timelines — but at very different times.

Medical Technology Requiring FDA Approval — Aastrom Biosciences

Growing out of research done by three faculty members at the University of Michigan in Ann Arbor, the idea of a bioreactor to grow human stem cells outside the body began to take shape in the mid-1980s. In 1988, the professors founded Aastrom Biosciences (while continuing their university research) and later brought in a partner with business experience. In 1991, with four employees, the company applied for an ATP award. Significant events for this project are shown in the top panel of Figure 3 on the following page.

After two years of research, Aastrom met the technical goals of its ATP project. Along the way the company invested heavily in protecting its discoveries by filing for numerous patents. It also submitted a substantial number of technical papers documenting its progress to professional societies and journals.

The technology for growing stem cells was embodied in the AastromReplicell™ Cell Production System (System). Because it will be used for human medical purposes, the System must be approved by the Food and Drug Administration (FDA), but only after successful completion of clinical trials and other tests. Several tests using human subjects have been conducted since the ATP project ended, with each test producing favorable results. If that success continues, the device will likely be approved and available for sale in the next one to three years.

The need for FDA approval creates a lag of several years between the start of commercialization efforts and the ultimate sale of the product. In this case, the effort is now in its 11th year, and the total time from concept to first commercial sale of the Aastrom System will likely be 12 to 14 years. Nevertheless, there are factors — including test results from cancer patients and the positive response of investors to Aastrom's stock offerings — which suggest that the technology has a very bright future.

Parallel Processor Computer Technology With Immediate Applications — Torrent Systems

The idea for this project came from the work and conversations of two computer programmers who formed a company in 1993 and applied the same year for ATP funding for a project which started the following year. The project made rapid progress in developing parallel processing technology, and it began to receive inquiries from potential customers about using the technology in new software applications. Torrent requested that the project be shortened so that the company could move quickly to commercialize products incorporating the new technology. Significant events for this project are shown in the bottom panel of Figure 3.

Unlike developers of medical devices, computer software vendors are not required to have any kind of approval to sell their products. Thus, Torrent was able to enter into licensing agreements with other companies a mere 18 months after starting its ATP project.

The huge difference in development times for these two technologies is illustrated in Figure 3, where key events are graphed against the same time scale. The first event for Aastrom's System was 12 years in the past, and broad economic benefits still lie a few years in the future. The first event for Torrent's new parallel processing technology was the company's founding in 1993, and customers were already using the product and receiving its benefits in 1996. Yet both projects stayed essentially on track and have largely continued to meet ATP's expectations.

Figure 3a. Aastrom Biosciences Example from the ATP 38 Project Sample — Successful Project, Slow Commercialization

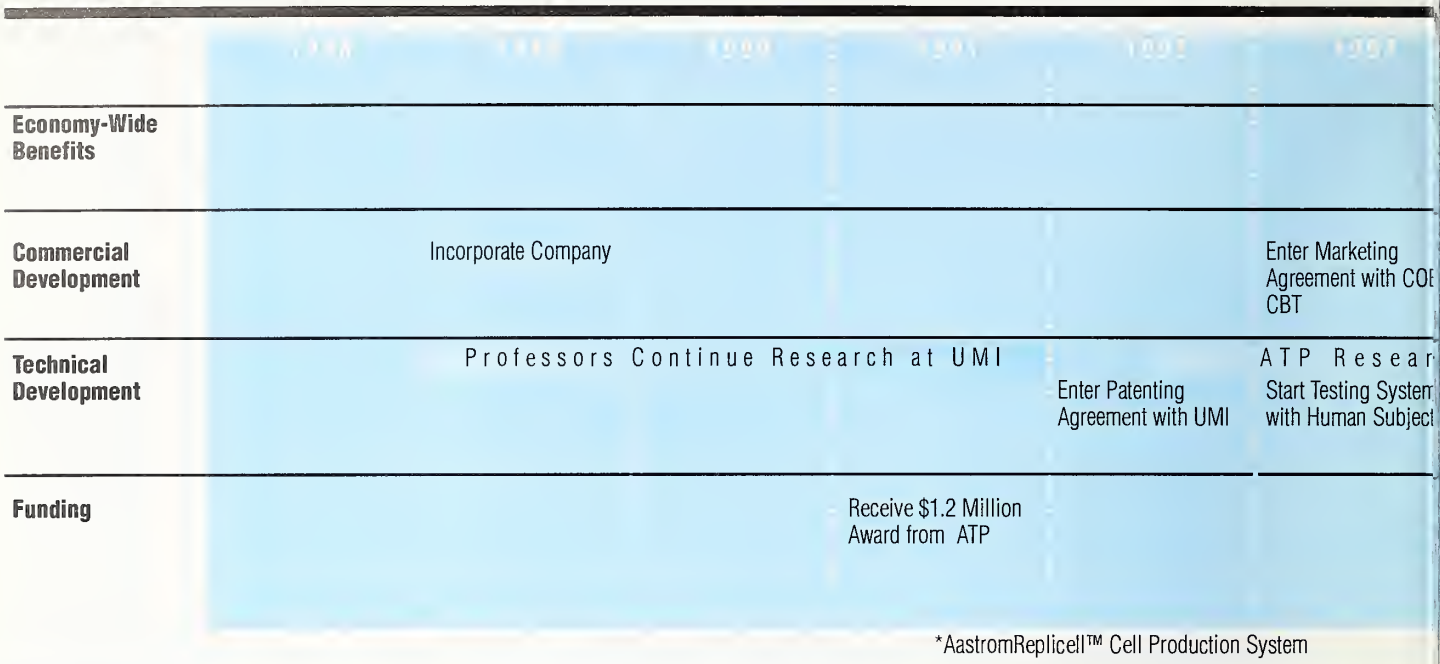
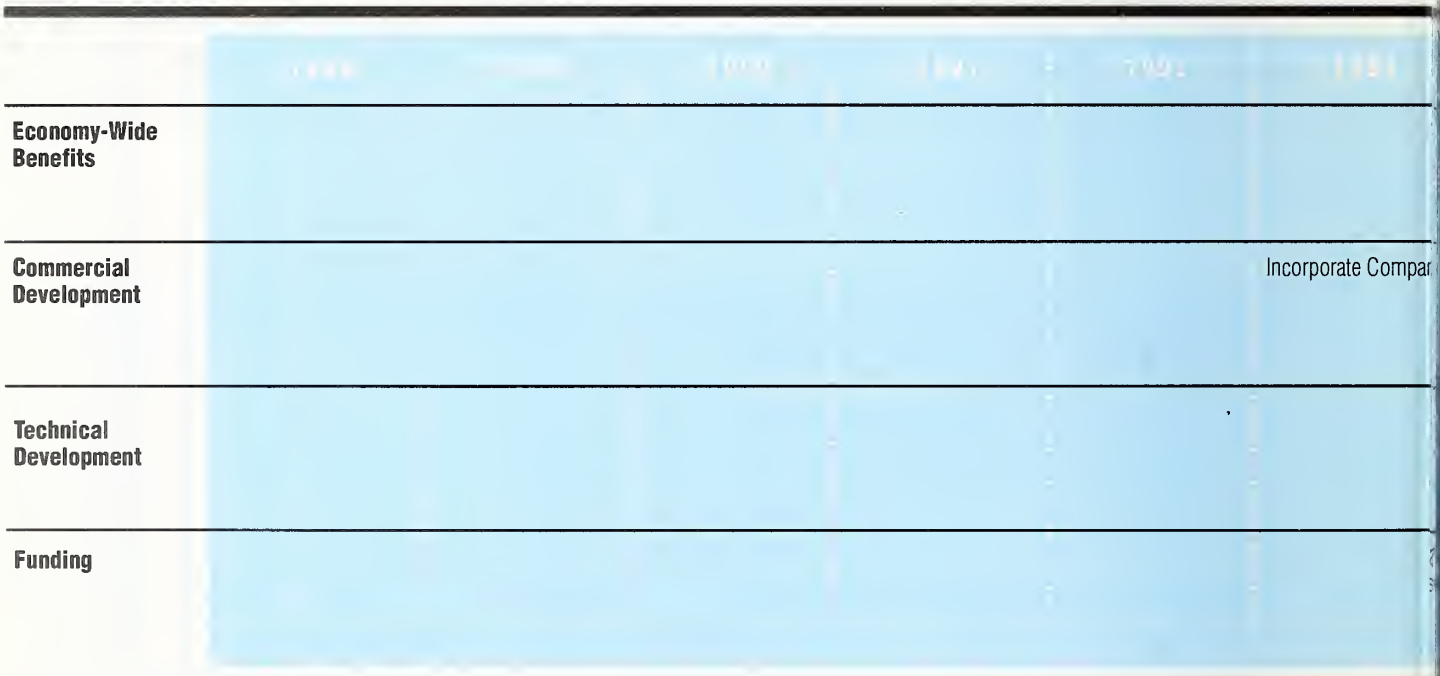


Figure 3b. Torrent Systems Example from the ATP 38 Project Sample — Successful Project, Fast Commercialization



ATP Awards — Part of a Larger Funding Picture

For some projects, such as Torrent's, funding from the ATP constitutes a substantial portion of the total capital used to support research and development and, indeed, a substantial share of the overall costs. For most projects, including Aastrom's, ATP funds are a relatively small percentage of the total amounts that will ultimately be spent to bring the technology into use. Commercialization costs typically dwarf research costs. Nonetheless, ATP funding — targeted at a critical stage where technical risks tend to inhibit private investors — may be essential for ultimate success, as was the case for the Torrent and Aastrom projects.

Funding by the ATP has been shown by another study[8] to address two types of timing

		60 Test Patients Benefitting		Large Number of Cancer Patients Are Helped
	Enter Marketing Agreement with Rhone-Poulenc	Enter Agreements to Manufacture System* Components		FDA Approves Patient Use of System*
				Start Selling System*
der Way	Apply for System* Bioreactor Patent	Report Clinical Results for Cancer Patients	Report Clinical Results for More Patients	
	Continue Testing System with Human Subjects	Receive Bioreactor Patent		
	Receive $35 Million from Rhone-Poulenc	Receive $21 Million from IPO		
		Receive $11 Million from Additional Stock Offering		

			United Airlines Starts Using the Product for Improved Scheduling	United Airlines Increases Revenue by Millions of $
				Others Benefit from Use
	Develop Orchestrate™	License Orchestrate™ to Additional Users	IBM Partnership Integrates Hardware with Orchestrate™	Identify New Applications
	Introduce Orchestrate™ to Market for Licensing	Form Marketing Partnerships		Form New Partnerships
	ATP Research Under Way			
ve $1.2 Million Award from ATP	Receive $3.8 Million in Private Capital			
	Receive $6.2 Million in Private Capital			
				Receive License Fees for Orchestrate™

issues: overcoming an inability to start a project and speeding up progress needed to address a critical window of opportunity. Thus, even though ATP funds will in most cases amount to a relatively small share of the total costs expended to bring a technology to fruition, they can be a key factor in making it happen.

Of course, from an evaluation standpoint, multiple funding sources make the task of assigning cause and effect relationships more problematic. Which funding dollars caused what effect? One aspect of this study, therefore, has been to try to identify the role that the ATP has played in the developments to date.

Gains in Technical Knowledge

A major goal of the ATP is to build the nation's scientific and technical knowledge base. Each of the 38 completed ATP projects targeted a number of specific technical knowledge discovery goals, which are described in Chapters 2-8. Those chapters also briefly describe, in non-technical language, the technical advances of the 38 completed projects. More detailed descriptions of the research are available in the scientific papers and patent applications generated by the projects. The following section provides an overview of the wealth of technical knowledge generated by these projects.

A Host of New Technologies and Knowledge Gains

A number of new technologies have emerged from the 38 completed projects, and all of the projects have added something to the U.S. scientific and technical knowledge base. Even those projects that were not fully successful in achieving all of their research goals, or those that have not been followed by strong progress in commercialization, have achieved knowledge gains—of course, some more than others. Indeed, even the projects that were carried out by the several companies that have since ceased operations, or that have stopped work in the technology area, resulted in knowledge gains — albeit the direct market route of diffusion of the knowledge gains in those cases may be lost or postponed.

Advances were made in each of the seven technologies areas. In the field of electronics, advances were made, for example, in new processes and procedures for altering electrical properties of materials through ion implantation, for fabricating, testing and aligning extremely precise aspherical, multilayer-coated mirrors, for interconnecting thin-film integrated circuits, for constructing new devices utilizing the giant magnetoresistance effect, and for growing large silicon carbide single crystals.

In the field of information technology, examples of knowledge gains are embodied in new mathematical algorithms useful for restoration of digitized video images and for animated visualization, and in component-based software tools for building parallel processor applications.

In the field of biotechnology, knowledge gains include how to grow human stem cells outside the human body in large quantities at reasonable cost, how to deactivate viral contaminants in blood and other fluids, how to genetically engineer plant extracts, as well as techniques for rebuilding lost or damaged human tissues with engineered tissue.

In the fields of energy supply and environmental protection, knowledge gains are reflected in the new fabrication processes that were developed for superconducting materials; in the improved ability to control microstructure of aerogels, and in new methods of compatibilizing polymers for recycling.

Knowledge gains important to discrete manufacturing include new ways to measure and control dimensional variation in parts assembly, and intelligent thermal-error correction techniques for machine control. In the field of materials technology, knowledge gains led to new processes for safer, less costly near-net-shape gelcasting and new ways of producing optoelectronic polymers with desirable characteristics. Finally, in the field of chemicals and chemical processing, advances were made in multiphoton detection methods.

These and other technologies developed in the 38 projects are listed in Tables A1-A7 of Appendix A, column B, together with a listing in column C of commercial products or processes that are based on the technologies. This set of tables is provided for convenient, quick reference by the reader.

While the entries are arranged according to the seven technology areas which are used in Chapters 2-8, it should be noted that most of these projects and the knowledge developed in them do not lend themselves to easy classification. Most entail a mixture of technologies and interdisciplinary know-how; many could easily be put into one or more of the other categories shown. For example, the thermal-error correction technology is listed under "discrete manufacturing," but it could also fit well in the "information technology" category. As another example, the process technology for superconducting materials is listed under "energy and

Table 3. Outside Recognition of Technical Achievements in the First 38 Completed ATP-Funded Projects

Project Awardee	Year	Awarding Organization	Award
American Superconductor	1996	*R&D* magazine	One of the 100 most important innovations of the year.
American Superconductor	1996	*Industry Week* magazine	Technology of the Year Award.
Communication Intelligence #1	1997	Arthritis Foundation	"Ease-of-Use Seal of Commendation" for the development of natural handwriting technology, for use by disabled people who have trouble with keyboard entry.
DuPont	1993	*Microwave & RF* magazine	One of the Top Products of 1993, for high-temperature superconductivity component technology.
Engineering Animation	1994	*Computerworld* magazine	Smithsonian Award, for the use of information technology in the field of medicine.
Engineering Animation	1995	Association of Medical Illustrators	Award of Excellence in Animation.
Engineering Animation	1995	International ANNIE Awards	Finalist, together with Walt Disney, for best animations in the film industry.
Engineering Animation	1996	*Industry Week* magazine	One of the 25 Technologies of the Year, for interactive 3D visualization and dynamics software used for product development.
HelpMate Robotics	1996	*Discover* magazine	One of 36 finalists for Technology of the Year, for the HelpMate robot used in hospitals.
HelpMate Robotics	1997	Science and Technology Foundation of Japan	Japan Prize, to CEO Joseph Engelberger, for "systems engineering for an artifactual environment."
Illinois Superconductor	1996	*Microwave & RF* magazine	One of the Top Products of 1996, for cellular phone site filters and superconducting ceramics.
Illinois Superconductor	1997	American Ceramic Society	Corporate Technical Achievement Award.
Molecular Simulations	1996	*Computerworld* magazine	Finalist for Smithsonian Award, the 1996 Innovator Medal.

environment," but could fit well under "materials."

Another point to notice is the great diversity of technologies resulting from these projects. Knowledge gains range from mathematical algorithms underlying new software tools, to the science of growing human tissue, to new techniques for fabricating high-temperature superconducting devices. The diversity reflects the fact that all but one[9] of the projects were funded in the ATP's General Competitions, which cast a wide net for good ideas regardless of technology area.

Outside Recognition for Technology Advances

Although it is beyond the scope of this report to rate the degree of significance of the scientific and technical knowledge gained from the projects, various forms of recognition by other organizations indicate that outside parties see considerable value in the technical discoveries of some of the projects. Table 3 provides information about such outside recognition.[10]

Dissemination of New Knowledge

The pursuit of the tasks in a project usually produces a number of distinguishable outcomes. Projects generate new knowledge about how to apply underlying scientific principles to develop products or processes. If the technology is commercially successful, it provides the basis for products or processes that can be marketed. And with commercial success and dissemination of the newly gained knowledge comes the possibility of benefiting the economy in ways that go beyond the benefits received directly by the innovating firm.

Parties Other than the Innovator Can Benefit

If a project creates and disseminates new technical knowledge, parties other than the developers tend to benefit. That is true even if the new knowledge takes the form of "We tried to develop this technology using the following approaches, and we were unsuccessful." In that case, others may use this information to avoid pursuing comparable methods that would likely be wasteful. Or an underlying technology may be successfully developed even though a larger commercialization goal is not met.

New knowledge developed in a project can be diffused in a variety of ways. One way, discussed in the next section, is the marketing of new goods or services. Other ways relevant to the 38 completed ATP projects are publication by the U.S. Patent and Trademark Office (USPTO) of patents granted; registration of copyrights; interactions among research partners, suppliers, customers and others; preparation of technical papers that are published or presented at conferences; distribution of nonproprietary project descriptions by government funding agencies; and project-related workshops and meetings.

Public Disclosure of Patent Filing Information

When applying for a patent, an inventor must explicitly describe the invention. Because patent law requires that the invention be both novel and useful, the inventor must demonstrate that the invention is essentially different from any other invention and must describe how it can be used. When an application is filed, the USPTO discloses neither the application nor the fact that it has been filed. But when the USPTO grants a patent, the full application text describing how the invention may be used and how it is related to other technologies is put into the public record.

The decision to seek patent protection for intellectual property is influenced by many factors, including the ease with which others can copy the property's intellectual content and the difficulty of defending a patent position from infringers. Some companies, therefore, may decide that patent protection is not worth its expense, or they may decide that a strategy of trade secrets and speed to market is a more effective strategy. Or patents may be filed at an earlier stage in the process and trade secrets used in later stages.

The importance of patents as a strategy to protect intellectual property varies among technology fields. In some, particularly computer software, patenting is rarely a viable option. Among the six projects that involve only software, no patents have been granted and only one patent was sought.

In other fields patents are important, and many were sought for technologies that emerged from ATP projects. American Superconductor, for example, has received six patents for its ATP-funded electric-motor technology and has eight applications still under consideration.

Even when patent protection is sought, there are substantial differences across industries in the lag time between patent application and grant. Consequently, the absence of patents at this time does not imply that patents will not be granted in the future. An application may have been filed but the patent not yet granted.

In yet other fields, patenting typically occurs at the very early stages of a project, when the basic ideas are forming. The consequences of this fact might show an ATP-funded project without patent activity, because the ATP funding comes after the very early stages of the R&D efforts.

Even with all these considerations, patent statistics contain useful information about technology development and dissemination of the new knowledge. Fifteen of the projects have thus far been granted patents, with a total of 50 patents granted to them.

Figure 4 displays the number of projects which had different numbers of patent grants. Three projects each produced five or more patents. Two projects each produced four patents. Fifteen projects each produced at least one patent. For 23 projects, more than half, no patents have yet been granted.

For some projects, applications for patents have been filed but the patents have not yet been granted. The delay can be caused by a number of factors, such as the technology area and extent of review by the Patent and Trademark Office, among others. Figure 5 presents data for patent applications filed but

Figure 4. Distribution of 38 Completed Projects by Number of Patents Applied for and Granted

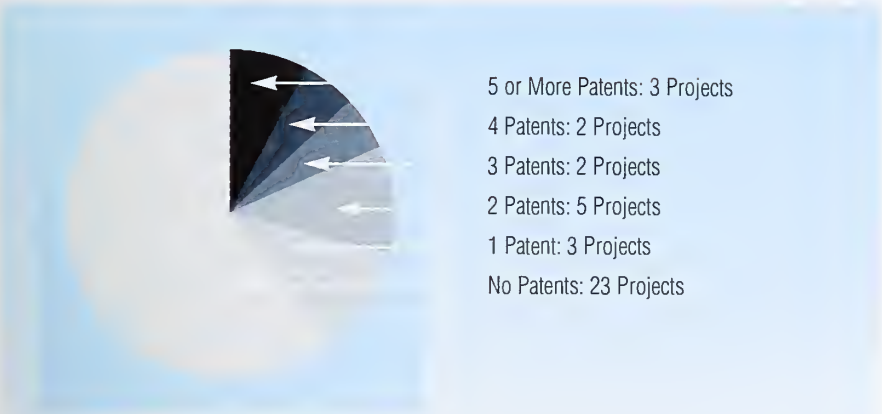


Figure 5. Distribution of 38 Completed Projects by Number of Patents Applied for But Not Yet Granted

not yet granted for the 38 completed ATP projects. For 12 projects, patent applications have been filed but patents have not yet been granted. The total number of outstanding patent applications is 51 for the 12 projects.[11] Three projects have five or more applications outstanding. For 26 projects, about two-thirds of the 38, there are no patent applications outstanding.

Eight of the 12 projects which have patent filings not yet granted are among the 15 projects which have already received patent grants; four of the 12 projects that have one or more outstanding patents applications have not already been granted patents. Thus, 19 of the 38 projects, or 50%, have engaged in patent activity for technologies developed with the ATP funding.

Copyrights and Registration for Software

The U.S. copyright system, also administered by the USPTO, works somewhat like the patent system but with important differences. A writer or other creator of a work or expression has an inherent copyright. The creator may register the copyright with the USPTO for added protection. For technology creations, protection via copyright is not as useful as patent protection. So when patenting is an option, it is usually chosen over copyright registration.

Registration of copyrights would seem to be important for ATP projects that generate computer software applications. Though six of the projects primarily entailed software technology, copyrights were not registered for any of them. In one case, however, the company is considering such a move to better protect its intellectual property.

Technology Transfer to Partners and Customers

If it conducts a project alone, a company can maintain a high level of secrecy about its technology. It may, however, develop technology in conjunction with three general classes of collaborators: joint venture members, subcontractors or informal partners. If it does so, it frequently shares technological information with these collaborators. In addition, the collaboration may be involve several types of partners: companies, universities, national laboratories, or non-profit organizations.

Providing a precise tabulation of collaborations across the classes and types of partners is difficult because of the many ways in which collaboration may be accomplished. Using a fairly broad definition of collaboration, it appears that for slightly more than half of the 38 projects, there was collaboration with one or more other companies. The next most prominent type of partner was the university, with about half of the projects involving one or more universities in the research and development effort. Government laboratories and non-profit organizations were each involved in less than a sixth of the projects.

For about two-thirds of the projects, there was an explicit arrangement for collaboration for at least one of the types of partners described above. In addition, some of the other projects had collaborative arrangements of a more informal nature that were not captured in the tabulation of research-related collaborations.

For the vast majority of new technologies, successful development and commercialization requires the inventor to also secure the participation of companies beyond those involved in the research. Some will be suppliers of inputs to the production process. Some will be partners in production. Others will be potential users and distributors of the new products or processes derived from the technology.

Table 4. Papers Published or Presented

Number of Papers	Number of Projects	Percentage[2]
0 or Unknown	22	58%
1-5[12]	9	24%
6-10	2	5%
11-20	4	11%
≥21	1	3%
Total	**38**	

Disclosure in Technical Presentations and Publications

Much technology is disseminated via the publication of papers in technical and professional journals. Through publication, the knowledge gained by participants in an ATP project is passed on to others outside the project. These recipients of the knowledge may then use it commercially. Publication of research findings is therefore frequently delayed until patents or some other kind of protection for the intellectual property has been secured.

Table 4 summarizes information about technical papers generated by the 38 projects. At least sixteen of the projects yielded publications (where the existence of publications is unknown, the project is counted in the "0 or unknown" line in the table), and five projects produced more than ten publications each.

Government Award Announcements, Workshops and Product Releases

When the government enters into an agreement with an organization, certain information about the agreement is generally made public. Such is the case with the ATP/company cost-sharing partnerships. Nonproprietary information has been disclosed to the public for each of the 431 projects funded by the ATP through 1998. The project information is available on the ATP web site on the Internet (www.atp.nist.gov), and new nonproprietary project descriptions are added to the site as new awards are made.

ATP Workshops

To help the public learn more about the projects it funds, the ATP organizes and sponsors numerous public workshops, where companies present nonconfidential aspects of their ATP-funded research and engage in open discussions. These workshops facilitate information flow in several directions — among awardee companies and from them to other companies, ATP project managers, other government program managers, the press, potential investors, and universities.

Knowledge Gained From Product Use or Examination

When a good or service that incorporates new technology is delivered, the buyer often will be able to learn a great deal about the technology. The mere functioning of a new product will reveal some information about the technology. Intentional investigation into how the product works will reveal more. Taking it apart, sometimes called reverse engineering, will reveal even more. For 24 of the 38 projects reviewed for this study, some commercial products or processes based on the ATP-funded technology are already on the market, where through use or examination they are providing others with information about the new technologies.

Commercialization of the New Technology

New technical knowledge must be put to use if economic benefits are going to accrue to the nation. In most instances, the use will be through the introduction into the market of a new product or process by the inventing firm or other companies. The new knowledge may be used by outside researchers before it makes its way onto the marketplace. But the new knowledge must eventually result in new products or processes in the marketplace for there to be real-world benefits to the economy.[13] In competitive markets, the producer is typically unable to capture all the benefits of a new product, and the consumer reaps part of the benefits.

Commercialization — A Critical Step Toward National Benefits

For 24 of the 38 completed projects, a new product or service is on the market or a new process is being used to improve the quality or reduce the cost of making an existing product or service. Eighteen projects have introduced new products, five are using new processes in their own production, and one has introduced a new service. All of the products and processes are used by commercial companies in their production processes.

Among the new products are substantial devices that are self-contained, including receive filters for cellular phone sites, lasers that can be tuned to different wavelengths for a wide range of applications, flat fluorescent lights to serve as back-lights for color liquid crystal displays in a variety of applications, wall units made of mixed recycled plastics for use in pre-fabricated buildings, robots to provide delivery services in hospitals and other installations, machine tools that can produce much higher quality metal parts because they are self-adjusting for the effects of high heat that otherwise would cause errors, and a super-sensitive measurement instrument for detecting minute amounts of viruses and toxic chemicals in medical and environmental applications.

Several of the new products are much smaller devices, commonly viewed as components in other products. These include controllers and fiber-optic collimators for wavelength multiplexers, cheaper blue light-emitting diodes for inclusion in full-color displays, epitaxial laser wafers, giant magnetoresistance sensors for automatic brake systems and other applications, high-temperature superconducting (HTS) wiring for connecting super-cooled electrical devices to ordinary devices, thin-film HTS components for magnetic resonance imaging equipment in hospitals, and minute porous glass components in sensors for toxic gases.

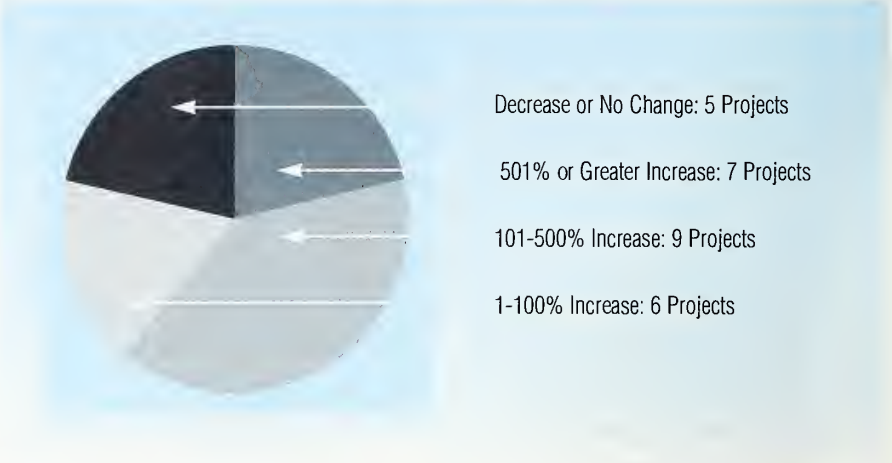
Additional new products and a new service have resulted from research in the computer software field. These include a pad and stylus system for allowing the input of handwritten characters into computers, detailed images and dynamic presentation of the inner parts of the human body for CD-ROMS and books used in medical education, a programming tool that makes the development of programs for parallel processing computers much easier, a system that produces rotatable three-dimensional views of very complicated molecules for a number of applications in the chemical and drug industries, a user interface for use in sharing product model data, and a service that helps producers and archivers of movie films improve film quality by removing blemishes from film masters.

Finally, there are new processes that improve the manufacturing of a variety of products. They include processes for the epitaxial growth of semiconductor components, the implantation of ions of various materials on large silicon crystal wafers in a much cheaper way, the production of very high quality spherical and aspherical mirrors for use in photolithographic and other fabricating equipment, and the assembly of automobiles which are of higher quality because stamped metal parts fit together better.

For a convenient, quick reference by the reader, brief descriptions of the new products or processes are listed in Tables A1-A7 in Appendix A, in Column C. For each new product or process, the new technology on which it is based is also listed in the Appendix A tables, in Column B.

Commercializing a technology is an important step, but it does not mean that the project is necessarily a full success from the perspective of either the company or the ATP. Some products have been sold for testing and evaluation, and after testing, the purchaser may decide not to place a larger order. Other sales are by struggling companies that may fail in the future, even if the product is a good one. Widespread diffusion of the technology may or may not ultimately happen, but it is significant that these products and processes are actually on the market. This is an extremely important step for the eventual generation of broad-based benefits for the economy as a whole.

Figure 6. Distribution of 27 Completed Projects at Small, Single-Applicant Companies by Percentage of Employment Change



Rapidly Growing Companies

The introduction of a new or improved product into the market is clear evidence of commercialization. Even before that happens, however, other indicators can signal that a company is probably on the path toward commercialization. One of these is company growth, and some limited data on this performance "indicator" is provided in Figure 6, which focuses on employment at the small, single-applicant companies. Employment changes in joint ventures, larger companies and nonprofit organizations are less closely tied to the success of individual research projects, and, therefore, they are not shown in the figure.

Clearly, this group of companies as a whole has grown rapidly, as measured by employment growth rates. All but five of the 27 small companies at least doubled in size; one company grew 1,900 percent. Employment at four companies actually declined, while it remained constant at one company.

Companies "Going Public"

Another development that is useful in assessing commercial prospects for small companies is the initial public offering (IPO) of stock by a company whose stock has heretofore been privately held. For the most part, these are start-up or near-start-up companies.

This event is relevant for the 21 single-company applicants that were privately held at the beginning of their ATP funding periods. Seven of the 21 companies filed IPO statements with the Securities and Exchange Commission (SEC). Five of them conducted IPOs during their ATP funding periods. In addition, one company conducted an IPO in early 1998, after project completion.

Another company, in filing the required form with the SEC, noted its intention to conduct an IPO and has since been acquired by a larger company, at an apparent substantial premium over the approximate value placed on the company at the time of the SEC filing.

Conducting an IPO subjects the company to the scrutiny of stock market analysts and to the financial decisions of investors. It is a demanding test of whether the capital market believes the company has a promising future. Even announcing the intention to conduct an IPO invites potential investors to examine the data presented by the company in its SEC filing, and only infrequently do companies announce intention to file without following through.

Broad-Based Economic Benefits

The actual use of new products and processes that result from a new technology generates a variety of benefits for the economy. These benefits may result from lower costs or higher quality relative to products and processes they replace. Or they may stem from unprecedented performance capabilities, such as a novel treatment for cancer. Those who receive these "incremental" benefits typically do not pay for their full value.

What Effect Did ATP Have on the Project?

Before turning to economy-wide benefits, it is useful to consider the impact of ATP funding on the research that led to them. Project leaders from each company were questioned about the role ATP funding played in their projects. Their answers are presented in the detailed discussions of Chapters 2-8 and summarized in Table 5.

For all 38 completed projects, awardees were asked whether the project would have been done at some point without ATP funding. Answers were received for 32 of the projects.[14] For 21 of them (66%), the companies and other organizations indicated they would not have done the project at all without ATP funding.[15] For the other 11 projects, they said they would have done the project at some later date or slower pace. For the 32 projects as a whole, none would have been completed in the same time frame without ATP funding, and 21 of them would not have been completed at all, according to officials at the companies and other organizations.

For the 11 companies whose projects would have been delayed without ATP funding, the typical lag reported was about two years, with a wide variance around the average. A lag of just 24 months may seem short, but its effects can be substantial when the costs and benefits of accelerating the technology development are considered. For illustrations, see the detailed treatments of two ATP projects, Aastrom Biosciences and Tissue Engineering, later in this section, where acceleration of the availability of new medical treatment technology is shown to have a potentially large impact on societal benefits.

Receipt of an ATP award also enhanced the ability of some of the companies to raise additional capital and acquire partners. Thirteen of the 32 responding companies reported that the ATP award helped them raise additional capital (four of them were among the companies that conducted an IPO after receiving ATP funds), and 23 said it boosted their ability to find partners.[16]

Assessing Private and Social Returns from New Technology

Counting the number of projects that would not have been done without ATP funding provides some limited information on the benefits of the program, as does tabulating the number of months that projects would have been delayed if they would have been done, but on a delayed schedule. These limited data are insufficient to assess whether the ATP awards for the 38 completed projects were good uses of public funds, however. More detailed assessment is needed.

The value of the ATP-funded research can be assessed by probing the benefits and costs of projects and the return on the ATP investment. It should be kept in mind, however, that full diffusion of technologies generally takes considerably more time than has elapsed for these projects, and at this time their ultimate, long-run outcomes cannot be known with certainty.

The Mansfield Study of Private and Social Returns

More than 20 years ago Professor Edward Mansfield[17] of the University of Pennsylvania established general procedures for economists to follow when compiling estimates of the private and social returns from groups of innovations (new products or processes). His work focused on estimating "consumer surplus" benefits to consumers of new and improved goods and services resulting directly from commercial activities of the innovators — a type of spillover effect.

Mansfield's method and estimates addressed market spillovers and those knowledge spillovers which generate benefits via the development of new or improved competitive goods and services by imitators of the original

Table 5. Impact of ATP Funding on Conducting Projects

Would Have Proceeded Without ATP Funding	Number of Projects	Percentage
Yes, But at a Slower Pace, with Delay of[18]	11	34%
• 18 Months	4	
• 21 Months	3	
• 24 Months	3	
• 60 Months	1	
No	21	66%
Total	**32**	

innovating companies. He did not address other kinds of knowledge spillovers, such as use of the new knowledge in a research process leading to other new technologies in a different industry. Hence, for the type of enabling technologies that ATP funds, Mansfield's approach could be expected to capture an important, but partial, share of the total impact.

Case Studies of Seventeen Innovations

Mansfield based his analysis on 17 extensive individual case studies. His procedures have been upgraded over the years, but they still constitute a good starting point for any empirical study of the effects of innovation. He and his colleagues collected annual data for: cost, revenue and profits from the innovating firm; cost, revenue and profits from other firms in the same industry for competitive products or processes they introduced after imitating the new product or process; cost, revenue and losses from the innovating firm or other firms in the industry for products or processes the new product or process supplanted; cost, revenue and profits for producer goods from other firms that purchased the new product or licensed the new process; and cost and benefit data from final users for consumer goods.

Once these data were in hand, they were used to calculate: the annual costs of the innovation; the annual private dollar returns to the innovator; the annual dollar returns to all other parties (competitive firms, purchasing firms, final users); the net annual social dollar returns, by summing all these annual dollar returns (netting out any negative values); the annual private dollar return (using data for the innovating firm alone); the private rate of return; and the social rate of return.

Data Requirements for the Mansfield Analysis

The landmark results published by Mansfield, et. al., have been cited numerous times in the economics and technology policy literature, usually in the context of examining differences between the private and social returns from innovation. The focus here, however, is on a different aspect — the amount of data required to support his analysis. Table 6 presents data from the Mansfield study showing when the 17 innovations entered the market and how many years of data were available for the empirical estimates. In most cases, Mansfield was able to draw on 11 to 18 years of historical data for the older innovations. For more than a third of them, however, some projected data were used.[19]

Sufficient Data for Analysis of 38 Completed ATP Projects not Yet Available

Few data of the type collected in the Mansfield study exist for new products and processes generated by the 38 ATP projects, since the technologies are still so young. Most of these innovations have multi-application potential, making their evaluation even more complex. And most of their benefits and many of their costs are yet to come. Economists can, nevertheless, project the values of these items (as Mansfield, et. al., did in some cases) in order to calculate the private and social returns. The earlier an analysis is conducted, relative to the year of the innovation, the greater the necessity to use projected data and, consequently, the greater the uncertainty in the results. Uncertainty in results is unavoidable at this time for benefit-cost evaluations of this kind for ATP-funded projects.

After a sufficient number of years have passed, an exercise like the Mansfield study — relying on more years of empirical data — can be performed for the innovations that emerge from these 38 ATP projects. That exercise will be much easier if data are collected and carefully archived along the way. The ATP is doing that as part of its evaluation plan.[20]

Table 6. Years of Data Available for Estimating Effects of 17 Innovations, Mansfield, et. al. (1977)

Market Entry	Number of Innovations	Years of Data
1955	1	18
1958	1	15
1962	5	11
1965	4	8 or 15
1968	3	12
1972	3	8

A Portfolio Approach to Costs and Benefits for the 38 Projects

The ATP awarded $64.6 million to the 38 completed projects described in Chapters 2-8 and contributed another $9.4 million to the 12 terminated projects (see Appendix B), bringing total ATP spending on the 50 projects completed or terminated by March 1997 to $74.0 million.

Since it is not expected that every project will be fully successful — all research goals reached, commercialization achieved, widespread dissemination of the knowledge and extensive benefits realized from the use of the resulting goods and services — it is more reasonable to assess the effectiveness of ATP awards as a group of funded projects, as an "investment portfolio," much as an investor in stocks and bonds might do. Pursuing that line of thought with the combined set of 50 completed and terminated projects leads to a simple question: For its investment of $74.0 million, what has the public received, or is likely to receive, in return?

Expected Returns for Just Three of the Projects

This study did not attempt to estimate returns to project participants or to society for the entire portfolio of 38 projects. To do so would entail an involved process requiring detailed economic evaluation case studies and a much larger effort than was allocated for this report. But for three of the projects, such detailed estimates have been calculated by other researchers.[21]

Aastrom Biosciences: Stem-Cell Therapy Cost Reductions

The availability of ATP funds enabled Aastrom Biosciences to achieve its results one to two years earlier than it would have otherwise. This finding implies that benefits from the use of the company's new AastromReplicell™ System would start one to two years sooner.

Benefits of several kinds are expected to result from use of the System, as noted in Chapter 2. One of these is a reduction in the cost of stem cell therapy for cancer patients after chemotherapy or radiation treatments. Other benefits are reductions in the patient's pain and in the risk of complications.

Economists at the Research Triangle Institute (RTI), a consulting firm in North

Carolina, have calculated estimates of the value of accelerating the availability of the System, using only the reduction in procedure cost.[22] RTI economists estimated the number of cancer patients who would use the System in its first year of availability (16,000), estimated the annual growth in applications of the System, determined the cost reduction per patient, and used conventional present-value calculations to get a current value for the cost reduction effect. RTI conducted the calculations assuming the System would be available with ATP funding at the beginning of the year 2000 and repeated the calculations for the "without ATP funding" case that assumes the Systems would be available 18 months later.

RTI estimated that the System, once implemented, would save about $87 million (in 1997 dollars) in medical treatment costs without the acceleration provided by ATP support and $134 million with the acceleration. The difference, $47 million, is the estimated additional value, in terms of cost savings, created by the ATP funds, based on this one application area. Other applications of stem-cell therapy using the System are also expected, which will likely add to the future benefits.

This estimate considers only cancer treatment cost savings. Besides these benefits, the typical patient is expected to have less pain, suffering and trauma when stem cells are collected if the System is used instead of an alternative procedure. However, the value of the pain and trauma reduction is not included in the calculations because data for those effects were not available.

It is also expected that the stem-cell mixture that is injected back into the patient will be freer of cancer cells, leading to a better eventual outcome, if the System is used, but value was not assigned in the RTI study to that beneficial effect, either. Finally, with lower cost and less trauma, stem-cell therapy might become a possibility for some cancer patients who would otherwise not receive it. Stem-cell therapy is expected to increase survival chances for some of these patients, but the value of their prolonged lives is also not included in the estimate.

According to the estimates calculated by RTI, we can expect the additional returns to society attributable to ATP's award to Aastrom Biosciences to be on the order of $47 million, at least. Funding by ATP for the Aastrom project was $1.2 million. And the contribution by ATP to all 50 completed and terminated projects was $74.0 million. Since the RTI estimates from the use of the Aastrom System product were based on only one of several kinds of potential benefits, it seems clear that returns from this project alone are likely to account for a substantial percentage of the ATP expenditure for all 50 projects.

Auto Body Consortium: Higher Quality Car Bodies

While the economic and social impact of the Aastrom System is almost entirely in the future, the Auto Body Consortium's ATP project is already producing measurable benefits, as noted in Chapter 4. Chrysler, a member of the consortium, is making its Concorde line with the new dimensioning technology, as discussed in its marketing literature. Cars in this line are assembled in a plant that has already implemented the new technology and has the capacity to assemble about 250,000 cars per year. To date, the new technology has been implemented in six of the 10 Chrysler plants in North America, and each is expected to produce a minimum of 200,000 cars in 1998.

In a detailed study of this ATP project, Consad Research Corporation (Consad), a consulting firm in Pittsburgh, Pennsylvania, estimated a range of $10 to $25 per vehicle in production cost savings.[23] Multiplying the smaller number ($10) by the minimum number of cars to be assembled in the six Chrysler plants yields an estimate of at least $12 million in production cost savings for 1998 alone. Multiplying by the larger number ($25) results in a savings estimate of $30 million.

Every one of those cars produced in 1998 will also cost less to maintain, with the producers saving on warranty costs and consumers saving on out-of-warranty costs. Consad estimated maintenance savings of $50 to $100 per car over its life, implying that for these 1.2 million cars (six plants producing 200,000 cars each), between $60 million and $120 million in maintenance costs will be saved over the life of the cars. Only a small portion of those maintenance savings have been realized so far, because none of these cars has been on the road for much more than a year.

Actual current savings have also already been realized by General Motors, the other automobile assembler involved in the project. The new technology has been implemented in 16 of its 31 plants in North America. Since the number of cars produced per plant by GM is comparable to that by Chrysler (at least 200,000 per year), GM will realize production cost savings of at least $32 million in 1998, and the figure could be as high as $80 million. And maintenance savings over the life of these cars would be between $160 and $320 million.

The estimates do not take into account cost savings from extending the technology to the other 4 Chrysler and 15 GM plants. The savings for those additional plants are still in the future, but the likelihood of these savings occurring in the U.S. economy is high.

Once again, a comparison with the size of the portfolio investment is in order. At least $44 million ($12 million at Chrysler and $32 million at GM) in production cost savings were expected to be realized in 1998 alone. The savings could be as high as $110 million. Comparable savings at the six Chrysler and 16 GM plants in 1999 and beyond are expected, as well. The Consad study projected economywide benefits of about $3 billion in the year 2000 due to resulting quality improvements in U.S.-produced automobiles and associated market share gains.[24]

Tissue Engineering: New Materials to Repair Damaged Ligaments

The availability of ATP funds enabled Tissue Engineering to achieve its results two years earlier than it would have otherwise, as noted in Chapter 2. RTI, which also included this project in its detailed case studies,[25] estimated that products using a new prosthesis material — animal-derived extracellular matrix, or ADMAT — based on technology developed by Tissue Engineering with ATP support, would reach the market in 2001.

The RTI study focused again on a single application of ADMAT in calculating benefits from the use of this technology, namely, the repair of damaged knee ligaments (specifically, anterior cruciate ligaments, or ACLs). To estimate the number of potential users, RTI questioned officials at Wright Medical Technologies, a partner with Tissue Engineering, who provided an estimate of the number of persons who damage their ACLs annually. Based on that estimate, RTI estimated that the number using the Tissue Engineering technology would start at 9,000 in

the first year of availability and grow to 72,000 10 years later. In addition, the RTI study explicitly incorporated benefits from the improvement in the quality of life for such persons, using a "quality-adjusted-life-years" index value.

RTI concluded that the total benefit to persons who receive the treatment is expected to approximate $33 billion with the support of the ATP funds. Without that support, it is expected to be on the order of $18 billion, because without the ATP funding benefits are not expected to start to accrue until 2003. Thus, about $15 billion of the expected net benefits from the new technology was estimated to be attributable to ATP funding.[26]

The difference in the sizes of RTI's estimated benefits from uses of the Aastrom Biosciences and Tissue Engineering technologies occurs for two major reasons. One is that the number of potential users of Tissue Engineering's ADMAT (patients with ACL damage) is larger than the number of potential candidates for bone marrow transplantation using Aastrom's System. The other is that the estimated patient benefits for ACL repair includes an estimate of the value of improvements to the patient's quality of life, whereas the estimates for bone marrow transplant benefits reflect only treatment cost savings and include no values for physical benefits to the patient.

These estimates for benefits to be received by users of the Tissue Engineering technology are so much larger than the ATP contribution to the project — $2 million — that making a comparison seems beside the point. What seems clear, though, is that the expected benefits appear to be much larger than the cost expended to achieve them.

Projected Benefits From ATP Contribution in Three Projects Exceed Total ATP Costs

The value of the projected benefits resulting from the ATP contribution in just the three ATP projects profiled above would greatly exceed total ATP costs to date. Cost savings already realized by Chrysler and GM as a result of the Auto Body Consortium project appear likely to be larger than the $74.0 million that ATP put into all 50 projects addressed in this report, not to mention the larger gains to the economy from quality improvements. If Aastrom Biosciences succeeds in bringing its product to market and if the RTI estimate of the value of the acceleration of market availability proves accurate, the return from ATP's assistance to the Aastrom project alone would cover more than half of all ATP funds provided for these 50 projects.

In addition, the estimated social return attributed to the ATP for the Tissue Engineering project is in the billions of dollars. The value of those benefits obviously swamps the $74.0 million in ATP funding for the 50 projects. Indeed, if the ADMAT technology proves to be anywhere nearly as beneficial as the RTI estimates predict, its benefits would swamp all ATP funding for all projects since the beginning of the program. Even if the expected number of patients who would benefit were cut, for example, by 80 percent and the expected benefit per patient were reduced by a like percentage, the estimated return from the ATP's contribution to this technology would still be more than half a billion dollars.

Potential Benefits from Other Projects

Based on the investigations of projects conducted for this study, considerable evidence suggests that others among the 38 projects are also quite promising in terms of their future benefits potential.

To mention only a few of the additional promising technologies that have resulted from this first group of 38 completed projects, consider first the Torrent Systems Project. It was found, for example, that an early user of its computer software technology expected to generate between $50 and $100 million per year in increased revenue on a $17 million investment in a system incorporating Torrent's technology, and that other users were also adopting the technology.

As another example, it was found that the software technology of Engineering Animation is being used to improve the training of doctors, among other things, and that patients in a particular surgical procedure were having better outcomes as a result of the company's imaging software. To these we can add other projects that were found to have produced promising technologies — technologies that may facilitate better weather forecasts, improve communications, enable new drug discovery, improve electronic devices, and lower loss of limb and life globally by improving detection of old land mines and toxins.

Preparing the Way for Future In-Depth Studies

Although this study does not provide a detailed quantitative analysis of the benefits deriving from these 38 completed ATP projects, it does document a number of project performance characteristics that will be useful for detailed estimates of returns. The presentations of project status in Chapters 2-8 contain many references to relevant markets, the role that the technology plays in those markets, the position of the innovating firm relative to other firms in the vertical chain leading to final purchase by users, and other characteristics that would be used in such a study. It also documents progress as of a point in time.

Chapter 2

Biotechnology

Aastrom Biosciences, Inc.

A Patient-Friendly Approach to Human Cell Transplantation

One of the most important recent developments in cancer treatment has been the ability to harvest stem cells from bone marrow or blood to produce blood and immune system cells, and inject them into a cancer patient after drug or radiation therapy. These therapies kill cancer cells, but they also destroy life-protecting stem cells. Reinfusion of harvested stem cells enables the body to regenerate the blood and immune systems in the now cancer-free patient. Preferably, the stem cells come from the patient's own bone marrow. When that is not feasible, they may be taken from another donor.

Ex Vivo Cell Expansion - From the Lab to the Clinic

Serious Drawbacks to Existing Methods

Good as it is, stem cell harvesting has important drawbacks. Harvesting stem cells from bone marrow is painful, usually requiring 100 to 140 needle sticks — performed as major surgery under general anesthesia — to extract from the hip or other large bones enough marrow for successful transplantation. Some cancer patients are not strong enough to withstand so many extractions. A few are so ill they can't afford to postpone therapy while stem cells are being harvested. Still others suffer significant side effects (pneumonia, pulmonary embolism, bone marrow inflammation) from the extraction process itself. A typical procedure involves eight separate donor visits (one for the extraction, several for blood testing and other medical procedures, one for reinfusion of the stem cells), takes about 16 hours altogether and costs $10,000 to $15,000.

Another harvesting method — peripheral blood progenitor cell (PBPC) collection — is in some ways an improvement over traditional bone marrow harvesting. PBPC involves injecting the donor (who might be the patient) with drugs to stimulate the movement of stem cells from the bone marrow into the blood stream. When it becomes enriched with stem cells, the blood is circulated through an apheresis machine, where stem cells are separated, and then back to the donor.

PBPC collection typically involves 21 donor visits (at least one for drug administration, three or four for apheresis, some for blood work, others for follow-up work related to the apheresis, one for reinfusion), takes an average of 39 total hours, requires about 22 needle sticks and costs around $16,000. It has gained popularity over bone marrow harvesting in recent years, the company reports. This is particularly true for collecting cells from cancer patients themselves, in part because some patients receiving PBPC-based treatment have less need for platelet transfusion.

The overall costs of cancer treatment where stem cell therapy is used may total $100,000 or more. These costs include diagnosis, chemotherapy, radiation therapy, stem cell transplant therapy, and patient management. The costs of stem cell transplant therapy include the costs of cell collection, the costs of reinfusing the cells, and patient support during post-transplant recovery. The latter involves hospitalization, antibiotic treatment, infusions of platelets and red blood cells, and management of adverse reactions to large-volume cell infusions.

PROJECT:

To design and construct a desktop-size device that can expand small samples of stem cells, a process that would enable reductions in the risk, pain, time and cost of collecting these specialized blood-production cells for use in bone marrow transplantation for cancer patients.

Duration: 7/1/1992 — 6/30/1994
ATP Number: 91-01-0243

FUNDING (IN THOUSANDS):

ATP	$1,220	45%
Company	1,514	55%
Total	$2,734	

ACCOMPLISHMENTS:

Aastrom designed, constructed and validated a desktop-size bioreactor to produce large amounts of stem and other cells from bone marrow, umbilical cord blood and possibly other human tissues. A number of signs indicate the value of this accomplishment:

- Aastrom received a fundamental patent for its bioreactor:

  "Bioreactor for Mammalian Cell Growth and Maintenance"

  (No. 5,688,687: filed 6/7/1995, granted 11/18/1997).

- It has applied for several additional patents for technologies related to the ATP project.
- By the end of the ATP award period in June 1994, Aastrom staff had published or presented at professional conferences numerous technical papers on the company's AastromReplicell™ Cell Production System (System), which incorporates the Biochamber developed with ATP funds.
- In October 1995, Aastrom received $35 million from Rhone-Poulenc Rorer for use of System technology worldwide for cell and gene therapies involving lymphoid blood cells.
- Aastrom raised $21 million in new investment capital via an initial public stock offering in February 1997.
- In November 1997, when Aastrom received the patent listed above, the company's stock price jumped more than 60 percent in one day.
- By the end of 1997, Aastrom had entered into agreements with SeaMED and Ethox Corporations and Anchor Advanced Products for the collaborative development and manufacture of certain components of the system.
- To date, the System has been used in clinical trials at six U.S. and two foreign sites with more than 60 patients, and additional trials are under way.

COMMERCIALIZATION STATUS:

Clinical trials are in progress. The firm is also looking for partners with whom to develop a marketing relationship.

OUTLOOK:

There are high expectations that this new technology will be useful in a variety of medical treatments. Test results at various stages in the regulatory process have been promising. The stock market response to the initial public stock offering, patent-grant announcements and attention from investment analysts suggest that the private market believes the company and its technology have a good future. Also, a recent detailed economic study indicates this new technological approach could yield significant social benefits just in treating cancer patients with solid tumors.

COMPANY:

Aastrom Biosciences, Inc.
Dominos Farms, Lobby L
24 Frank Lloyd Wright Drive
Ann Arbor, MI 48106

Contact: Alan K. Smith
Phone: (734) 930-5555

Number of employees:
4 at project start, 70 at the end of 1997

New Approach Promises Large Benefits

A cell expansion system developed by Aastrom Biosciences could potentially mitigate most of the drawbacks associated with current harvesting techniques while reducing costs and increasing the number of patients who could use Aastrom's procedure. The company was founded in 1989 and had only four persons on staff when it gained ATP support three years later. Wide-scale use of its system would produce large benefits across the economy via new therapies, reduced treatment costs and lower risks to patients undergoing cell harvesting and transplantation.

Aastrom expects cell harvesting via its AastromReplicell™ Cell Production System — which induces cells to rapidly multiply or expand — will be cost competitive. The typical patient/donor is likely to need just two clinic visits, one for harvesting a small amount of bone marrow and the other for reinfusing the expanded cells. An average of just seven needle sticks would be required during the initial visit.

The core technology of the system is a bioreactor that expands small amounts of bone marrow into a transplant product rich in stem cells and progenitor cells (stem cells that have started maturing into blood or immune cells). During a single 20-minute outpatient procedure, less than 50 millimeters of bone marrow is extracted from the patient under local anesthesia. The marrow is injected into a disposable cassette — about the size of a large pizza — which is inserted like a video cassette into the automated bioreactor. A key aspect of the system is the creation of culture conditions that duplicate the human bone marrow environment. The cassette uses growth media, oxygen supplies and proprietary processes within the bioreactor to stimulate the marrow to produce its own growth factors. Over 12 days, the cell population expands five to 10 times while stem and progenitor cells expand even more, producing enough cells for effective transplantation.

. . . the cell expansion system . . . could eventually mitigate most of the drawbacks associated with current harvesting techniques while reducing costs and increasing the number of patients who could use Aastrom's procedure.

Scale-Up and Clinical Trials

Aastrom has successfully scaled up a small laboratory prototype of the cell expansion system to one large enough for clinical use. Clinical research has confirmed that cells produced by this device, called "the System," can safely be infused into patients.

In the first test of the System, a dose-ranging study with seven lymphoma patients at the University of Michigan Medical Center in 1993,

Injecting into processor.

Aastrom found that stem cells generated with its procedure were as safe as those collected by the direct bone-marrow harvesting technique. And in the first feasibility trial of the System — with 10 breast cancer patients at the University of Texas M.D. Anderson Cancer Center in Houston — standard clinical recoveries were seen following injection of the System-produced cells, showing that the System can be operated adequately by clinical personnel.

Another clinical trial, completed in May 1997, reported excellent findings for six breast cancer patients treated through the Bone Marrow Transplant Program at Loyola University Medical Center in Chicago. The study demonstrated that the System technique produced recovery results in line with outcomes for transplantation using other cell harvesting procedures.

Favorable results were also reported at the American Society of Hematology conference in December 1997. A Duke University Medical Center preclinical study showed that the System reduced the number of tumor cells during production. At the same conference, Aastrom announced completion of another Loyola clinical study, this one with 19 patients, that generated further evidence that bone marrow grown in the System retained stem and other key immune cells needed to restore vital tissues after drug and radiation therapy.

Another clinical trial, completed in May 1997, reported excellent findings for six breast cancer patients . . .

Intellectual Property and Stock Market Reaction

Protection of its intellectual property has always been important to Aastrom. The company was founded as a joint effort between the company's initial investors and the University of Michigan. The investors and the University agreed that inventions by the three principal researchers, all University professors, would be assigned to the University and licensed exclusively to Aastrom. In March 1992, prior to the ATP award, Aastrom and the University signed

Aastrom's policy is to disseminate its findings widely after establishing protections for its intellectual property.

a detailed licensing and royalty agreement. Through the end of 1997, 12 patents covered by the agreement had come out of the Aastrom/University of Michigan collaboration. Most of them underlay the ATP-funded technology. News reports about the granting of two of them in September 1997 were immediately followed by a substantial increase in the price of the company's stock.

The company is also pursuing patent protection for inventions not covered by the agreement with the university. In 1997, Aastrom received in its own name a fundamental patent — "Bioreactor for Mammalian Cell Growth and Maintenance" — for the System method and device. News that this patent had been granted was accompanied by a one-day increase of 60 percent in the company's stock price.

Aastrom's policy is to disseminate its findings widely after establishing protections for its intellectual property. This is true of the technical specifics of its discoveries, as well as the results of clinical trials. Company staff have produced numerous papers for presentation at professional conferences or publication in professional journals.

Strategic Alliances for Commercialization

In 1993, the company entered into a strategic alliance with COBE Laboratories and COBE BCT (collectively, COBE) for the worldwide distribution of the System for stem cell therapy and related uses. COBE committed up to $20 million in equity investment in Aastrom. In addition, Aastrom and COBE initiated a clinical trial in France in early 1997 to evaluate the use of System cells to promote the recovery of blood cell production in breast cancer patients undergoing aggressive marrow-damaging chemotherapy. Aastrom is seeking approval to market the System in Europe.

In September 1995, Aastrom entered into a research and development collaboration with

Rhone-Poulenc Rorer (RPR), granting RPR a right to license the System for lymphoid cell applications. Under the agreement, RPR will invest $35 million. In September 1997, Aastrom had received $3.5 million in equity payments and $1.5 million in revenues from RPR.

Initial Public Stock Offering

In addition to financial support from strategic alliances, the company has secured funding in the public capital market. In February 1997, Aastrom conducted its initial public stock offering, which raised $21 million, and conducted another offering in December 1997 that raised $11 million.

All equity funding is invested in Aastrom's research and development (R&D) efforts and administrative activities required to support that research — the only focus of the companies activities. Thus, as Aastrom succeeded in attracting more private capital, ATP funding constituted a declining proportion of its R&D spending. ATP funds amounted to 23 percent of Aastrom's $2.6 million R&D budget in 1993 but only 11 percent of its $4.9 million R&D budget in 1994.

Aastrom does not manufacture products, nor does it intend to. It arranges with third parties to manufacture its candidate products and has agreements with SeaMED and Ethox corporations and Anchor Advanced Products, Mid-State Plastics Division, for the collaborative development and manufacture of certain components of the AastromReplicell™ System.

Large Potential Benefits

Patients — the main beneficiaries of the new technology — are expected to gain from a less evasive procedure that is cost effective, provides greater procedural flexibility, and offers tumor purging benefits. In addition, because of fewer hospital or clinic visits, total costs are expected to be as much as 25 percent less ($12,000 instead of $16,000) than costs for PBPC apheresis. Furthermore, if the Aastrom technology substantially decreases the cost of cell transplantation, others who could not have afforded the treatment will now be able to and will benefit. Their benefit may well be life itself, since bone marrow transplantation for cancer patients is frequently a life-saving therapy.

A study of tissue engineering projects, conducted by economists at Research Triangle Institute, Inc. (RTI), under contract to the ATP, noted that Aastrom achieved ATP-project results one to two years earlier than would have been possible without the ATP award.[1] Having the ATP funds also helped the company attract additional equity capital and establish new strategic partnerships. These, in turn, helped accelerate the company's R&D even more.

Wide-scale use of the System is expected to produce large benefits across the economy via reduced treatment costs and lower risks to patients undergoing cell harvesting and transplantation. The RTI study estimates that the present value of expected net benefits from using the System technology for just one type of application — treating cancer patients with solid tumors — exceeds $100 million.[2] The study estimates that ATP's contribution of $1.5 million to the project will generate nearly $50 million of the expected benefits by speeding the technology's development by one to two years. The RTI study did not attempt to develop estimates based on characteristics of System-based stem cell transplantation that might yield better patient outcomes. It focused only on cost savings.

In addition, the study did not attempt to estimate the value of the effects that a number of other potential applications might have. First use of the System technology is for expanding small amounts of stem cells from bone marrow. It has now been extended to the production of stem cells from umbilical cord blood. Other possible applications include immunotherapy, stem cell gene therapy and cells for solid tissue repair. More benefits can be expected to be generated as the company applies the technology to growing other types of cells — platelets and red blood cells, as well as liver, kidney and nerve tissue — outside the body.

Other possible applications include immunotherapy, stem cell gene therapy and cells for solid tissue repair.

Inserting Cell Cassette into Incubator.

Aphios Corporation (formerly BioEng, Inc.)

Reducing Viral Contamination in Donated Blood

This ATP project with Aphios Corporation, a small Massachusetts company founded in 1988 as BioEng, developed technology to improve the quality of donated blood in the United States. If the technology is fully developed and widely applied, substantial benefits would accrue to patients. The transfused blood or other therapeutic substances they receive would essentially be free of hepatitis virus, human immunodeficiency virus (HIV, which causes acquired immunodeficiency syndrome, or AIDS) and other viruses that may contaminate vaccines, donated blood, blood-related products, medical instruments and recombinant-DNA proteins.

Solving the Problem of Contaminated Blood

Several sterilization procedures using heat, a chemical, or ultraviolet radiation are already in use, but each method has drawbacks: it may leave unsafe levels of some viruses, be very costly, or damage the blood or plasma. The Aphios sterilization technology, called critical-fluid inactivation (CFI), uses a fluid such as carbon dioxide that is raised above its critical temperature and pressure. Above these levels, the substance cannot be liquefied. In laboratory tests, such fluids exhibit a combination of liquid and gaseous properties, and they have been found to effectively inactivate prototypical viruses. Critical-fluid viral inactivation uses low temperatures and short process times, so it has a minimal impact on blood and blood-related products. And, at an estimated cost of about $1 per liter, it is much less expensive than existing technology.

Overcoming Parvovirus

The procedure Aphios developed during the ATP project has been able to achieve 99.9999 percent inactivation or more for most viruses in 20 seconds (99.99 percent inactivation by an individual viral inactivation technique is considered acceptable). The most difficult challenge has been parvovirus.

Parvovirus B19 in blood and blood products has proven difficult to inactivate, not only by the CFI process but by others as well. The virus is relatively benign for patients with healthy immune systems. But it can have serious consequences for those with weakened immune systems, as well as for pregnant women and persons with sickle cell anemia. The current Aphios procedure has achieved 90 percent inactivation of this virus. The company is working on a five-step procedure that is expected to achieve better than 99.99 percent inactivation.

. . . commercial deployment . . . will be much easier if the company can demonstrate that its technology can inactivate parvovirus to an acceptable degree.

. . . signed a letter of intent with the Northeast Region of the American Red Cross to develop and field-test a viral inactivation prototype . . .

The blood industry has established an extremely high standard for new technologies. Therefore, commercial deployment of the Aphios technology will be much easier if the company can demonstrate that its technology can inactivate parvovirus to an acceptable degree. If it succeeds with this task, Aphios will seek to join a larger pharmaceutical company or consortium to further develop and commercialize the process, with substantial investment coming from these sources. In 1998, Aphios sought an arrangement with a consortium of five pharmaceutical companies to complete development of the CFI process.

If a company wishes to commercialize a product for use with donated human blood, it must deal with the American Red Cross (ARC), the source of most blood products used in clinics and hospitals in the United States. Aphios has signed a letter of intent with the Northeast Region of the ARC to develop and field-test a viral inactivation prototype for individual units of blood and is seeking funding for the project.

Health Benefits to Patients and Those Close to Them

If the technology is fully developed and commercialized, benefits are expected to accrue to users of blood and blood-derived products that

PROJECT:

To develop a critical-fluid viral inactivation process to protect the nation's supply of donated blood and blood-related products from contamination by AIDS, hepatitis and other viral diseases.

Duration: 7/1/1992 — 6/30/1995
ATP number: 91-01-0135

FUNDING (IN THOUSANDS):

ATP	$2,000	67%
Company	1,000	33%
Total	$3,000	

ACCOMPLISHMENTS:

Aphios developed a procedure using critical fluids to inactivate viruses in blood and established that the process is applicable to a large number of viruses, although to different levels of effectiveness. The following achievements indicate technical progress by the company, which:

- applied for a patent ("Viral Inactivation Method and Apparatus") on technology related to the ATP project;
- presented two papers at conferences on blood-safety issues;
- executed a letter of intent with the Northeast Region of the American Red Cross to develop and field-test a virus inactivation prototype for individual units of blood; and
- submitted a proposal to a consortium of companies to evaluate the viral inactivation technology for use in developing products and processes.

COMMERCIALIZATION STATUS:

Aphios has not commercialized the process yet. The firm has been negotiating with a health care company interested in sponsoring further development and commercialization of the technology. Some early knowledge benefits have emerged from the project via patent disclosures and scientific papers.

OUTLOOK:

Commercialization may occur after more R&D work, primarily on the inactivation of parvovirus. There has been evidence of interest in the technology by the health-care community in general and by the American Red Cross in particular. Benefits are expected to accrue to society if the development of the technology can be completed successfully. However, given the company's financial difficulties, the outlook at this time is uncertain.

COMPANY:

Aphios Corporation (formerly BioEng, Inc.)
3-E Gill St.
Woburn, MA 01801

Contact: Trevor P. Castor
Phone: (781) 932-6933

Number of employees:
3 at project start, 17 at the end of 1997

can be made virus-free with the Aphios technology. Reducing the spread of viral disease is expected to generate large health-cost savings and related benefits to the United States. Users will also benefit if the process based on the new technology is, as expected, less costly than current decontamination procedures. Economic benefits might also extend to people who avoid viral disease because users of blood or blood-derived products decontaminated with the Aphios technology do not become infected and spread the disease.

Without the ATP funds, Aphios officials say, the company would not have conducted the project. Moreover, it would have been impossible for this small company to attract the interest of the health care company or the American Red Cross.

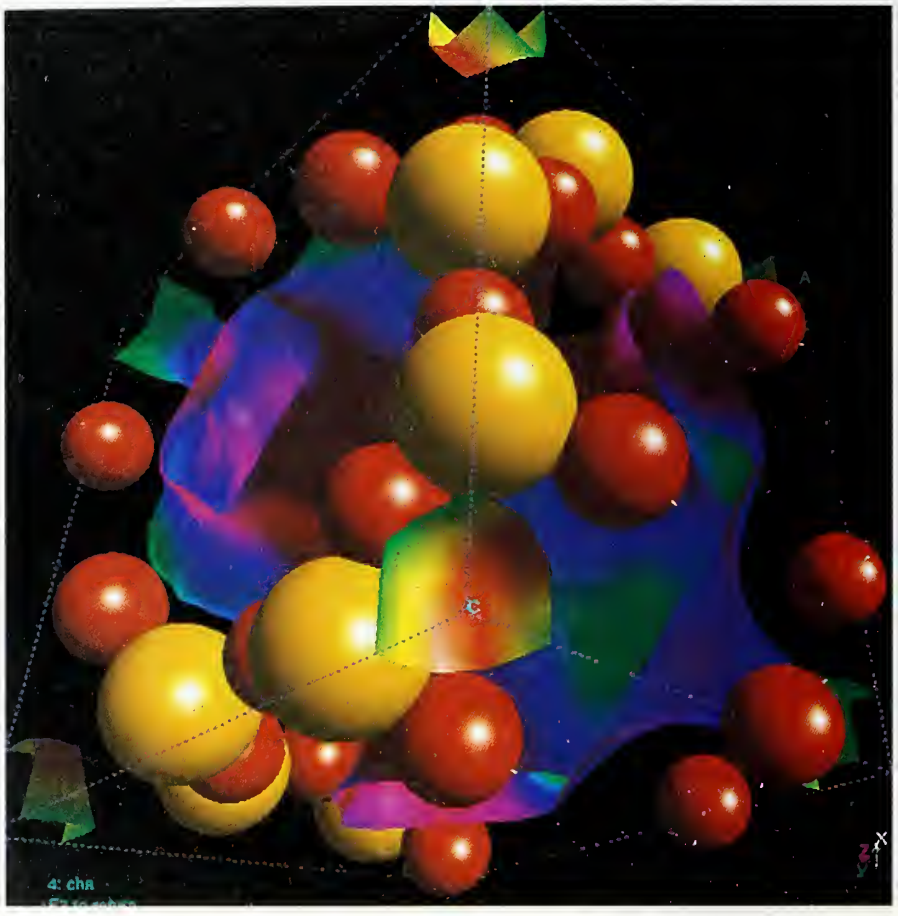
As this report was going to press in late 1998, it was learned that the company had reduced staff and was experiencing financial distress.

Without the ATP funds, Aphios officials say, the company would not have conducted the project.

Molecular Simulations, Inc. (formerly Biosym Technologies, Inc.)

Powerful Software for Designing New Molecules and Therapeutic Drugs

The traditional route to discovering new therapeutic drugs and other useful chemicals should probably be called "semi-automated serendipity." In the search for new drugs, hundreds of synthetic chemicals and natural substances are put through a long series of trials, starting with effectiveness tests in cell-based assays and concluding with toxicity and effectiveness trials in laboratory animals and, finally, humans. At each stage, the vast majority of substances fail the test and are discarded.



The geometrical and electron structure of a siliceous CHA-framework material isotopological with the mineral chabazite. Zeolites and related crystalline microporous solids such as chabazite have industrially useful separative and catalytic properties that are determined by both the micropore architecture and the nature of active sites.

Using Mathematics to Find New Drugs

This ATP project with Molecular Simulations, Inc. (MSI), a small San Diego company that had 170 employees when the project began, combined applied mathematics and computer programming to develop new methods for simulating molecular structures and reactions. The technology is more efficient than conventional molecule-design techniques, a quality that translates into speedier product development and lower costs.

Density functional theory (DFT) proved as accurate as other approaches, yet much less expensive.

The ATP-funded effort led to new understanding of density functional theory (DFT), a quantum mechanics method. Most work to understand molecules is mathematical, and DFT is a relatively new form of applied mathematics previously not widely used to simulate molecules. Researchers successfully demonstrated the applicability of DFT to the study of biochemical systems, the backbone of drug research, showing that DFT is as accurate as other approaches and considerably less expensive.

Applications in New Drugs and Petrochemicals

Prior to its ATP award, MSI was already developing, marketing and supporting a suite of software tools suitable for computing the behavior and properties of molecules. The suite includes tools for bioinformatics, combinatorial library optimization, determination of

PROJECT:

To develop density functional theory (DFT), a type of first principles quantum mechanics, for use in the development of new therapeutic drugs and other substances, an application that is expected to achieve substantial time and cost savings.

Duration: 6/1/1992 — 5/31/1995
ATP number: 91-01-0224

FUNDING (IN THOUSANDS):

ATP	$1,442	44%
Company	1,867	56%
Total	$3,309	

ACCOMPLISHMENTS:

MSI successfully demonstrated the applicability of DFT to the study of biochemical systems and developed software that employs DFT to efficiently calculate molecular structures and energies. The software was used to study biochemically relevant systems. It proved as accurate as other approaches, yet much less expensive. Also, the company:

- prepared more than 30 technical papers on the ATP-funded technology for publication in professional journals or presentation at conferences;
- implemented a highly accurate way of applying DFT in the company's Turbomole computer software product;
- expanded its physical plant to accommodate larger R&D and production facilities;
- was a finalist for a *Computerworld* Smithsonian Award, the 1996 Innovator Medal; and
- has grown at a cumulative annual rate of about 20 percent since the end of the ATP project in May 1995.

COMMERCIALIZATION STATUS:

Commercialization is in progress. MSI incorporated the ATP-funded technology into the company's existing Turbomole software package, which has been distributed to more than 100 sites. The ATP-funded technology has also been incorporated into MSI's quantum chemistry workbench software. Benefits from the ATP-funded technology are already accruing to users of MSI software, as well as to users of products developed with the software.

OUTLOOK:

Expectations for this technology and the company are strong. The technology has been incorporated into commercially distributed products that are being used extensively by a relatively small, yet global, community of scientists in academic, industrial and governmental laboratories for rational drug design and petrochemical research. It has potential applications in biotechnology, microelectronics and industrial fine chemicals research.

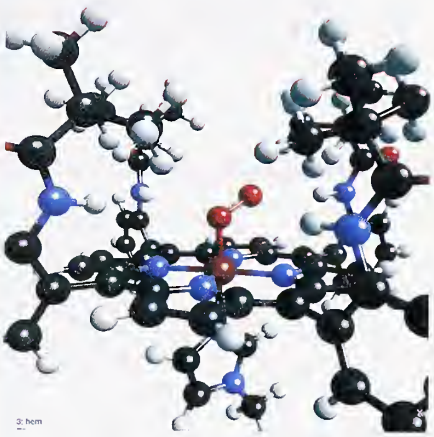
COMPANY:

Molecular Simulations, Inc.
(MSI; formerly Biosym Technologies, Inc.)
9685 Scranton Road
San Diego, CA 92121

Contact: John M. Newsam
Phone: (619) 546-5391

Number of employees:
170 at project start, 292 at the end of 1997

. . . prepared more than 30 technical papers . . . for publication . . .



The geometry of a heme complex, optimized by first principles density functional methods implemented in the program DMol, using technology developed under ATP sponsorship. In this molecule, which contains more than 150 atoms, the central iron atom (central, dark red) is coordinated by four nitrogen atoms (blue) of the heme group, and a dioxygen molecule (red).

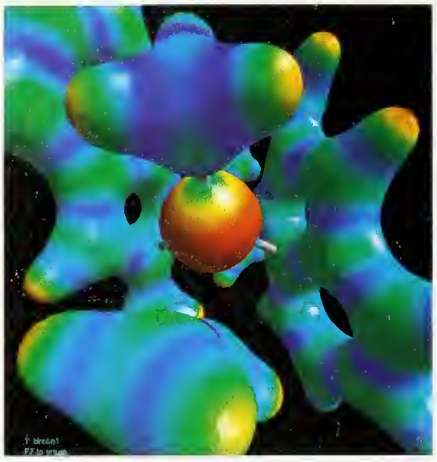
Researchers successfully demonstrated the applicability of DFT to the study of biochemical systems, the backbone of drug research . . .

protein structures from amino acid sequences, and structure- and analog-based rational drug design. The ATP project enabled MSI researchers to incorporate the new DFT knowledge into several of these tools. Most MSI software users benefit from access to several different tools and will use more than one of them in a given study.

One of the first MSI tools to be enhanced with the DFT technology was Turbomole, a computer software application that integrates a database of atomic functions, a modern user-interface and mathematical tools like DFT. The computer program calculates tables of molecular characteristics and generates a three-dimensional structure of the molecule that can be viewed by molecular graphics.

Another tool upgraded with the new technology is DMol, a quantum chemistry program that enables users to make reliable, quantitative predictions about molecular systems. The ATP-funded technology—a DFT-based component of the program—decreases the cost of these types of computation, potentially reducing the cost of designing new molecules. The ATP-funded technology is being used experimentally in petrochemical research, and it has potential applications in biotechnology, rational drug design, microelectronics and industrial fine chemicals research.

. . . potential applications in biotechnology, rational drug design, microelectronics and industrial fine chemicals research.



Electron density isosurface of a zirconocene complex, color-coded by electrostatic potential, as computed by the DMol program. The geometrical and electronic structures in metallocene complexes govern the nature of the polyolefin products produced when single site catalysts of this type are used to catalyze olefin polymerization.

Benefits to Companies and Consumers

Because the MSI software is relatively low-cost, enters the discovery and development cycle close to its beginning, and is used by research and development personnel in large organizations, the benefits to the users of the software can be large relative to what MSI earns through software licenses. Such benefits will accrue to chemical, petrochemical, pharmaceutical and biotechnology companies, as well as to companies in other industries that use MSI software incorporating the ATP-funded technology. Benefits will also accrue to people who use therapeutic drugs and other products made by companies using the new technology. In addition, scientists worldwide might benefit from a database of molecular structures developed under the ATP award — MSI is considering making the database available on the Internet.

MSI reports that the ATP funds enabled it to complete research on the DFT technology and incorporate the results into its software products some 18 months earlier than it would otherwise have been able to do. The company, its customers in the pharmaceutical and materials industries, and their customers have all benefited. The project also facilitated the dissemination of new knowledge, particularly via the many scientific papers that were published about the ATP-funded technology.

Company Grows, Announces IPO, is Acquired at a Large Premium

Since the end of the ATP project in May 1995, the company has grown at a cumulative annual rate of about 20 percent. In February, 1997, it filed a Form S1 with the Securities and Exchange Commission, announcing its intention to conduct an Initial Public Offering of stock, and noted that it expected to raise about $35 million by selling about half of the stock in the company. In February, 1998, the company and Pharmacopeia, Inc., announced that Pharmacopeia would acquire MSI. The acquisition was finalized in June, 1998, in a transaction valued at approximately $140 million.

. . . scientists worldwide might benefit from a database of molecular structures developed under the ATP award — MSI is considering making the database available on the Internet.

Thermo Trilogy Corporation
(original awardee: AgriDyne Technologies, Inc.)

Bioengineering of a Safe, Organic/Chemical Insecticide

Every year millions of tons of chemical pesticides are sprayed or irrigated onto plants in fields and gardens throughout the United States. Protected from weeds and insects, these plants flourish and grow to provide food and visual delight for us all. Chemicals used for pest control, however, sometime turn out to be poisonous for humans, and the results are often tragic. Consequently, efforts are under way to reduce the need for toxic chemical pesticides and, in the process, to eliminate the adverse side effects they can bring.

Reducing the Risk of Toxic Pesticides

One promising approach to reducing the hazards of pesticides is to use genetically engineered organic compounds based on naturally occurring pesticides that are harmless to humans. The ATP project with AgriDyne Technologies offered a novel way to do this by taking advantage of large-scale biochemical production. AgriDyne, founded in Utah in the early 1980s as Native Plants, was a small company that would have been unable to pursue this research without the ATP award.

Scientific knowledge generated by the ATP project . . . is disclosed in two patents and may be important to the genetic engineering of other plant extracts.

A Nontoxic, Chrysanthemum-Based Pesticide

The technology AgriDyne developed during its ATP project is based on the chemistry of pyrethrins, a group of six closely related natural insecticides derived from pyrethrum, a type of chrysanthemum. Pyrethrins kill insects on contact, have low toxicity for mammals, degrade shortly after application and produce no harmful residues. The only current source for natural pyrethrins is chrysanthemum from east Africa. But, according to AgriDyne's proposal to ATP, supplies were neither stable nor sufficient to meet the worldwide demand.

Although pyrethrins can be synthesized in the laboratory, production via traditional chemical processes is difficult and expensive. AgriDyne's alternative was to genetically engineer yeast cells to produce chrysanthemyl alcohol, a precursor that is then chemically converted to chrysanthemic acid. This, in turn, can be used to produce commercial quantities of pyrethrin.

Business Upheavals Stall Technology

AgriDyne achieved most of the technical goals of the project, but production costs were higher than predicted. The company encountered financial problems that forced it to close in 1995, just as the project was ending. AgriDyne apparently did not have enough management resources to handle the challenges of both developing the technology and commercializing a product. The firm was acquired by Biosys of Columbia, Md., another biopesticides company, which decided not to make the investment required to commercialize the ATP-funded AgriDyne technology.

Biosys, in turn, declared bankruptcy in 1996. Its assets, including patents, were acquired by Thermo Trilogy, the second largest biopesticides company in the world. Thermo Trilogy officials reported having no current plans to commercialize the ATP-funded technology, since the cost today of procuring chrysanthemyl from Africa is lower than the expected cost of producing pyrethrin with the new technology. In addition, they say, detailed knowledge of the scale-up process for the technology (requirements for physical plant invest-

The company encountered financial problems that forced it to close in 1995, just as the project was ending.

PROJECT:

To develop a genetic engineering process for producing pyrethrin, a natural insecticide from chrysanthemums that is nontoxic to mammals but was available only from Africa in limited, unstable supplies. The technology would provide a less-costly, stable domestic source of supply.

Duration: 6/1/1992 — 5/31/1995
ATP number: 91-01-0071

FUNDING (IN THOUSANDS):

ATP	$1,200	37%
Company	2,012	63%
Total	$3,212	

ACCOMPLISHMENTS:

AgriDyne achieved most of its technical goals and received two project-related patents:

"Storage Stable Pesticide Compositions Comprising Azadirachtin and Epoxide"

(No. 5,352,697: filed 7/28/1992, granted 10/4/1994) and

"Chrysanthemyl Diphosphate Synthase, Corresponding Genes and Use in Pyrethrin Synthesis"

(No. 5,443,978: filed 6/25/1993, granted 8/22/1995).

COMMERCIALIZATION STATUS:

No commercial product has yet been produced.

OUTLOOK:

Commercialization is uncertain, owing to the dissolution of AgriDyne, current market conditions that make the new production approach too costly to compete with natural sources of supply, and lack of plans, at this writing, by Thermo Technology (which now owns the intellectual property) to pursue further development. Scientific knowledge generated by the ATP project, however, is disclosed in two patents and may be important to the genetic engineering of other plant extracts. The knowledge has potential applications in pharmaceuticals and specialized materials and chemicals, as well as in pesticides.

COMPANY:

AgriDyne Technologies, Inc.
(acquired by Biosys, Inc. in 1995; Biosys assets acquired by Thermo Trilogy in 1996)
Thermo Trilogy Corporation
7500 Grace Drive
Columbia, MD 21044

Contact: Ramon Georgis
Phone: (410) 531-4711

ment, as well as information on the predictability of a viable, consistent production yield) was unknown to them and their counterparts at Biosys, and they found it difficult to assess AgriDyne's ATP project. Both companies considered further pursuit of the technology too risky for them.

Although no commercial product has yet resulted from the ATP-funded technology, new bioengineering knowledge has.

Gains in Bioengineering Knowledge

Although no commercial product has yet resulted from the ATP-funded technology, new bioengineering knowledge has. Some of it has been disclosed through two patents. But AgriDyne's manufacturing know-how was apparently not passed on to the company's successors. Should events in Africa decrease the supply or increase the cost of natural pyrethrin, the AgriDyne approach may be resurrected by funding development of the needed manufacturing skills.

Tissue Engineering, Inc. (TE)

Prostheses Made of Biomaterials That Regenerate Body Parts

From its beginning, the field of bioengineering has focused on providing the best artificial devices — hearing aids, artificial limbs and other prostheses — to replace body parts that are missing, broken or dysfunctional. This ATP project with Tissue Engineering (TE), a biotechnology start-up company, takes bioengineering far beyond artificial replacements to a technology that regenerates, rather than replaces, lost or damaged tissues. Although this claim sounds like science fiction, it is in fact quite real. And it promises to produce real medical benefits in the very near future.

Collagen fiber and braided structures from collagen fiber: (a) single collagen fiber, (b) 8-ply collagen fiber braid, (c) 64-ply collagen fiber braid, (d) 512-ply collagen fiber braid.

Technology to Regenerate Lost or Damaged Body Parts

TE is pioneering a new class of biomaterials called ADMAT (animal-derived extracellular matrix). The idea behind the company's ATP project is to use ADMAT materials in collagen-scaffold "prostheses" to replace damaged or dysfunctional tissues and organs. The prostheses are designed to provide templates that mobilize the body's own cells and induce them to rebuild the lost tissue, gradually replacing the prosthesis itself. Regeneration of body parts requires a biomaterial with a structure, components and chemical signals that allow the body's tissue cells to recognize, respond to and remodel the material without rejecting it as foreign.

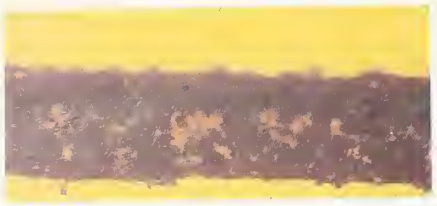
Demand for ADMAT Materials

ADMAT materials are derived from the by-products of land and marine animals processed for food. The material can be spun into fibers and woven into fabrics using techniques borrowed from the textile industry, or it can be formed into foams, sheets and films. ADMAT can be used to enhance collagen scaffolds for vascular grafts, ligaments, tendons, periodontal tissue and similar reconstructions.

This ATP project . . . takes bioengineering far beyond artificial replacements to a technology that regenerates, rather than replaces, lost or damaged tissues.

During the ATP project, TE successfully developed techniques and procedures for extracting and storing a mixture of collagens and for preserving the desired characteristics of the extracellular matrix. The company developed new materials for hosting the matrix and a process for adding the matrix to collagen fibers in the course of spinning.

The demand for products the company plans to offer clearly exists. The lag time, however, between technology conception and market availability — particularly for medical treatments — is long. Tissue-engineered products face clinical trials and other regulatory hurdles, in addition to technical and market-introduction barriers. The company is making good progress in navigating these barriers in accord with its technical and business plans.



Collagen fiber decorated with ADMAT microparticulates via ATP-funded patented process.

Commercialization is in progress. TE has placed periodontal prosthesis prototypes with potential customers for testing. It has created other products for research, testing and diagnostic applications. These activities are not regulated, so commercialization can happen more speedily. In addition, it has formed a venture with Wright Medical Technology for commercialization of orthopedic applications. TE is also in discussions with several other companies to commercialize other applications, such as a line of skin and wound-healing products.

TE has placed periodontal prosthesis prototypes with potential customers for testing.

Large Potential Benefits for Society

The eventual successful commercial introduction of the ATP-funded technologies will bring large health gains to patients with many forms of medical problems, ranging from dental to cardiovascular. Procedures and materials that would enable the regrowth of ligaments and cartilage in knees and enable dental tissue to regenerate with a single surgery — at costs lower than those offered by alternative medical approaches today, and that one day may even facilitate organ regeneration — would have great benefits for society.

These potential benefits are likely to be huge because of the large number of patients who could use these prostheses, the advantages the TE approach has over currently available alternatives, and improvements in the ability of patients to function as a result of using the new technology. The ATP award is playing an important role in bringing these benefits to society, because applications of the new technology are about two years ahead of where they would have been without ATP funding.

A recent detailed case study by the Research Triangle Institute estimated that TE's ADMAT technology could be expected to generate about $33 billion (in present value dollars) in net benefits for society in a single medical application area: anterior cruciate ligament repair.[3]

The study estimated that about 100,000 patients per year with ligament damage would be eligible for the new treatment, that the number using the Tissue Engineering technology would start at 9,000 in the first year of availability and grow to 72,000 ten years later, supplanting an increasing percentage of alternative technologies currently in use. The study incorporated estimated benefits from quality-of-life improvements, using a "quality-adjusted-life-years" index value. It estimated that about $15 billion of the expected benefits would be attributable to ATP's accelerating the technology development by two years.

. . . formed a venture with Wright Medical Technology for commercialization of orthopedic applications.

PROJECT:

To develop techniques and procedures for processing tissue, extracting and storing collagen, and spinning and weaving collagen fibers into fabrics and other forms suitable for human prostheses that could induce the body's own cells to rebuild lost tissue while gradually replacing the prosthesis.

Duration: 3/1/1993 — 2/28/1996
ATP number: 92-01-0133

FUNDING (IN THOUSANDS):

ATP	$1,999	48%
Company	2,128	52%
Total	$4,127	

ACCOMPLISHMENTS:

TE accomplished its technical goals. The company developed procedures for processing a tissue-specific extracellular matrix rich in cytokines (cell-generated proteins), extracting and storing type I collagen (a material present in all tissues), and spinning collagen into fibers that can be woven into prosthetic fabrics. The company:

- received two patents for technologies related to the ATP project:
  - "Apparatus and Method for Spinning and Processing Collagen Fiber" (No. 5,562,946: filed 11/2/1994, granted 10/8/1996) and
  - "Bipolymer Foams Having Extracellular Matrix Particulates" (No. 5,709,934: filed 11/22/1994, granted 1/20/1998);
- applied for three other patents related to the technology;
- made several presentations at conferences and workshops; and
- formed a joint venture with Wright Medical Technology, Arlington, Tenn., to develop and distribute products based on the ATP-funded technology for applications involving ligaments, tendons, cartilage and other musculoskeletal parts.

COMMERCIALIZATION STATUS:

A commercialization venture has been formed for orthopedic applications. Prototypes are in testing, although no product has yet entered the market. Patent disclosures and a joint venture to commercialize the technology may be providing useful knowledge to other researchers in the field.

OUTLOOK:

This project is on track for market entry in the very near future. The technology is scheduled to be used first in the fabrication of periodontal prostheses and orthopedic applications. Ideas for skin and wound-healing products are also being explored by the company with potential customers.

COMPANY:

Tissue Engineering, Inc. (TE)
451 D St., Suite 807
Boston, MA 02210

Contact: Eugene Bell
Phone: (617) 946-0520

Number of employees:
1 at project start, 18 at the end of 1997

Chapter 3

Chemicals and Chemical Processing

BioTraces, Inc.

Highly Sensitive Detectors for Biomedical and Environmental Diagnostics

A technology that can detect minute traces of biomolecules — pesticides, bacteria in water, organic toxins like botulin — much better than conventional detectors would be extremely useful in a number of fields. Medicine, for instance, has obvious need for highly sensitive methods of detecting viruses. Such a technology would also be applicable in a broad range of environmental areas, where early detection of chemicals or other substances could trigger corrective action early enough to head off disaster. Detecting traces of toxic materials in a municipal water supply, for example, might lead to the elimination of their source before they poison the city's population. A highly sensitive detection technology could also be useful for the optimized control of semiconductor fabrication.

Detecting Minute Amounts of Unwanted Molecules

This ATP project created such a technology through the efforts of BioTraces, a small company founded in 1989 to develop, manufacture and market instruments for detecting microtraces of various materials. During its ATP project, the company developed a highly sensitive biomolecule detection method based on an improved radioactive tracer detection system originally developed for cosmology. Instruments of this types use radioactive isotopes that are chemically bound to the target molecules or atoms. Photon or electron detectors that register radiation decay particles are used to spot the "tagged" targets. Sensitivity is limited by background radiation — 10 to 100 counts per minute for conventional commercial instruments in typical applications. BioTraces beats this limitation with a sophisticated multiphoton detector (MPD) that registers only counts that match the multiple-photon decay pattern of the isotopes used as tags. In contrast to conventional methods, background levels for BioTraces detectors are a few counts per day.

Detecting traces of toxic materials in a municipal water supply, for example, might lead to the elimination of their source before they poison the city's population.

Safer Analyses for Patients and the Environment

The BioTraces technology uses different isotopes to tag different types of molecules in the sample. This allows several different molecule types to be measured simultaneously, greatly speeding complex analysis tasks such as those used in clinical screening (for example, to detect contaminants in blood supplies). Since background interference is so low, the minimum amount of isotope needed for an analysis can be as much as 1000 times less than that used in conventional radioisotope analysis, making the BioTraces system considerably safer for patients and the environment.

The company met most of the project's technical goals. Its researchers developed prototype MPD instrumentation hardware and software that is much more sensitive than current state-of-the-art equipment. They also developed biomedical applications of the technology for enhanced immunoassay, chromatography and nucleic acid analysis.

First Fruits of Commercialization

At the start of the ATP project, BioTraces planned to do only the instrumentation work and to leave specific applications to partner companies. But lack of success in finding suitable partners led BioTraces to change its approach to commercialization. It is now finishing development work on the MPD technology and hopes to begin offering its own commercial products widely in the near future. The company has made enough progress to license the technology exclusively to a new company, PetroTraces, for petrochemical applications. PetroTraces uses it to tag and trace different liquids and gases that are transported in pipelines so it can supply customers with data for auditing and other applications.

BioTraces' own initial commercial product, the ssMPD (sequential sample MPD) is used for super-sensitive measurement in extremely small samples — up to a few milliliters. The

ssMPD received market clearance from the U.S. Food and Drug Administration for sale as a clinical diagnostics device and entered the market in 1997 on a limited basis for use in research. BioTraces expects to launch wide-scale sales of the ssMPD in late 1998 or early 1999, after enhancing protection for its proprietary software and establishing a strategic alliance with a major clinical diagnostics company.

The new MPD technology has great potential as an advanced biomedical diagnostic tool and for other uses where detection of minute traces of biomolecules is critical. BioTraces entered an agreement with Pasteur-Merieux Connaught, a French company, under which it developed an MPD-enhanced quantitative polymerase chain reaction assay for measuring tiny amounts of deoxyribonucleic acid (DNA) and ribonucleic acid (RNA). And in June 1997 it arranged for Genetics Institute, Inc., to evaluate the MPD technology as a pharmaceutical research and development tool. If the test is successful, it could lead to a license allowing Genetics Institute, Inc., to use the technology in its drug discovery program.

ATP Gives a Big Boost to a Small Startup

BioTraces is a very small company, having only three employees when it started the ATP project. Since then, the company has received $1 million in equity investment to support commercialization of the new technology. It has also entered into discussions with two venture capital firms about securing an additional $4 million in equity funding in 1998.

Company officials report that the ATP award enabled BioTraces to achieve its research results two to three years sooner than it otherwise would have been able to do. The funds also helped it develop research alliances and improved its ability to raise investor capital.

BioTraces expects to launch wide-scale sales of the ssMPD™ in late 1998 or early 1999 . . .

PROJECT:
To develop instrumentation based on multiphoton detection (MPD), high-speed/high-sensitivity sensors and proprietary software, one that can detect minute concentrations of chemicals in gas, liquid or solid matrices — a technology that would be extremely useful in environmental monitoring and biomedical research.

Duration: 1/1/1994 — 12/31/1996

ATP number: 93-01-0250

FUNDING (IN THOUSANDS):

ATP	$1,718	69%
Company	773	31%
Total	$2,491	

ACCOMPLISHMENTS:
BioTraces developed MPD instrumentation, both hardware and software, as well as biomedical applications of the technology for enhanced immunoassay, chromatography and nucleic acid analysis. The company:

- applied for two patents on technology developed during the ATP project:
  - "Enhanced Chromatography Using Multiphoton Detection" and
  - "Ultralow Background Multiple Photon Detection;"
- negotiated with the French company Pasteur-Merieux Connaught an agreement under which BioTraces developed an MPD-enhanced quantitative polymerase chain reaction assay for measuring tiny amounts of DNA and RNA;
- negotiated a $1.78 million agreement in July 1996 with a newly-formed company, PetroTraces, granting it an exclusive license for commercial applications of the new technology in the petroleum industry — a deal that so far has generated $585,000 in revenues for PetroTraces and $560,000 in license fees for BioTraces;
- arranged in June 1997 for Genetics Institute, Inc., to evaluate the MPD technology as a pharmaceutical R&D tool; if successful, the test could lead to a license allowing Genetics Institute, Inc. to use the technology in its drug discovery program;
- created a clinical diagnostics device, the ssMPD™ (sequential sample MPD), which received market clearance from the U.S. Food and Drug Administration and entered the market on a limited basis in 1997;
- has received since the start of the ATP project $1 million in equity investment to support commercialization of the new technology; and
- entered into discussions with two venture capital firms about securing an additional $4 million in equity funding in 1998 or 1999.

COMMERCIALIZATION STATUS:
Commercialization is in progress. Applications of the technology are underway in the petrochemical field via PetroTraces. BioTraces' first commercial product for medical applications, ssMPD™, has entered the market on a limited basis and is expected to be more widely available in 1998 or 1999.

OUTLOOK:
Once BioTraces works out a strategy for protecting its intellectual property, the new technology is expected to be disseminated more aggressively. Given its potential use in detecting viruses, bacteria, toxins and pollutants, the ATP-funded technology stands to generate substantial benefits to the economy. If, for example, it were used to detect a toxin in a water supply, preventing a whole town or region from becoming ill, the benefits would be enormous.

COMPANY:
BioTraces, Inc.
10517-A West Drive
Fairfax, VA 22153

Contact: E. James Wadiak

Phone: (703) 273-6941

Number of employees:
3 at project start, 14 at the end of 1997

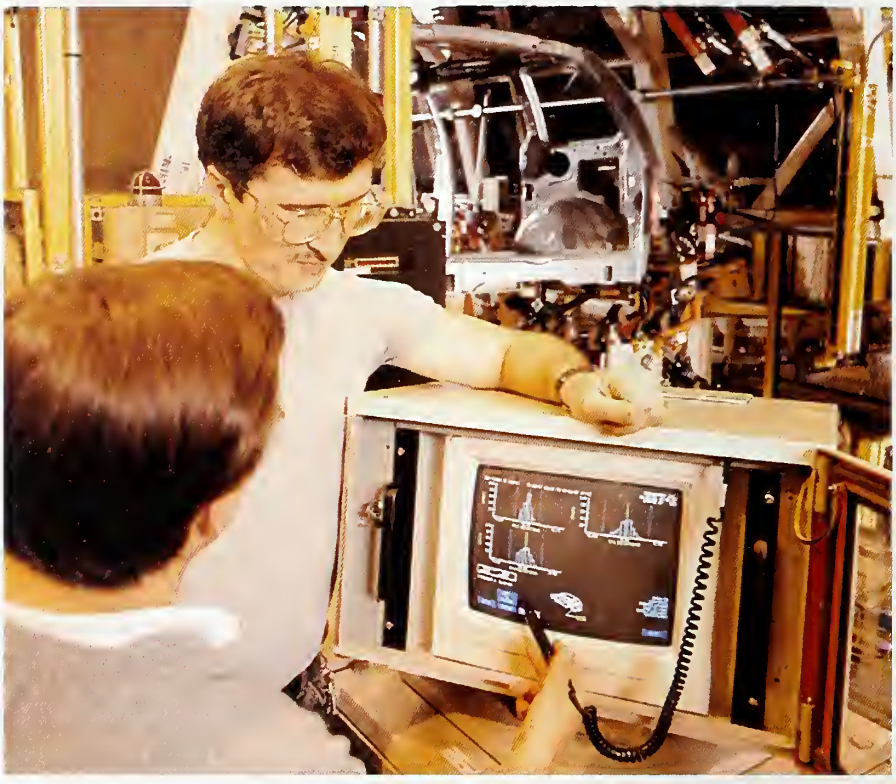
Chapter 4

Discrete Manufacturing

Auto Body Consortium (Joint Venture, formerly 2mm Auto Body Consortium)

A Systems Solution to a Quality Problem in Auto Body Manufacturing

Just a few millimeters make a big difference on an automated assembly line as doors, hood, windshield, wheel housings and other parts are installed on a body-in-white (BIW), the partially completed body of an automobile. If BIW openings are slightly off kilter or parts vary much from specifications, the overall fit and finish of the completed car suffers. When dimensions vary more radically, a BIW may have to be custom-assembled by hand. In addition, if the variations grow too large, the entire BIW may be pulled from the assembly line and junked.



Assembly plant staff members monitor operations using real-time analysis tools developed in the ATP project.

Toward a Tightly Fitted Car Body

In contrast, a tightly fitted car means fewer defects, less time and money for factory repairs, better appearance and performance for the owner, and lower long-term maintenance costs. And the quicker assembly-line changeovers can be made while retaining tightness of fit, the faster new models can be introduced at reasonable cost.

A U.S. Problem Overcome

The problem of "dimensional variation" has cost the U.S. automotive industry dearly in product quality, wasted materials, increased production time and lost sales. While European auto makers were building cars with dimensional variations less than 2.5 mm and Japanese manufacturers were achieving results at or below 2 mm, U.S. producers were assembling cars with as much as 5- or 6-mm variation. But with completion of ATP's "2mm Project" in 1995, American auto makers have shown a marked increase in their ability to assemble cars with world-class precision. In all five Chrysler and General Motors (GM) auto assembly plants where the new methods were tested, overall dimensional variation was brought down to, or below, the 2 mm standard. In addition, other technologies developed by the project have yet to reach the assembly line, and their full implementation in auto body plants promises to reduce dimensional variation even further.

The project has published a manual for use in extending the procedures developed during the project.

Lower Production Costs

With an investment of $4.9 million from the ATP and $9 million from the automobile industry, the 2mm Project developed a number of interrelated technologies and processes that have already cut net production costs (actual costs less the cost of implementing 2mm technologies) by $10 to $25 per vehicle in plants where they have been tested.[1] When full

PROJECT:

To develop improved measurement technology and process control needed to achieve tighter fit — as well as better quality and lower costs — in auto bodies and other products assembled from sheet metal parts.

Duration: 9/1/1992 — 10/31/1995
ATP number: 91-01-0177

FUNDING (IN THOUSANDS):

ATP	$4,487	43%
Companies	6,048	57%
Total	$10,535	

ACCOMPLISHMENTS:

The project achieved the R&D goal of developing measurement and process control technology, which participating companies verified in several in-plant tests. Widespread adoption of the technology is now underway in auto assembly plants. Indicative of progress, the companies:

- cut dimensional variation in auto body assembly to a world-class standard of 2 mm or less and demonstrated the reduction with existing workforces in all five plants initially targeted by the project;
- reduced production costs by $10 to $25 per vehicle at two plants initially adopting the technology, savings that are expected, according to consortium staff, to be applied eventually in plants which produce all 6.5 million cars and light trucks produced annually by Chrysler and General Motors;
- reduced expected future maintenance costs by an estimated $50-$100 per vehicle;
- published several papers in professional journals;
- published *The Capture and Communication of Knowledge: A Lessons-Learned Approach*, a manual that will speed the adoption of the technologies and processes developed during the ATP project by showing how to implement them;
- worked with the University of Michigan to begin transferring the technology to other GM and Chrysler assembly plants beyond the original five, implementing it thus far in 22 plants in the United States and Canada;
- generated via ISI Automation Group (formerly ISI Robotics) the spin-off development of a new type of clamp, called the SofTouch, for holding sheet metal parts during assembly; and
- provided member auto assembly companies a "quality" peg on which to hang marketing literature — Chrysler highlights the fact that its new Concorde "literally has a two-millimeter body."

COMMERCIALIZATION STATUS:

Some supplier companies have incorporated the new measurement and process technology in assembly line equipment, and the new approach to tighter fit has been put into use in six of 10 Chrysler plants and 16 of 31 GM plants in the United States and Canada. Net production cost reductions of $10 to $25 per vehicle are estimated to have already been achieved using the new approach, meaning millions of dollars saved per year. Higher-quality vehicles from these plants are becoming available to consumers, and U.S. manufacturers are expected to increase their market share.

OUTLOOK:

Because the technology is being used and being systematically transferred to additional plants, the outlook is excellent. It is now being transferred to all Chrysler and GM plants, and through the supply chain, to Ford Motor Company. The technology is expected also to be adopted or adapted for use by other discrete manufacturers in, for example, the appliance and furniture industries. Auto assembly companies that adopt this new technology can expect to save hundreds of millions of dollars annually in production and maintenance costs. Consumers will benefit from higher-quality vehicles and will likely see some of the manufacturing cost savings. Producers and consumers are expected to benefit from yearly savings of up to $650 million in auto maintenance costs. Quality improvements resulting from the project have been projected to boost U.S. industrial output by the automotive and related industries by more than $3 billion in the year 2000 and to create thousands of new jobs. To the extent the quality improvements extend to other manufacturing industries, the output and employment effects will be even greater.

COMPANIES:

Auto Body Consortium (joint venture lead; formerly 2mm Auto Body Consortium)
2901 Hubbard Road
Ann Arbor, MI 48105

Contact: Ernest Vahala
Phone: (734) 741-5905

Joint venture participants: CDI-Modern Engineering; Classic Design, Inc.; Detroit Center Tool, Inc.; ISI Robotics; Perceptron, Inc.; Pioneer Engineering & Manufacturing; Progressive Tool & Industries, Inc.; Weber Technologies, LLC; Chrysler Corporation; General Motors Corporation (GM), Technical Center; University of Michigan, Mechanical Engineering and Applied Mechanics.

Subcontractor: Wayne State University

adoption by all GM and Chrysler assembly plants is achieved — probably by the year 2000 — annual production cost savings are projected in the range of $65 million to $160 million on the current production volume of 6.5 million vehicles, which amounts to 48 percent of the cars and light trucks sold in the United States. Some of the cost savings are likely to be passed on to consumers as a result of competition among U.S. and foreign producers in the new vehicle market in the United States.

ATP's financial contribution helped small- and medium-supplier companies pay for an expanded university effort while large assemblers provided most of the industry cost share, which covered their own expenses and joint venture overhead.

Less Maintenance, Faster Launch

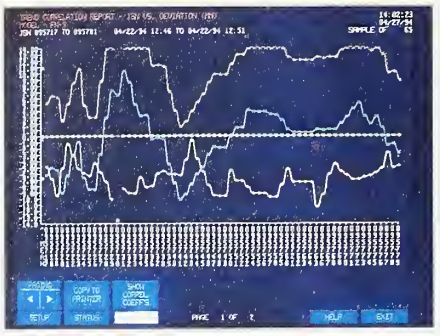
Cars and trucks built with 2mm Project innovations should also cost less to maintain as better body fit results in reduced wear, less rust and fewer other problems. These savings are estimated to range from $50 to $100 per vehicle over its useful lifetime. Several years after GM and Chrysler have fully implemented the 2mm Project results, total maintenance savings are expected to reach $325 million to $650 million per year based on current production volume. And, although a dollar value has not yet been estimated, the new technology is expected to decrease the time required to launch new auto models.

Higher Quality and Lower Costs Mean Increased Market Share and Jobs

In addition, assuming the 2mm Project quality and cost improvements lead to at least a 1 percent increase in market share for GM and Chrysler (at the expense of vehicles built abroad), economic projections show an overall increase in U.S. economic output in the year 2000 of more than $3 billion and the creation of around 70,000 new jobs. These estimates take into account the impact of an increase in vehicle sales on related sectors, but they do not include any increases due to adoption of 2mm technologies by companies outside the auto industry.

Collaborative Research to Solve a Complex Systems Problem

The 2mm Project was initiated by the Auto Body Consortium (eight small- and medium-size companies that provide tooling and engineering services for auto body assembly lines), two big auto manufacturers (Chrysler and General Motors) and two universities, one a joint venture partner, and the other a subcontractor. The joint venture treated BIW dimensional variation as a systems problem, selecting 11 subprojects, or tasks, to be accomplished in four general areas. Separate task groups, with staff from various joint venture members, worked on each subproject. After the operational tasks were completed, the final task of the 2mm Project was to synthesize the information, processes and lessons learned from the research and incorporate the results into a user-friendly database to help companies adopt the new technologies and methodologies



The computer display for one of the many diagnostic procedures provided by the new dimension control system.

and establish an infrastructure for future improvements.

The 2mm Project would have been difficult to achieve without the involvement of the ATP for several reasons. Dimensional variation in auto body production is a systems problem that could not have been solved by any one of the 11 project members alone. The ATP encourages formation of joint ventures like the Auto Body Consortium to solve complex systems problems. The public/private partnership was helpful in the face of a long history of federal antitrust enforcement that has left auto makers fearful of cooperating with each other without federal government involvement. Assembly line suppliers are generally small- or medium-size companies without research budgets large enough to fund work of the type undertaken by the 2mm Project, and auto makers have been reluctant to fund research by their suppliers. The fact that development risks were unevenly born by consortium member firms was another obstacle that ATP participation helped to overcome.

. . . organized meetings to share results with interested people from the aerospace, appliance and metal furniture industries, as well as other industries that use automation to assemble metal parts.

ATP's participation in the 2mm Project proved critical to the formation of this research joint venture. The ATP provided the catalyst needed to overcome multiple barriers. ATP's financial contribution helped small- and medium-supplier companies pay for an expanded university effort while large assemblers provided most of the industry cost share, to cover their own expenses and joint venture overhead.

The 2mm Project shows how small- and medium-size supply companies, large auto producers, and universities were able to cooperate in the development of an integrated system to reduce dimensional variation in body assembly and to improve the quality of the final product. It also demonstrates the unique role that comparatively modest investments of money and leadership by ATP can play in catalyzing complex, cooperative research ventures that pay off handsomely in technological and economic returns.

Widespread Adoption Underway in Auto Plants

The new approach to tighter dimensional fit has been put into use in six of 10 Chrysler plants and 16 of 31 GM plants in the U.S. and Canada, and it is being transferred to the remaining GM and Chrysler plants and to Ford Motor Company through the supplier chain.

HelpMate Robotics, Inc. (formerly Transitions Research Corporation)

Robot Navigation Technology

Robots are frequently seen as exotic, make-believe objects in science fiction movies. They walk, talk, crack jokes and worry about whether they are human or have souls. Real robots are much more mundane, but they are becoming increasingly useful in industry. They do work too tedious or dangerous for humans, enduring tedium without erring and danger without harm. They paint cars in factories without needing protective masks. They transport radioactive materials in power plants without suffering from radiation.

Using Robot Technology for Deliveries in Hospitals

Robots are also delivering medicines in hospitals faster and more reliably than humans can. "Do you really see hospitals and nursing homes starting to use that kind of technology?" an interviewer asked Paul Hoffman of *Discover* magazine after he demonstrated robot technology on CBS Good Morning America in May 1996. Replied Hoffman: "They do. This company, HelpMate Robotics in Danbury, is already using it in hospitals, right now."

Improved Navigation Capabilities

HelpMate Robotics, using ATP funds, has indeed developed the navigational technology needed to create mobile robots that can scurry around a hospital or other industrial environment. And with other funding, it has built them. This advance, set on the technical foundations laid by robotics pioneer and company CEO Joseph Engelberger, has helped to expand the use of mobile robots throughout the country.

These robots do some of the ambulatory work traditionally done by humans. To work well, the robots must have dependable vision systems that can use light from many different sources and recognize light-shading differences. They have to be trainable (programmable). They must make quasi-intelligent decisions — "Go around the gurney with the patient on it." And they have to be able to report to their human supervisor and ask for help when encountering problems they cannot handle — "There is no one here to sign for the parts."

Specifically, HelpMate researchers successfully developed an improved light direction and range (LIDAR) scanner. LIDAR is a device in the "eyes" of the robot that senses light, calculates direction and determines the range to objects in its path. This is a clear advance over previous technology, which used sonar to detect shapes. Researchers also developed navigation capabilities based on new sensing systems and ways of combining data from different sensors. These capabilities permit the control of robots in quasi-structured environments — places with predefined components such as doorways, light fixtures, windows and elevators that are fixed in place and definable from photos or engineering drawings — and among objects that are not predefined, such as a patient on a gurney and human workers moving about the space.

They do work too tedious or dangerous for humans, enduring tedium without erring and danger without harm.

Drugs are loaded on the HelpMate robot by a hospital pharmacist for delivery to staff in one of the hospital's wards.

HelpMate in Hospitals

Most of the ATP-funded technology has been embedded in the hospital version of the HelpMate robot. More than 150 HelpMate robots have been rented by scores of hospitals in Europe, Japan, Canada and the United States. Purchased outright, the robots cost about $110,000. Most are rented for $4 to $6 an hour. If a robot is used 100 hours a week, the annual rental fee is about $25,000.

HelpMate Robots are delivering medicines, supplies, prepared food, x-ray images and other material in about 100 hospitals in the United States and Canada.

Marketing Agreements for Distribution Abroad

Company officials say that ATP funding enabled HelpMate to achieve its research and development results much sooner than it would otherwise have been able to do. The award also helped it develop strategic marketing arrangements abroad. The company has signed an agreement for Otis Elevator to distribute HelpMate hospital robots exclusively in Europe. It has also developed marketing arrangements with other parties in Europe and Japan.

HelpMate raised $6 million through an initial public stock offering in 1996 and used the money to build production and sales capabilities. A second offering of $5 million did not go through, and the company had to downsize temporarily. New funding, however, has been committed, which should enable rebuilding of staff and marketing, as well as further work on a home-service version of the robot. In addition, the population of HelpMate robots in the field continues to serve well and will back up the company's renewed sales effort.

PROJECT:

To develop the technology for intelligent, autonomous mobile robots, or "robot carts," that can find their way around a factory, hospital or similar place by sensing and avoiding obstacles and taking alternative routes if a path is blocked. Such robots could reduce costs for delivering materials and supplies in many different environments.

Duration: 6/15/1992 — 3/31/1994
ATP number: 91-01-0034

FUNDING (IN THOUSANDS):

ATP	$699	44%
Company	875	56%
Total	$1,574	

ACCOMPLISHMENTS:

The company achieved the target navigation capabilities, including successful development of a specialized LIDAR (light direction and range) scanner. Evidence of progress includes the following:

- The company incorporated the new navigation capabilities into its original HelpMate robot and is now producing and selling the upgraded version.
- HelpMate raised $6 million through an initial public stock offering in 1996, and used it to build production and sales capabilities. (A second offering did not go through, and the company temporarily downsized in 1997. New funding commitments are expected to rebuild staff and marketing.)
- The upgraded HelpMate robot was named one of 36 finalists in the *Discover* magazine competition for technology of the year for 1996.
- CEO Joseph Engelberger, the principal investigator for the ATP project, received the Japan Prize in "systems engineering for an artifactual environment" in 1997 from the Science and Technology Foundation of Japan.
- The company and Otis Elevator entered into an alliance in which Otis is to be the exclusive distributor of HelpMate hospital robots in Europe.

COMMERCIALIZATION STATUS:

Robots incorporating the new navigational technology have been rented or sold to about 100 hospitals in the United States and Canada, and the company has entered marketing arrangements with parties in Europe and Japan.

OUTLOOK:

Since the robots are already in use commercially, the outlook for the technology is excellent, despite a temporary downsizing at HelpMate. The company now plans to expand the use of the technology by developing robots that can provide assistance in the home to infirm and elderly persons, a venture that potentially could save billions of dollars by eliminating some need for hospitalization or professional help in the home. Opportunities exist for applying these mobile robots in factories, warehouses and many other environments. Thus, the potential for future utilization of the technology is high.

COMPANY:

HelpMate Robotics, Inc.
(formerly Transitions Research Corporation)
Shelter Rock Lane
Danbury, CT 06810-8159

Contact: J.F. Engelberger
Phone: (203) 798-8988

Number of employees:
27 at project start, 14 at the end of 1997

HelpMate plans to expand the use of the ATP-funded technology by developing robots that can assist infirm and elderly persons at home.

Benefits From Robots

Hospitals using HelpMate robots are benefiting. HelpMate Robots are delivering medicines, supplies, prepared food, x-ray images and other material in about 100 hospitals in the United States and Canada. They have lowered the cost and improved the quality of these delivery services. One hospital pharmacy director, for example, reported net annual savings of around $10,000 per robot per year. In addition, the robots made the deliveries faster than humans did. There are about 150 HelpMate robots in these hospitals, according to company officials. If the savings for each robot to the hospital is $5,000 to $10,000 per year, then these hospitals are already realizing an annual savings of $750,000 to $1.5 million. The cost savings at the 100 hospitals alone over 10 years would be in the millions. These are savings above the rental cost of the robots. As more hospitals, factories and other facilities adopt these robots, cost savings will multiply.

In addition to these cost savings, benefits accrue to hospitals, physicians and patients through improved delivery service. Not only is robot delivery faster than human delivery, but it is also frequently more reliable, according to hospital officials, because of fewer delivery mistakes.

Robots to Serve the Elderly and Infirm

The analysis above is only for robots already employed in hospitals. For in-home nursing services, the use of robots could generate much larger savings. HelpMate plans to expand the use of the ATP-funded technology by developing robots that can assist infirm and elderly persons at home. But for this application, the company must first solve additional technical problems. These robots must have highly functional arms, improved vision, more sophisticated programming and some speech recognition capabilities. The company has estimated that, if successful, this development could substantially reduce health care costs by eliminating some of the need to hospitalize or hire home help for the frail elderly.

Other Potential Uses

Two industrial applications currently being explored are in computer chip fabrication and clinical laboratory work. In clinical labs, vials containing substances, such as the human immunodeficiency virus, that are highly dangerous to human workers could be moved from one workstation to another by robot. In a chip fabrication plant, robots could move supplies to the fabrication line in response to specific orders from operators. For these applications to be realized, capital will have to be raised to support the additional engineering required to tailor robots to the specific needs of each environment. Lab robots, for example, will need to be built to work without bumping into delicate research instruments and materials, and chip-plant robots must be engineered to operate so cleanly they do not contaminate the superclean rooms where chips are fabricated.

In addition to these applications, company officials say, the ATP-funded technology is expected to be used for mobile robots in all kinds of factories and has potential applications in warehouses, maintenance facilities, mail distribution centers and shopping malls (for delivery, maintenance and cleaning services). As in hospitals, the use of robots in these environments is expected to lower costs substantially and improve service.

Two industrial applications currently being explored are in computer chip fabrication and clinical laboratory work.

PreAmp Consortium (Joint Venture)

New Models to Speed the Development of Electronics Components

Printed circuit boards are ubiquitous. Most people know that boards are in computers, and that each computer actually contains several boards. They are also found in televisions, VCRs and the hand-held controls for these devices, as well as in printers, airplanes, thermostats, automobiles, appliances, calculators, garage-door openers, industrial controls, communications satellites and numerous other devices.

Data Sharing Speeds Component Development

In this ATP project, the PreAmp consortium developed common parts identifiers (a standard "product model" for components) and fabrication procedures (a generic "manufacturing process model" for making components) that can be shared among producers and users of printed circuit boards and other electronics components all along the production chain. These models will enable true concurrent (simultaneous) engineering of component design and manufacturing processes, an arrangement that will reduce the cost of developing components, improve their quality and decrease their time-to-market. These improvements, in turn, will lead to similar improvements in finished electronics products that incorporate printed circuit boards and other components developed via this new technology.

PreAmp is a joint venture of the South Carolina Research Authority (SCRA) and four large companies that use printed circuit boards

These models will enable true concurrent (simultaneous) engineering of component design and manufacturing processes . . .

in their finished products. Funding from ATP enabled the consortium to conduct research that it otherwise would have been unable to do. It also facilitated the formation of alliances among the research partners, helping them to demonstrate technology-enhanced concurrent engineering concepts to industry.

The research involved four major tasks: the design of software architecture for electronically sharing component specifics; the development of software prototypes; the implementation, analysis, evaluation and demonstration of a component database and access mechanism; and the refinement of the manufacturing capability database, its software architecture and manufacturing process planning.

Easier to Share Information

The PreAmp "product model" for electronics components was successfully developed. It is a complete standards-based, data-sharing framework for automating the design and manufacture of electronic components such as printed circuit boards. It is an extension to the electronics industry of STEP (Standard for Exchange of Product Model Data), an international standard that defines a standard product model for automation systems in order to facilitate the capture and use of all information relevant to product design and manufacture. This extension will speed the development of electronics components (and, ultimately, finished electronics products) by greatly easing the sharing of information among the engineers who design electronics components and those who design the processes for manufacturing these components.

In addition, the PreAmp generic model of manufacturing processes was designed to further aid manufacturing engineers by capturing all relevant data on the manufacturing capabilities of a particular plant, information such as shop-floor equipment capabilities, equipment layout, and operating requirements and limits. As part of this effort, researchers developed a knowledge-based software system that can extract process "rules" from the manufacturing process data — for example, "Given current equipment, interconnects may not be spaced closer than X." Such rules will improve the functioning of the system.

The combination of the full product and manufacturing models allows concurrent (simultaneous) engineering of component design, process design and component manufacturing. Studies cited by the consortium suggest the new technology can reduce time-to-market by 50 percent or more, double component quality levels and reduce development costs by 30 percent to 70 percent. The project's commercialization work is still underway, so it is not yet known whether these expectations will be matched by improvements in the quality of actual component design and manufacturing processes.

Initial Commercialization

Some of the technology developed by the PreAmp consortium has been adapted and incorporated in software tools by STEP Tools, Inc., an informal participant in the ATP project. STEP Tools developed a prototype STEP

PROJECT:

To develop a standards-based data-sharing framework for automating the design and manufacture of electronics components. The framework will enable true concurrent (simultaneous) engineering of component design and manufacturing, which will reduce the cost of developing components, increase their quality and decrease their time-to-market. Such improvements will lead to similar improvements in finished electronics products that incorporate these components.

Duration: 7/1/1992 — 7/31/1996
ATP number: 91-01-0267

FUNDING (IN THOUSANDS):

ATP	$5,166	37%
Consortium	8,625	63%
Total	$13,791	

ACCOMPLISHMENTS:

PreAmp successfully completed all technical goals, including development of a knowledge-based software system that can extract process "rules" from manufacturing process data. Other accomplishments include:

- STEP Tools, an informal participant in the project, developed prototype software to validate a standard data access interface library that has since become part of its ST-Developer product. ST-Developer has been distributed to more than 100 customers worldwide and is being used to build and maintain STEP (Standard for Exchange of Product Model Data) applications and databases.
- Researchers presented several papers at professional conferences, including the
  - Design and Automation Conference,
  - National Electronics Packaging Conference, and
  - Reliability in Agile Manufacturing Symposium.
- PreAmp hosted a "Vendor Opportunity Forum" to give software vendors opportunities to commercialize the technology developed by the project.

COMMERCIALIZATION STATUS:

A modest amount of commercialization is under way via the product introduced by STEP Tools, but the main commercial goals of the consortium have so far not been accomplished. Boeing is conducting a pilot project, and SCRA continues to develop the technology and promote commercialization.

OUTLOOK:

The core technology developed by the project may be commercialized in several years, after additional R&D work. Thus, there is some prospect of benefits to eventual users. If commercialization does occur, the spillover benefits could be large, since so much of the work of this project is in the development and promulgation of data-sharing standards.

COMPANIES:

PreAmp Consortium
South Carolina Research Authority
(SCRA, consortium lead)
1330 Lady St., Suite 503
Columbia, SC 29201

Contact: Gerry Graves
Phone: (803) 760-3793

Other consortium members: Boeing Company, Defense & Space Group; Hughes Aircraft Company; Martin Marietta Corporation, Electronics Information & Missiles Group; and Rockwell International Corporation, Collins Avionics & Communication Division

Informal participants: Rensselaer Polytechnic Institute and STEP Tools, Inc.

data application interface for the project. Afterward, the company enhanced the prototype to make it suitable for commercial use and incorporated it in the ST-Developer™, an application that already has several hundred customers.

The principal "test-bed" implementation of the models developed during the ATP project was carried out by PreAmp members. Boeing is conducting a pilot project to determine whether it can use the new software technology in its internal operations to increase the productivity of printed circuit board design work. The company is working with an ATP-project subcontractor in developing software to translate existing database information to work in the new "product model" system. It will probably be known by 1999 whether the Boeing effort succeeds. If it does, the creation of commercial products will be much more likely.

Three members (Boeing, Hughes and Rockwell) have arranged with SCRA for it to serve as the PreAmp agent with vendors interested in creating commercial software systems that include the ATP-funded technology. Consortium members, with the help of SCRA, proposed the enhanced STEP procedures to the International Standards Organization for registration, which is expected to be issued as STEP Application Protocol 210.

Reorganization and company upheavals among consortium members, however, seem to be hindering further progress toward commercialization. Organizational energy has been siphoned off to deal with mergers and acquisitions. In addition, reductions in national defense work have caused turmoil in three of the four corporate members of the consortium that have been very active defense contractors. But if energy can be refocused on further developing the ATP-funded technology, it could be commercialized in several years.

Studies cited by the consortium suggest the new technology can reduce time-to-market by 50 percent or more, double component quality levels and reduce development costs by 30 percent to 70 percent.

Large Potential Benefits From Data-Sharing Standards

The new technology was intended for use in the production of printed circuit boards, and it has potential applications in the manufacture of other electronics components as well. If widely adopted, the product and manufacturing process models would provide a "common language" for the production process. In that case, the economic spillover benefits from widespread use of the technology could be large since so much of it involves data-sharing standards. Given the hundreds of millions of printed circuit boards produced for use in the United States each year, the benefits from this kind of standardization would be extremely large.

Saginaw Machine Systems, Inc.

Better Precision for Machine Tools Through Thermal-Error Correction

Machine tools are used in hundreds of thousands of plants and shops to cut and shape metal parts and pieces. The interface between the cutting or shaping tool and the material being worked almost always gets hot. In most cases, a coolant is directed onto the interface area to take away enough heat to allow the job to be performed.

High Heat Degrades Machining Quality

Even with the coolant, the machine tool itself often becomes warm enough to change shape slightly, and the accuracy of the machining operation degrades. The result can be a finished part that fails to meet specifications. What would have become a salable part becomes scrap metal, and some high-precision parts cannot be made at all.

Thermal-Error Compensation

With ATP funding, Saginaw Machine Tools — a small, privately held company founded in 1983 to build precision computer-controlled machine tools for high-volume manufacturing — together with researchers at the University of Michigan, developed a solution to the heat problem. Their technology monitors the temperature gradients in computer numerically controlled (CNC) machine tools and alters the control process dynamically (while the machine is working) to compensate for heat-related changes in the machine tool as the part is being worked. When the new technology is incorporated into machine tools, the result is higher-quality parts.

A new high-precision vertical lathe which incorporates the new thermal-error compensation technology, first delivered to customers in 1998.

The technology uses a laser system to measure machine geometric and thermal errors and heat sensors to monitor temperatures near the interface between the cutting tool and the metal being worked. A computer program, using a thermal volumetric error model, processes the laser and sensor data and sends corrective instructions to the machine tool in real time, as it shapes the metal. Use of this thermal-error compensation technology enhances the accuracy of CNC machine-tooled products by fourfold to fivefold as measured by spindle drift (shifting of the shaft, in a lathe or other machine tool, that holds the piece being formed), at a commercially viable cost.

Customers manufacturing high-precision parts realize productivity improvements of 10 percent to 30 percent . . .

First Products to Market

At the end of the ATP funding period, additional development work not originally foreseen by the company remained to be done. Saginaw continued to advance the technology and has invested as much of its own funds since the close of the project as the ATP put in at the beginning.

Since completing the development work, the company has begun to move its first product, which uses the Accu-System incorporating the ATP technology, into commercialization. By early 1998, Saginaw had developed prototype tools. One prototype was tested by an independent laboratory and pronounced ready for market. Another tool from Saginaw was subjected to a competitive evaluation process by a large tool buyer, in which the Saginaw tool was pitted against tools from seven other suppliers. The results showed that the Saginaw machine with the Accu-System was the most accurate. All in all, 30 characteristics of machine performance were measured, and the Saginaw machine had a weighted average score that was 50 percent higher than the next best machine. On the critical characteristic of spindle drift, the Saginaw machine achieved a two-thirds reduction in drift compared with the next best machine.

PROJECT:

To develop an easily adaptable thermal-error correction technology for enhancing the accuracy of computer numerically controlled machine tools.

Duration: 4/15/1991 — 11/16/1993
ATP number: 90-01-0232

FUNDING (IN THOUSANDS):

ATP	$540	84%
Company	100	16%
Total	$640	

ACCOMPLISHMENTS:

Saginaw, working closely with researchers at the University of Michigan, accomplished the project's technical goals by developing a generic mathematical model of thermal errors, as well as the sensor and computer-control systems for a thermal-error correction technology. The company also

- developed several prototype tools incorporating the new technology;
- submitted a prototype, as did seven other manufacturers, for testing by an independent laboratory, which found that the Saginaw machine was the most accurate of the eight machines, with an overall score 50% higher than the next best machine; and
- developed the Accu-System, which incorporates the ATP-funded technology, offered commercially for the first time in a machine tool in early 1998.

COMMERCIALIZATION STATUS:

Commercial products were introduced to the market in early 1998.

OUTLOOK:

The outlook for this technology is very promising. Saginaw started receiving orders in early 1998 for machine tools that incorporate the new technology. Machine tools that could benefit from the improved accuracy are used in plants and shops throughout the nation. Other tool producers are likely to imitate the technology, which is not expected to receive patent protection. Users of the tools that incorporate the new technology will benefit from a substantial improvement in machine tool accuracy, increasing the overall precision of the pieces produced by the machines.

COMPANY:

Saginaw Machine Systems, Inc.
301 Park St.
Troy, MI 48083

Contact: Gerald J. Romito
Phone: (248) 583-7200

Number of employees:
120 at project start, 120 at the end of 1997

Subcontractor: University of Michigan

. . . most machine tools that make high-precision parts are likely to be improved in the long run.

If Saginaw had not received the ATP award, company officials say, it would not have done the project.

By March 1998, Saginaw had received orders from other companies for eight machines priced at more than $200,000 each. Orders for several dozen additional machines of the same type were expected over the next several months.

Productivity Improvements

Users of the technology are able to take advantage, at reasonable cost, of a substantial increase in the accuracy of their machine tools, improving the precision of the workpieces the machines produce. Customers manufacturing high-precision parts realize productivity improvements of 10 percent to 30 percent because of reduced requirements for part testing and rework.

The number of potential applications is large. Because the Saginaw equipment is now in use, other manufacturers may imitate the technology. The company has concluded that none of the technology is patentable, and it is likely that competitors will be able to imitate its methods. Consequently, most machine tools that make high-precision parts are likely to be improved in the long run.

If Saginaw had not received the ATP award, company officials say, it would not have done the project. Being primarily a manufacturing company, it did not have a substantial research and development capability. While working on the ATP project, Saginaw collaborated with the University of Michigan on a subcontractor basis to extend the company's research capabilities. In addition, officials say, having the ATP award helped Saginaw win a subsequent $1 million award from the Defense Advanced Research Projects Agency for a related project.

Chapter 5

Electronics

Accuwave Corporation

Expanding the Number of Light Signals in an Optical Fiber

Over the last two decades, the use of optical fiber as an alternative to metal wire and cable has exploded. Optical fiber is now the technology of choice for use undersea and for most terrestrial applications of more than the shortest distances.

More Light Signals Per Optical Fiber

This ATP project with Accuwave Corporation, a small California company specializing in the development of holographic communications systems, created a way to substantially increase the number of signals that can be transmitted in a single strand of fiber-optic cable. The new technology is designed to enable the transmission of 80 or more channels per fiber. If adopted, it could eventually reduce the cost per transmission and save hundreds of millions of dollars over a period of just a few years.

A Unique Holography-Based Approach

The new technology is based on the concept of wavelength division multiplexing (WDM), which transmits light of more than one wavelength through a single optical fiber, separating the individual wavelengths at the receiver. Such systems must discriminate among the different wavelengths and so are limited by the accuracy of the multiplexing and demultiplexing optics.

Accuwave had previously developed a unique approach to WDM using volume holography: holograms "written" in the interior of thick crystals of photorefractive (light-bending) materials. In the demultiplexer crystal, for example, multiwavelength light enters one end of the crystal and encounters a series of holographic gratings — each tuned to deflect a specific wavelength of light — that separate the light signals of different wavelengths. Accuwave had demonstrated the individual elements of a system that could multiplex wavelengths more than 10 times better than the current state of the art at visible wavelengths. With its ATP funding, Accuwave extended its technology to the infrared wavelengths used for long-distance telecommunications, and designed a prototype WDM system.

. . . multiwavelength light enters one end of the crystal and encounters a series of holographic gratings . . . that separate the light signals of different wavelengths.

Accuwave officials report that ATP funding enabled it to develop WDM for signal transmission, a task it would otherwise have been unable to do. In addition, receiving the ATP award helped the company form important alliances with research partners during the ATP project (not identified here for confidentiality reasons).

Marketing Disappointment Spurs Alternative Commercialization

Near the end of the ATP funding period, while Accuwave was trying to raise additional private capital to complete the technical work on its WDM system and sign commercialization agreements with potential customers, another company beat it to market with a competing system operating in the same infrared wavelengths. Nonetheless, Accuwave continued to work toward completion of its WDM multiplexer, which it believes provides multiplexing capabilities of higher signal accuracy, with more channels per fiber and in a smaller package than the products offered by competitors.

Though Accuwave did not succeed in its original commercialization plans for sale of a WDM system in the bulk-signal-transmission market, it launched several component products based on the ATP-funded technology. These include wavelength controllers, wavelength lockers and fiber-optic collimators, all of which are being sold to producers of WDM systems. The company developed contacts with potential telecommunications clients in Europe, Japan and Brazil, as well as the United States, and it planned to introduce its own wavelength multiplexers in the near future.

Potential Big Savings in Telecommunications

With its potential to increase the number of signals that a single optical fiber can carry, the Accuwave technology could significantly affect the cost of communications via fiber-optic cables, particularly if used for undersea applications. Because of the volume of messages transmitted via this medium, cost savings would be great, even if the number of signals per fiber were doubled. The Accuwave technology has the potential to double and redouble the number of signals per fiber many times

. . . another company beat it to market with a competing system operating in the same infrared wavelengths.

PROJECT:

To develop holographic-optics technology that will increase (by more than 10 times) the number of signals that can be transmitted through a single optical fiber.

Duration: 3/1/1993 — 3/14/1995
ATP number: 92-01-0055

FUNDING (IN THOUSANDS):

ATP	$1,987	69%
Company	898	31%
Total	$2,885	

ACCOMPLISHMENTS:

Accuwave developed a process for producing photorefractive materials suitable for fiber optics telecommunications applications. The company also:

- received two patents for technologies related to the ATP project:

  "Photorefractive Systems and Methods (Divisional)"

  (No. 5,684,611: filed 6/6/1995, granted 11/4/1997) and

  "Wavelength Stabilized Laser Sources Using Feedback From Volume Holograms"

  (No. 5,691,989: filed 9/14/1993, granted 11/25/1997);

- applied for two additional patents for technologies related to the ATP project;
- completed pilot production of wavelength division multiplexing (WDM) components designed for incorporation into equipment manufactured by other companies, and introduced the components in 1996;
- signed a purchase agreement with a major telecommunications equipment manufacturer;
- raised $4 million from venture capitalists and other investors since 1990; and
- built a plant and ramped up volume production in 1998.

COMMERCIALIZATION STATUS:

In 1996 and 1997, Accuwave introduced three WDM system components: wavelength controllers, wavelength lockers and fiber-optic collimators. The company continued to pursue its original goal of selling WDM products for fiber optics telecommunications applications.

OUTLOOK:

Despite the heretofore promising prospects for growing applications of this technology in the telecommunications sectors, the commercialization outlook at this time is bleak. As this report was going to press in late 1998, it was learned that the company had ceased operations and was in the process of declaring bankruptcy. While it is possible that the technology will be picked up by other companies and carried forward in the future, at this point there is insufficient information about the likelihood of this to comment further on the outlook.

COMPANY:

Accuwave Corporation
1651 19th St.
Santa Monica, CA 90404

Contact: Neven Karlovac
Phone: (310) 449-5540

Number of employees:
5 at project start, 16 at the end of 1997

. . . launched several component products based on the ATP-funded technology.

. . . in late 1998 it was learned that the company had ceased operations and was in the process of declaring bankruptcy.

over, with the count possibly reaching as many as 80 signals per fiber.

In addition to applications in the bulk-signal-transmission market, the ATP-funded technology has the potential of providing greater cable bandwidth to homes and offices for use with high-definition TV and to the closed-circuit TV market, particularly for security uses. The company was interested in pursuing these potential applications, but instead used its resources to develop the WDM system for telecommunications applications. The technology also has potential applications in ultranarrow band filters, spectrometers and optical disk memories.

As this report was going to press in late 1998, it was learned that the company had ceased operations and was in the process of declaring bankruptcy. It is possible that the technology will be picked up by other companies and carried forward in the future.

AstroPower, Inc.

Manufacturing Technology for High-Performance Optoelectronic Devices

Optoelectronic devices — from light-emitting diodes (LEDs) and solar cells to lasers and detectors — are abundant in everyday life. Millions of LEDs are used in automobile dashboards and consumer electronic products (clocks, radios, VCRs, CD players, coffee brewers and microwave ovens), as well as in commercial and industrial products such as fax machines, copiers and printers.

LEDs That are Four Times as Bright

Although LEDs are used in many applications where digital readout is needed, they have limitations. They do not emit much light, so they cannot be seen at a distance. If they produced really bright light, LEDs would be even more widely used than they are already. This ATP project with AstroPower, a small Delaware company incorporated in 1989, developed a new approach to production-scale liquid-phase epitaxy (LPE). The company has fabricated LEDs in a way that significantly increases, by a factor of four, the brightness of the light they emit.

. . . made significant advances in understanding growth processes for compound semiconductor materials . . .

A large area solar grade silicon sheet emerging from a silicon growth reactor which incorporates new ATP-funded technology.

A New Approach

LPE is a widely used technique that involves melting a semiconductor material and letting it crystallize on a substrate. AstroPower's novel enhancement, the first technical goal of the project, involved the use of a thermal gradient that promotes the growth of the epitaxial layer laterally much faster than vertically from the substrate. Company researchers made significant advances in understanding growth processes for compound semiconductor materials and in applying LPE to lateral growth over buried reflectors and other components. The technology can be used for volume production of low-cost compound semiconductor devices — those made from a compound of elements, such as gallium arsenide, rather than a single element.

. . . succeeded in designing and assembling a modular prototype production growth system . . .

AstroPower's second technical goal was to develop the technology to automate the new LPE growth process in integrated factory-scale fabrication equipment. Company researchers succeeded in designing and assembling a modular prototype production growth system that has already significantly shortened production scale-up times for currently fabricated products, as well as for potential products under consideration by customers.

PROJECT:

To develop new crystal growth methods and high-throughput manufacturing technology for fabricating light detectors and emitters with integrated reflecting mirrors.

Duration : 7/15/1992 to 7/14/1995

ATP number: 91-01-0142

FUNDING (IN THOUSANDS):

ATP	$1,423	47%
Company	1,580	53%
Total	$3,003	

ACCOMPLISHMENTS:

The company achieved the goals of the ATP project: developing new epitaxial growth methods, as well as new processes for plant-scale industrial production operations. Evidence of the company's achievements are that it:

- received four patents related to the ATP project technology;
  - "Columnar-Grained Polycrystalline Solar Cell and Process of Manufacture"
  - (No. 5,336,335: filed 10/9/1992, granted 8/9/1994)
  - "Hetero-Epitaxial Growth of Non-Lattice Matched Semiconductors"
  - (No. 5,356,509: filed 10/16/1992, granted 10/18/1994)
  - "Columnar-Grained Polycrystalline Solar Cell and Process of Manufacture"
  - (No. 5,496,416: filed 8/5/1994, granted 3/5/1996)
  - "Semiconductor Device Structures Incorporating "Buried" Mirrors and/or "Buried" Metal Electrodes"
  - (No. 5,828,088: filed 9/5/1996, granted 10/27/1998)
- demonstrated the application of the new epitaxial production technology to optoelectronic device structures that have integrated reflecting mirrors for enhancing light output (an ultrabright light-emitting diode (LED) with buried reflectors), achieving a fourfold increase in brightness;
- completed scale-up of liquid-phase epitaxy (LPE)-growth technology to a high-throughput, production-scale process;
- significantly shortened production scale-up times for specific products, compared with previous manufacturing processes;
- constructed a demonstration production facility to implement the technology; and
- conducted an initial public offering of stock in February 1998, raising $16.7 million.

COMMERCIALIZATION STATUS:

Direct commercialization of ultrabright red LEDs, a proposed initial goal of the project, did not occur, mainly due to economic and market developments. Knowledge of new crystal growth methods acquired during this project contributed, however, to the enhancement of fabrication methods for the company's Silicon-Film™ solar cell and for other compound semiconductor devices.

OUTLOOK:

AstroPower has applied the ATP-funded crystal growth technology to its current manufacturing processes, improving productivity and lowering costs. It also plans to use the technology for several breakthrough devices when appropriate market size has been achieved; if such markets develop substantially, the outlook is promising. Two significant products that are nearing introduction are combustion sensors based on gallium-phosphorus compounds, and avalanche photodiodes and detectors based on indium-gallium-arsenic-antimony compounds.

COMPANY:

AstroPower, Inc.
Solar Park, 461 Wyoming Road
Newark, DE 19716-2000

Contact: James B. McNeely
Phone: (302) 366-0400

Number of employees:
86 at project start; 160 at the end of 1997

Market Developments Upset Initial Commercialization Plans

Commercialization of the enhanced compound semiconductor devices in high volumes has not yet happened. An initial goal, to produce high volumes of red LEDs, has been stymied by market developments. The Japanese have come to dominate the market for red LEDs, which have become a commodity product. Although AstroPower has a technical advantage in producing the devices, the value of this market to the company is quite small, since the cost of entering the market is too high to make such a venture profitable.

Use of the Technology for Current Product Lines

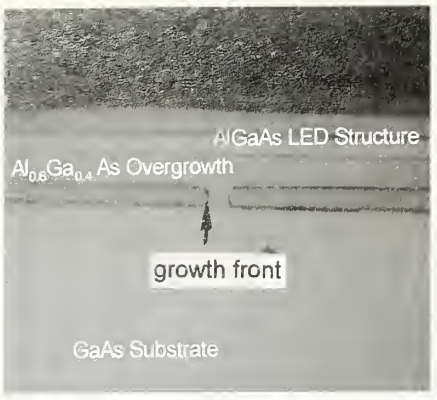
Knowledge developed in the ATP-funded project, especially advances in understanding epitaxy technology, has proven useful across all company production activities, AstroPower officials say. They report that the company's product lines have all grown rapidly in recent years, and they attribute much of the growth to the ATP project. All of AstroPower's compound semiconductor-based products incorporate epitaxial growth in their fabrication. This includes their flagship product, the Silicon-Film™ solar cell. Silicon-Film™ is a continuous production process to manufacture crystalline silicon sheets and layers.

. . . the company's product lines have all grown rapidly in recent years, with much of the growth attributed to knowledge developed in the ATP-funded project.

Shortened Production Scale-Up Times

The success of the ATP-funded project ensures that new and innovative optoelectronic devices will have significantly shorter production scale-up times than were possible before the project. The establishment of a technology that permits low-cost, high-throughput synthesis of compound semiconductor structures is potentially useful for many optoelectronic device products. It can be used, for example, in making specialty devices on a job-order basis using gallium arsenide, gallium arsenide-on-silicon, indium phosphorus and a host of other unexplored alloys. These devices are used in the fabrication of common products like detectors, solar cells, sensors and light-emitting products. The new technology can also be used in the production of highly sophisticated devices such as vertical cavity surface emitting lasers and resonant optical cavity detectors with back reflectors.

AstroPower intends to incorporate this technology in a number of breakthrough devices that it can produce in sufficiently large quantities when appropriate market size has been achieved. Two significant applications are nearing product introduction. The first is combustion sensors, based on gallium phosphorus compounds, that can be used for flame control in internal combustion engines and utility burners. The second is avalanche photo-



Cross-sectional photomicrograph of a light emitting diode showing device active layers and buried mirror overgrowth.

diodes and detectors, based on indium-gallium-arsenic-antimony and indium-arsenic-antimony-phosphide compounds, that can be used for light direction and range instruments, collision avoidance, atmospheric gas measurements, weather prediction, spectroscopy, blood gas analysis and noninvasive medical analysis. These two products are currently in pilot production and are being tested by NASA, the Air Force and industrial companies.

An initial goal, to produce high volumes of red LEDs, has been stymied by market developments . . . red LEDs have become a commodity product.

Company Growth

At the beginning of the ATP project in 1992, AstroPower had annual product sales of $1 million. By 1997, sales had grown to $16 million. And in February 1998, AstroPower successfully conducted an initial public offering of stock, raising $16.7 million.

AstroPower is convinced that had it not conducted the ATP-funded project, its growth experience (as measured by product sales) would have been set back by three years, the length of the ATP project. This belief is based on the use of improved epitaxial growth technology across all of its product lines, its application of manufacturing automation processes to all of its manufacturing operations, and to the overgrowth of semiconductor materials on dissimilar substrates as well as on mirrors, insulators, and conducting planes. Without the ATP funds, AstroPower says it would not have carried out the project.

. . . had it not conducted the ATP-funded project, its growth experience . . . would have been set back by three years.

Potential Large Economywide Benefits

AstroPower noted at the beginning of its ATP project in 1992 that it expected in a project like this that products might take as long as 10 years to move from initial technology development to new product sales. The demonstration production facility AstroPower developed is capable of producing millions of LEDs or other LPE-based optoelectronic devices per month. When sufficient demand for the new products emerges, AstroPower plans to construct an optoelectronic semiconductor chip-manufacturing facility for new products made possible by the innovative LPE-growth technology.

Benefits are already accruing to purchasers of the company's solar cells, which have higher quality and cost less than they did before the ATP project. If the company succeeds in bringing to market additional products that use the new technology, even more benefits will accrue to its customers. Because of substantial uncertainty about these events, it is too speculative at this time to try to predict the magnitude of these future benefits.

Benefits are already accruing to purchasers of the company's solar cells, which have higher quality and cost less than they did before the ATP project.

Cree Research, Inc.

Processes for Growing Large, Single Silicon Carbide Crystals

Most computer chips today consist of tiny electrical and electronic components on a thin slice of silicon crystal. As many as 5 million discrete components can be placed on a piece of crystal less than 2 inches square. Silicon crystal chips, however, are quite sensitive to heat. Electricity passing through a chip's super-thin connecting wires creates heat, just as it does in the heating element of a toaster. If too much heat builds up, the chip loses its functionality.

Cree's LED chips are used by Siemens A.G. for back lighting for this dashboard.

Beating the Heat in Electronic Devices

This ATP project with Cree Research, a small company in North Carolina's Research Triangle Park, made significant progress in the development of an alternative raw material for making crystal slices — silicon carbide. This material belongs to a class of semiconductors having "wide bandgap," which means they are relatively insensitive to increased temperatures. Silicon carbide's thermal conductivity is greater than that of copper, so it rapidly dissipates heat. It is impervious to most chemicals and highly resistant to radiation. Silicon carbide is extremely hard — it is used as grit in common sandpaper — indicating that devices made with the substance can operate under extreme pressure. It also possesses high field strength and high saturation drift velocity, characteristics suggesting that devices made of it can be smaller and more efficient than those made of silicon.

. . . full-color LED displays become possible with the existence of blue LEDs, as blue was a missing primary color.

Cree and others have shown that, even at red-hot temperatures, silicon carbide devices maintain functionality. Some of them, in fact, have continued to operate at 650 degrees Celsius. The wide bandgap also allows silicon carbide devices to operate at shorter wavelengths, enabling the creation of blue light-emitting diodes (LEDs) that could not be made from silicon. Moreover, full-color LED displays become possible with the existence of blue LEDs, as blue was a missing primary color.

Growing Large Crystals to Reduce Costs

Cree was founded in 1987 to commercialize silicon carbide and began by making LEDs on a silicon carbide substrate. Prior to its ATP project, Cree was already the world leader in silicon carbide technology and had been making 1-inch-diameter silicon carbide crystals. But progress in the development of devices based on silicon carbide had been stymied by difficulties in growing large, high-quality single crystals, a bottleneck that led Cree to pursue more research.

During the ATP project, Cree advanced silicon carbide technology by developing methods to greatly reduce the amount of imperfections in crystals and to increase their size to two inches or greater in diameter. Larger-diameter crystals result in lower production costs, which

The *Real Color Display*™, a moving sign which is capable of displaying the full range of colors, made possible by the use of blue LEDs.

PROJECT:

To substantially reduce the cost and improve the durability of light-emitting diodes (LEDs) and other electronic and optoelectronic devices by increasing the quality and size (to 2 inches or more) of silicon carbide (SiC) single crystals.

Duration: 6/15/1992 — 6/14/1994
ATP number: 91-01-0256

FUNDING (IN THOUSANDS):

ATP	$1,957	82%
Company	435	18%
Total	$2,392	

ACCOMPLISHMENTS:

Cree essentially met or exceeded all of the technical milestones. Successful development of the technology is indicated by the fact that the company:

- applied for one patent on technology related to the ATP project;
- presented several papers at professional conferences;
- raised $13.2 million via an initial public stock offering in February 1993;
- made high-quality, 2-inch SiC wafers, greatly opening up the blue LED and SiC wafer markets;
- raised approximately $17.5 million in a private stock offering in September 1995;
- increased annual revenues from $3 million at the start of the ATP project in 1992 to $7.5 million at the end of the ATP award period in 1994;
- received $5.8 million from the Defense Advanced Research Projects Agency in May 1995 for further development of silicon carbide growth processes to support production of 3-inch wafers;
- formed Real Color Displays, a wholly owned subsidiary, to exploit this technology for full-color LED displays;
- received a $6 million order in September 1996 from Siemens for blue LEDs; and
- supplied the SiC wafers for components in the SiC solid-state transmitter used by Westinghouse Electric to make the first U.S. commercial-scale high-definition TV (HDTV) broadcast in April 1996.

COMMERCIALIZATION STATUS:

The larger SiC wafers, made with the ATP-funded technology, are being used in the fabrication of blue LEDs sold to many industrial customers. The wafers are also being provided in limited quantities for development projects in government and industry research laboratories.

OUTLOOK:

The improved processing technology makes the outlook for the commercial use of SiC crystals highly promising. The cost of producing blue LEDs has already been reduced substantially, and the expected widespread commercial availability of larger-diameter SiC wafers promises a new range of applications, including HDTV transmitters. Benefits in the form of lower costs and higher quality will accrue to industrial users of blue LEDs and SiC wafers, as well as to consumers who use devices containing these two Cree products.

COMPANY:

Cree Research, Inc.
2810 Meridian Parkway, Suite 176
Durham, NC 27713

Contact: Calvin Carter
Phone: (919) 361-5709

Number of employees:
41 at project start, 210 at the end of 1997

. . . devices that were impractical to make with pure silicon can be made with silicon carbide.

are crucial to opening markets for silicon carbide devices. The company also developed ways to significantly improve the doping (adding impurities to achieve desired properties) and epitaxial deposition (growing one crystal layer on another) processes for silicon carbide. Improving doping uniformity directly increases production yield and thus reduces costs.

Cree's success with the ATP project enables the fabrication of electronic devices that can operate at much higher temperatures and withstand high power levels. Silicon carbide components used in experimental high-definition television (HDTV) transmission, for instance, delivered more power, lasted longer and cost less to produce than conventional silicon-based components. Now equipment that was costly to manufacture (owing to the need for heat-dissipation systems) can be produced less expensively, and devices that were

Cree's success with the ATP project enables the fabrication of electronic devices that can operate at much higher temperatures and withstand high power levels.

impractical to make with pure silicon can be made with silicon carbide.

New Products: Blue LEDs and Silicon Carbide Wafers

The ATP project has been highly productive for Cree and the economy at large. The company has used the new technology to produce larger silicon carbide wafers to use in its fabrication process for blue LEDs. It is also offering the larger silicon carbide wafers for sale to other companies.

Cree is using the ATP-funded technology to reduce the cost of producing blue LEDs, and their sales have increased substantially. Production cost is primarily a function of the number of wafers processed. If wafer size can be increased dramatically, the cost per device will decrease dramatically because so many more devices can be made on a wafer. The silicon carbide wafer technology is also aimed at markets for other blue light-emitting optoelectronic devices, optical disk storage, microwave communications, and blue and ultraviolet laser diodes, as well as high-temperature, high-power and high-frequency semiconductors.

Benefits for the Economy

Benefits from the new silicon carbide technology are already accruing to customers who have bought large volumes of blue LEDs or silicon carbide wafers to use in their own production. Performance measures (resistance, power output, sensitivity to light, operating temperature) for silicon carbide devices are frequently large, relative to available alternatives. Economic benefits from these performance improvements spill over to other producers involved in fabrication and assembly before a wafer-based product reaches the end user. The total of these incremental benefits is expected to be much larger than the profits Cree receives for selling the silicon carbide wafers.

Cree's private success has led to public benefit, which is expected to grow as the number of applications for larger silicon carbide wafers increases. Westinghouse, for example, used Cree's silicon carbide wafers in fabricating components for the transmitter it used in the first commercial-level HDTV broadcast in the United States, in 1996. Westinghouse said its transmitter can deliver three times more power, has longer life and costs less to produce than conventional silicon-based transmitters. Although the number of HDTV transmitters that will use silicon carbide wafers is unknown at this time, widespread use of this technology in HDTV broadcasting could produce large general economic benefits if it speeds commercialization of HDTV.

ATP Advantages

Cree reports it was attracted to the ATP as a funding source for the development of the bulk crystal and epitaxial growth technologies because the company could retain its process technology knowledge. The ATP award also helped Cree form alliances with research partners and speed the development work, enabling the company to get results about 18 months sooner than it would otherwise have been able to do. During the course of its two-year ATP project, Cree also grew significantly.

Company officials say the success of the ATP-funded project was primarily responsible for a subsequent award of $5.8 million from the Defense Advanced Research Projects Agency (DARPA) to further develop silicon carbide growth processes to produce 3-inch wafers. If wafer size can be increased to 3 inches, the cost per device will drop even further. This DARPA project got under way in May 1995.

. . . silicon carbide wafers . . . used in the first commercial-level HDTV broadcast in the United States . . .

The low-cost blue light emitting diode (LED) produced with new silicon carbide crystal technology.

Cynosure, Inc.

Harnessing Cheap Diode Lasers to Power a Low-Cost Surgical Laser

Surgery is performed tens of millions of times a year in the United States, and it is usually a painful, risky procedure for the patient. It is also risky for the surgeon in terms of malpractice liability. Patients, surgeons and health insurance companies are constantly looking for new, less-invasive procedures to replace conventional surgery. Laser surgery is a prime candidate. One problem that limits this approach, however, is the price of equipment. A typical 100-watt surgical laser costs about $700 to $1,000 per watt of laser output, or about $70,000 to $100,000.

Photomicrograph of an array of multi-level diffractive lenses, fabricated with a 193 nanometer excimer laser.

A Laser for Lower-Cost, Less-Invasive Surgery

This ATP project with Cynosure, founded in 1991, was designed to develop a smaller, less-expensive laser source for surgery and other applications. The idea behind the Cynosure laser system — which was expected to sell for about $150 to $200 per watt of laser light delivered at the end of a surgical optical fiber — is based on harnessing the light from an array of 200 semiconductor, or diode, lasers. The problem with this approach in the past has been the difficulty of exactly aligning all 200 beams before they go into the diffractive optics transformer that collimates them into one tight, powerful beam. Minor inaccuracies in the alignment of the individual lasers can greatly degrade the performance of the system.

Cynosure's innovation was to develop an automated system to custom-mill arrays of 200 corrective lenses to match arrays of 200 diode lasers. In such a system, diagnostic equipment measures the alignment error of each laser beam and feeds the results to a computer, which drives a powerful laser that mills the lens array in less than 10 minutes. The result is a customized lenslet array that corrects the beams before they enter the transformer.

Barriers to Commercialization

Cynosure successfully designed and built a customized lenslet array to correct the beams from an array of 200 diode lasers. The researchers, however, failed to build a system that could generate the target power level — 20 watts of laser light from a medical optical fiber — because the company was unable to secure an adequate, low-cost supply of a low-tech component: a collimating array. The intended supplier, which was the sole source of the collimating array, stopped making the device and sold its production division. The new owner also chose not to produce the array.

The researchers, however, failed to build a system that could generate the target power level . . .

To make use of some of the technology developed in the ATP project, Cynosure is collaborating with the Lincoln Laboratory at Massachusetts Institute of Technology and using about $100,000 from the Small Business Technology Transfer Program to develop a "low-cost diode-laser system for treatment of arrhythmia" for the National Heart, Lung and

PROJECT:

To design an optical system for collecting, aligning and combining beams from an array of semiconductor lasers into one powerful beam, an achievement that will lead to the development of smaller, cheaper lasers for surgery and other applications.

Duration: 5/1/1993 — 4/30/1995
ATP number: 92-01-0136

FUNDING (IN THOUSANDS):

ATP	$1,965	49%
Company	2,067	51%
Total	$4,032	

ACCOMPLISHMENTS:

Cynosure designed and built a fault-tolerant optical system for a diode-laser array but was unable during the project to obtain a laser beam with the targeted 20 watts of output from a medical optical fiber. Later, the company achieved this goal with an alternative approach built, in part, on the knowledge developed during the ATP project. The company:

- received one patent for technology related to the ATP project:

  "Fault-Tolerant Optical System Using Diode Laser Array"

  (No. 5,369,659: filed 12/7/1993, granted 11/29/1994);
- published a paper on its research findings;
- was ranked number 112 in the 1996 *Inc.* magazine list of the 500 fastest-growing private companies in America;
- increased its sales from $626,000 in 1991 to more than $23 million in 1997; and
- is collaborating with Lincoln Laboratory and using funds from the Small Business Technology Transfer Program to develop a "low-cost diode-laser system for treatment of arrhythmia," based on the ATP technology, for the National Heart, Lung and Blood Institute.

COMMERCIALIZATION STATUS:

Commercialization was stymied by Cynosure's inability to secure the supply of a critical part at an affordable price. Since the ATP project ended, the company has taken a different, less-sophisticated approach to building a commercializable medical laser, using its own funds. That device has achieved the 20-watt ATP goal, and the company is scaling it to achieve 200 watts output. Commercial lasers are scheduled for market introduction in the near future.

OUTLOOK:

The benefits originally expected from commercialization of the ATP-funded technology should be realized via commercialization of the alternative technology that built on the technical knowledge developed in the ATP project.

COMPANY:

Cynosure, Inc.
10 Elizabeth Drive
Chelmsford, MA 01824

Contact: Horace Furumoto
Phone: (978) 256-4200

Number of employees:
30 at project start, 120 at the end of 1997

Informal collaborator:
Massachusetts Institute of Technology, Lincoln Laboratory

Blood Institute. The company is proposing to extend the scope of the project to include other conditions, besides arrhythmia, that can be treated with minimally invasive surgery. This new project is based in part on the demonstration that the ATP-funded technology, as modified by the company, is capable of delivering 10 watts of power into a 100-micron fiber-optic tube.

Alternative Approach

After the ATP project, Cynosure investigated alternative techniques, based on commercially available components, to channel the many beams from diode-laser arrays into a surgical optical fiber. The company found this can be done by grinding a hyperbolic lens onto the end of a small optical fiber, fitting one such fiber to each diode and stacking the fiber-coupled diodes into a two-dimensional array, as the ATP proposal had suggested. The fibers take the place of the diffractive optics in the proposed ATP laser system, with the tiny lenses directing the output from the diode array into a single fiber.

The company's switch to a different technological approach using readily available parts to concentrate the laser beams allowed commercialization to resume. Commercial lasers are now scheduled to be available in the near future.

Mission Accomplished

Lower-cost, higher-power medical diode lasers are a necessity for minimally invasive surgery, and it is said that necessity is the mother of invention. Cynosure invented the approach using fiber-coupled lasers, which are manufactured using standard optical fabrication methods and readily available components. The company expects this approach will not only reduce the cost of medical lasers but will also cost less than the diffractive optics-combiner approach envisioned by the ATP project.

By significantly reducing the cost of surgical lasers, the Cynosure technology would enable wider use of minimally invasive surgery, reducing hospitalization times and lowering health-care costs. For example, gall bladder removal by conventional surgery requires a 4- to 6-inch incision that results in four to seven days of hospitalization and a month of recovery time. When the removal is done by laser via a fiberoptic scope inserted through a small incision (a procedure already in widespread use), the patient is hospitalized for only two or three days and recovers much faster. Less-costly medical lasers would likely increase gall bladder removal by laser.

The company's switch to a different technological approach using readily available parts to concentrate the laser beams allowed commercialization to resume.

Funding from the ATP allowed Cynosure to perform research and development work it would otherwise have been unable to do. The award enabled it to hire highly qualified optical physicists to conduct the research on diffractive optics, and to develop the technical capability needed for future manufacture of diffractive optics devices. Cynosure is currently considering licensing this technology to a company whose core business is diffractive optics. In addition, the availability of highly sophisticated optical diagnostic equipment allowed Cynosure to better understand and test the fiber-coupled equipment it is developing for the commercial sector.

Diamond Semiconductor Group, LLC (DSG)

Lowering the Cost and Improving the Quality of Computer Chips

Worker holding the world's first 300 millimeter silicon wafer populated with electronic components using the wide beam ion implantation technology.

Billions of integrated circuits — the tiny chips that run personal computers and thousands of other electronic devices — are fabricated every year in the United States through ion beam implantation, a technique for introducing carefully controlled impurities, or dopants, into specific locations on the semiconductor wafers from which chips are cut. Dopants control the electrical properties of the semiconductor, forming the transistors and other microscopic components of each chip.

. . . the new approach enables the production of about 2.5 times as many chips from a single wafer as the 200-mm technology can make.

Ion Beam Implantation for 300-mm Wafers

With chip components getting smaller and denser, the need for more accurate control of dopant implantation has risen. At the same time, competitive manufacturing has driven the size of production wafers up, making increased accuracy problematic because of the difficulty in precisely scanning the implantation beam across the wafer.

This ATP project allowed Diamond Semiconductor Group (DSG), a two-person start-up company when it applied to the ATP, to develop a new and better way to implant dopants on large silicon crystal wafers measuring 300 mm or more in diameter, compared with the previous industry standard of 200 mm. Because the area of a 300-mm wafer is 2.25 times that of a 200-mm wafer and some waste always occurs at wafer edges, the new approach enables the production of about 2.5 times as many chips from a single wafer as the 200-mm technology can make. The use of DSG's new technology in production equipment makes it possible to lower the cost and improve the quality of computer chips and other integrated circuits.

Multiple Advantages of Wide-Beam Technology

A key innovation in the new technology is passing the wafer under a 350-mm-wide ion beam for implantation, rather than scanning the ion beam across the wafer. The broad beam is very stable and therefore highly accurate. The new equipment incorporating this technology is also significantly simpler than earlier machines and so is cheaper to build and maintain and is more reliable. Use of the DSG technology has already improved fabrication quality substantially relative to the existing industrywide standard. It doubled the mean time between failures, which means that on average, failures occur only half as often as with current equipment.

The DSG technology also lowers fabrication costs by allowing implant equipment to be designed to work on one wafer at a time. Although it seems counter-intuitive, single-

PROJECT:

To develop a novel approach for introducing dopants — substances that alter the electrical properties of semiconductor materials — into large semiconductor wafers to enable faster, less-costly fabrication of larger wafers with smaller, more-densely packed components.

Duration: 3/1/1993 — 6/30/1994

ATP number: 92-01-0115

FUNDING (IN THOUSANDS):

ATP	$1,326	77%
Company	393	23%
Total	$1,719	

ACCOMPLISHMENTS:

DSG developed broad-beam ion-implantation technology (now embodied in Varian's SHC80 Serial High-Current Implanter) that successfully implanted the first commercially viable 300-mm semiconductor wafer. The new technology doubled the existing industrywide mean time between failures and provided additional ways to increase the quality and reduce the cost of chip fabrication. The company:

- received two patents for technology related to the ATP project:

  "Compact High-Current Broad-Beam Ion Implanter"

  (No. 5,350,926: filed 3/11/1993, granted 9/27/1994) and

  "High Speed Movement of Workpieces in Vacuum Processing"

  (No. 5,486,080: filed 6/30/1994, granted 1/23/1996);

- applied for two additional patents for technologies related to the ATP project;

- licensed the technology developed during the ATP project to Varian, which incorporated it in its SHC80 implant system and is actively selling the equipment to commercial customers; and

- licensed its technology to Mitsui Electronics and Shipbuilding for a flat-panel display application, after U.S. companies declined the licensing opportunity. DSG used $6.1 million from Mitsui to develop a 650-mm flat-panel component for displays. In 1997, Mitsui signed its first contract to supply the displays to a customer.

COMMERCIALIZATION STATUS:

The technology has been commercialized in one application and is very near commercialization for a second application. Chip manufacturers using the Varian SHC80 implant system (which incorporates the technology) are producing larger (300-mm) wafers than before (200-mm) and making them faster, with higher quality and at lower cost.

OUTLOOK:

The outlook is excellent. Varian is already selling semiconductor fabrication equipment that incorporates the new technology, and a flat-panel display application is under way. The technology generates cost savings not only for companies using it to make computer chips but also for those who ultimately buy the chips and the products containing them. The benefits directly captured by DSG will likely be only a small fraction of the total net benefits the technology generates for the economy.

COMPANY:

Diamond Semiconductor Group, LLC (DSG)
30 Blackburn Center
Gloucester, MA 01930

Contact: Manny Sieradzki
Phone: (978) 281-4223

Number of employees:
9 at project start, 25 at the end of 1997

Informal collaborator:
Varian Associates Inc.

The new equipment . . . is cheaper to build and maintain and is more reliable.

wafer processing is actually an advantage. Fewer wafers are lost if equipment fails, compared with current technology. The latter involves clamping 13 to 17 wafers to a large wheel, which then rotates at about 1,200 rpm under the ion beam. One failure may result in 13 to 17 unacceptable wafers. With single-wafer processing, only one wafer would be lost. In addition, single-wafer processing enables ion implantation to be coordinated much better with other fabrication steps, most of which are also performed one wafer at a time.

Licensing for Two Different Applications

The ATP project is already a commercial success. DSG licensed the technology to Varian Associates, an ion-implant equipment manufacturer, which has incorporated the new technology into products now being sold.

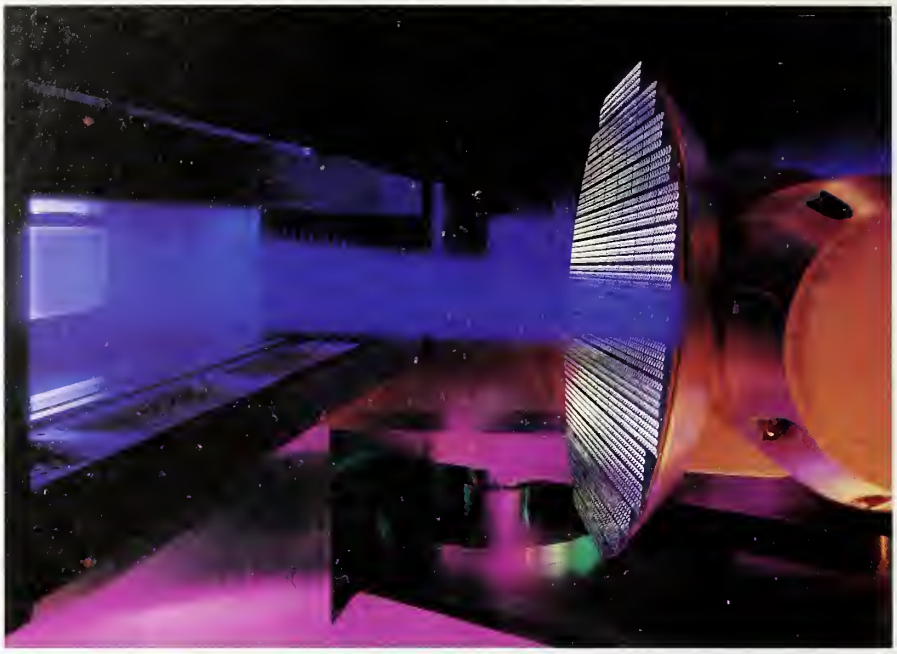
Worldwide sales of ion implanters total $1 billion to $1.2 billion per year, and Varian has 40 percent to 50 percent of the market. Most of the equipment currently sold is for 200-mm wafers, and Varian was the first to market equipment that handles 300-mm wafers. Over the next five years, industry analysts say, the majority of implanters sold will be for 300-mm wafers. All 300-mm-wafer ion implanters currently manufactured by Varian include the DSG technology, and those produced in the future are expected to, as well.

DSG is also developing the technology for another application: flat-panel displays, such as those used in notebook computers. The company has completed the development work through a licensing agreement with Mitsui Electronics and Shipbuilding, which invested $6.1 million in the effort. In late 1997, Mitsui announced it had already won a contract to supply the panels to a customer. Prior to licensing the technology to Mitsui, DSG attempted to interest U.S. flat-panel display companies in it. But most of this industry is off shore, and there were no interested parties in the United States.

Benefits All Along the Supply Chain

DSG's broad-beam technology enables the generation of substantial economic benefits. Varian sells its ion implanters to chip-fabrication companies such as Intel, Motorola and Texas Instruments. These companies, in turn, sell their chips to manufacturers that use computer chips in their products — computer companies like Apple, Gateway, Hewlett-Packard and IBM, as well as firms that make automobiles, appliances, consumer electronics and communications equipment. All along this chain of production, the new technology is saving costs and improving quality.

End users of these products can also expect to benefit from the new technology. Businesses that use desk-top computers containing chips made with this technology, for example, will



The uniform ribbon beam vertically scanning a wafer, in an ion implanter manufactured by Varian Associates.

get lower-cost, higher-quality machines. These will enable better services at lower costs, producing economic benefits for the businesses and their customers. Ultimately, company officials say, the profit DSG earns from its new technology will likely be only 1 percent to 2 percent or less of the total incremental economic benefits the technology is apt to generate across the economy, that is, the spillover benefits are likely to be large.

. . . the company's status as an ATP participant facilitated the agreement it negotiated with Varian . . .

ATP Award Invigorates Small U.S. Company

DSG reports that without the ATP award, it would probably have been unable to do the research or survive as a company. Its only other alternative then was to become part of a foreign company. All the high-risk research and development work on DSG's broad-beam technology was done during the ATP project, and there was a high likelihood of failure. In addition, the company's status as an ATP participant facilitated the agreement it negotiated with Varian to help DSG meet its cost share for the project and, later, to include the technology in Varian's wafer implantation equipment.

FSI International, Inc.

A Gas Method to "Dry" Clean Computer-Chip Wafers

Manufacturing processes create parts for further assembly or final use, as well as a certain amount of waste. Even if waste is severely controlled, the part that emerges from fabrication is almost always contaminated to a greater or lesser degree by unwanted particles. The level of unwanted particles varies with the process, and so does its effect on the rest of production. If the new part is a slice of silicon crystal about to be covered by microscopic integrated circuits, the presence of unwanted particles — even in minute amounts — is disastrous. Extreme cleanliness, therefore, is the rule in silicon chip-making plants, where fabrication takes place in "clean rooms" designed to eliminate contamination.

New Technology to Clean Ever Smaller Chip Features

In computer-chip fabrication, a silicon-crystal wafer is thoroughly cleaned before microscopic electronic components are deposited on it. Conventional cleaning techniques use caustic "wet" chemicals that could be hazardous to workers and that must be discarded after use, generating disposal costs and the potential for environmental pollution if the chemicals are not handled properly. In addition, for chips with feature sizes below a minimum, wet chemicals may not be able to get to some features, such as trenches, because of surface tension.

. . . the presence of unwanted particles — even in minute amounts — is disastrous . . .

Potentially Safer and Less-Costly

The ATP award allowed FSI International, which provides semiconductor wafer surface conditioning equipment and support products, to develop a "dry" cleaning procedure that uses chlorine, chlorine/hydrogen and other gases to clean dirt, trace metals and other particles from wafer surfaces. Researchers completed the assembly and installation of an experimental module and developed required support processes. Although the gases are toxic, they are more easily controlled than wet chemicals. And even though the gases incur disposal costs, the amount of chemical waste generated by the FSI technology is expected to be much smaller than that created via traditional wet cleaning. Thus, the new technology should improve human and environmental safety and reduce cleaning costs during wafer processing.

FSI's methodologies for gas-phase dry cleaning were developed for use in making computer chips and have potential applications in the fabrication of printed circuit boards, disk drives and optoelectronics. If the market emerges and the FSI technology becomes widely used, substantial economic benefits would likely accrue all along the supply chain for computers and other equipment that include chips. The technology is undergoing initial testing at Texas Instruments. If the testing is successful, FSI officials say, Texas Instruments would likely buy and use systems incorporating the new technology.

ATP funding was critical to generating the gas-phase dry cleaning technology, FSI officials report. The company would not have done the research and development work at that time without it. The ATP award also enabled FSI to collaborate with Massachusetts Institute of Technology researchers during the project.

Commercialization Delayed but Still Expected

Since initiation of the ATP project, manufacturers of wafer-surface conditioning equipment have found ways to squeeze more improvements out of wet-chemical cleaning methods. Consequently, chip fabricators have less need for a dry cleaning technique than was initially anticipated. The company expected that the shift in 1997 to smaller (0.25 micron) minimum feature sizes for wafer processing would challenge the capabilities of conventional wet cleaning processes. Wet processing, however, continues to meet cleaning needs at this level and may even be viable to minimum feature sizes of 0.18 micron, which are expected to be introduced in the year 2000. Furthermore,

. . . caustic "wet" chemicals that could be hazardous to workers and that must be discarded after use, generating disposal costs and the potential for environmental pollution . . .

. . . the new technology should improve human and environmental safety and reduce cleaning costs during wafer processing.

progress has been made in reducing the amount of chemicals needed for wet cleaning processes.

Commercialization of the ATP-funded technology, therefore, depends on how much more the wet method can be extended, as well as on the remaining development work needed to demonstrate the robustness, manufacturability and reliability of the process and equipment in a chip-manufacturing environment. Although the new technology has not become a broad replacement for traditional wet cleaning in wafer processing, as originally envisioned by the ATP-project proposal, FSI anticipates the emergence of new applications requiring the unique capabilities of its technology. If the dry cleaning technology is commercialized, chip fabricators that use the new technology might achieve process improvements worth up to five times their costs for the technology, company officials say. FSI has continued to develop this technology while delaying commercialization until demand increases sufficiently. If that happens soon, the company could have a product on the market in 1999.

PROJECT:

To develop a cost-effective process to remove surface contaminants from computer-chip wafers during manufacturing, using dry gases (as opposed to wet chemicals) that can clean the ever smaller features on new generations of chips.

Duration: 3/1/1993 — 2/28/1995
ATP number: 92-01-0022

FUNDING (IN THOUSANDS):

ATP	$2,000	36%
Company	3,482	64%
Total	$5,482	

ACCOMPLISHMENTS:

FSI achieved its R&D goal of developing a dry gas wafer-cleaning method. Evidence of progress is that the company:

- received three patents related to the ATP project:
  - "UV-Enhanced Dry Stripping of Silicon Nitride Films"
  - (No. 5,534,107: filed 8/18/1994, granted 7/9/1996),
  - "Apparatus for Surface Conditioning"
  - (No. 5,580,421: filed 12/21/1994, granted 12/3/1996), and
  - "Cleaning Method"
  - (No. 5,716,495: filed 3/25/1996, granted 2/10/1998);
- applied for nine additional patents, one of which has been unofficially granted (allowed but not yet published);
- presented or published nine technical papers in the area of dry cleaning, etching or stripping of surfaces;
- received a license to complementary technology that could accelerate the commercialization of an advanced dry gas-phase cleaning system;
- entered into an agreement with Texas Instruments for early-stage testing of a prototype; and
- constructed a manufacturing facility to handle all FSI International Surface Conditioning Division manufacturing, including products incorporating the ATP-funded technology.

COMMERCIALIZATION STATUS:

No commercialization has occurred so far, owing to unanticipated changes in demand for the new technology. The shift in 1997 to 0.25-micron minimum feature sizes for wafer processing was expected to challenge the capabilities of conventional wet cleaning processes. Wet processing, however, continues to meet cleaning needs for 0.25-micron features and may even be viable to minimum sizes of 0.18 micron, which are expected to be introduced in the year 2000.

OUTLOOK:

Commercialization prospects are uncertain. Much depends on how the market moves, as well as on remaining development work needed to demonstrate the robustness, manufacturability and reliability of the process and equipment in a chip-manufacturing environment. Although the ATP-funded technology has not replaced traditional wet cleaning in chip processing, as originally envisioned by the ATP-project proposal, FSI anticipates the emergence of new applications requiring the unique capabilities of its technology.

COMPANY:

FSI International, Inc.
322 Lake Hazeltine Drive
Chaska, MN 55318-1096

Contact: Jeff Butterbaugh
Phone: (612) 448-8089

Number of employees:
540 at project start, 1,295 at the end of 1997

Unofficial collaborator: Massachusetts Institute of Technology, Department of Chemical Engineering

FSI has continued to develop this technology while delaying commercialization until demand increases sufficiently.

Galileo Corporation

Low-Cost Night-Vision Technology

Objects around us emit or reflect electromagnetic radiation, some of it in the form of visible light that we can see. None of us sees well when the light is poor, whether at night, in fog or under other circumstances of darkness.

Seeing in the Dark

If a way could be found to magnify the unseen emissions that remain even in darkness, by passing them through special "glasses," then we could "see" things even when the light is too dim to sense objects with the naked eye. Such glasses already exist. They were developed for military use and are quite expensive. High-performance night-vision devices typically cost more than $1,000 — too much for general consumer use.

This ATP project with Galileo Corporation, founded in the middle 1970s to develop microchannel plates (MCPs), aimed to develop a much less-expensive process technology that would make night-vision devices widely available to, for example, law enforcement officials and the estimated 400,000 Americans suffering from retinitis pigmentosa (night blindness). Another potential use of the technology is in detector components for highly miniaturized analytical instruments. Funding from the ATP enabled Galileo to perform research to develop the new fabrication processes and higher performance prototype MCPs that it would otherwise have been unable to do and helped the company form alliances with research partners and contractors.

. . . a much less expensive process to make devices widely available to law enforcement officials and the estimated 400,000 Americans suffering from retinitis pigmentosa . . .

New Electron Multipliers

The ATP project involved the development of new kinds of electron multiplier devices based on the same kind of manufacturing technology used in semiconductor fabrication. An MCP is a flat, usually disc-shaped array of closely packed microscopic tubes that act as tiny amplifiers. Electrons, photons or ions entering one side of the plate trigger a cascade of thousands of electrons out the other side. MCPs form the heart of image intensifiers used in night-vision and scientific devices and electronic imaging systems. MCPs are currently made using glass-working techniques developed for producing fiberoptic bundles. The process has been improved greatly over the years but has reached its limits in terms of further cost reductions and performance improvements.

Galileo's ATP project abandoned the glass-fiberoptic production approach to MCPs and instead used the photolithography, dry-etch, wet-etch, and thin-film-deposition technologies developed by the semiconductor industry to develop improved MCPs. The company succeeded in the technical goals of the project, developing new fabrication procedures and using them to demonstrate prototypes of working, high performance electron-multiplier devices.

Financial Distress

During the last six months of its 26-month ATP project, Galileo encountered financial problems and decided to abandon its original goal of in-house commercialization of the new process technologies for electron multipliers. The company has continued to produce MCPs using its earlier fabrication process and sell them. Even though feasibility of the new approach was demonstrated by the ATP project, Galileo officials reported that another $5 million investment would have been needed to commercialize the advanced performance MCPs using the new process. They say they could not justify the investment for commercialization, given the company's financial difficulties and the length of time needed to build revenue streams.

Commercialization Potential

At the close of the project, the company entered into an agreement with the Center for Advanced Fiberoptic Applications (CAFA), a new nonprofit consortium charged with commercializing technologies developed by Galileo and other CAFA members, mainly small to

During the last six months of its 26 month ATP project, Galileo encountered dire financial problems and decided to abandon its original goal of in-house commercialization . . .

Galileo granted a non-exclusive royalty-free license of the ATP-funded technology to CAFA.

medium sized optics companies in the mid-Massachusetts area. Galileo granted a non-exclusive royalty-free license of the ATP-funded technology to CAFA. The principal investigator on the ATP project left Galileo to become section head for microelectromechanical systems in the CAFA consortium. In addition to licensing agreements, CAFA is pursuing partnerships with a number of companies as an avenue for commercializing the ATP-funded MCP technology, but the chances for commercialization are uncertain at this time.

In theory, it is expected that the technology will reduce the costs of MCP production and improve performance, but these effects have not yet been shown in practice. The prototype demonstration focused on the feasibility of the new process technology adapted from the semiconductor industry to produce MCPs and on improved MCP performance, rather than on their comparative costs. Laboratory tests and calculations suggested that production costs would be lower using the new technology, but no pilot project has yet been developed, so those predictions have not been confirmed. Demonstrated lower costs and improved performance would make it more feasible to pursue new market opportunities for applications to address night blindness.

. . . CAFA is pursuing partnerships with a number of companies as an avenue for commercializing . . .

PROJECT:

To develop fundamentally new, lower-cost fabrication processes for and prototypes of higher quality microchannel plates (MCPs) — which form the heart of image intensifiers used in night vision — to enable wider use of the technology, including applications for the estimated 400,000 Americans suffering from retinitis pigmentosa (night blindness).

Duration: 4/1/1993 — 5/31/1995
ATP number: 92-01-0124

FUNDING (IN THOUSANDS):

ATP	$1,910	57%
Company	1,428	43%
Total	$3,338	

ACCOMPLISHMENTS:

Galileo developed new processes for fabricating MCPs and other types of electron multipliers, using techniques from semiconductor fabrication, and used the new processes to produce prototype MCPs. As evidence of these accomplishments, the company:

- received four patents for ATP-related technology:
  - "Method for Fabrication of Discrete Dynode Electron Multipliers"
  - (No. 5,618,217: filed 7/25/1995, granted 4/8/1997),
  - "Method for Fabrication of Microchannel Electron Multipliers"
  - (No. 5,569,355: filed 1/11/1995, granted 10/29/1996),
  - "Microfabricated Electron Multipliers"
  - (No. 5,568,013: Filed 7/29/1994, granted 10/22/1996) and
  - "Fabrication of a Microchannel Plate From a Perforated Silicon Workpiece"
  - (No. 5,544,772: filed 7/25/1995, granted 8/13/1996);
- published five technical papers, including one as a dissertation and four in professional journals;
- produced working vacuum-electron multipliers by microfabrication methods; and
- developed thin-film techniques to produce dynode structures that support electron multiplication in MCPs and other channel electron multiplier devices.

COMMERCIALIZATION STATUS:

No products based on the ATP-funded technology have yet reached market.

OUTLOOK:

Prospects for commercialization of this technology are uncertain. Financial difficulties forced Galileo to abandon plans to directly commercialize the ATP technology. The company now is working with the Center for Advanced Fiberoptic Applications (CAFA), a nonprofit consortium charged with commercializing technologies developed by Galileo and other CAFA members. If CAFA can commercialize the ATP technology to benefit people suffering from night blindness, or if the technology is adopted for use in producing miniature scientific and analytical instruments, such as a mass spectrometer on a chip, the broad economic benefits could be very large.

COMPANY:

Galileo Corporation
Galileo Park
Sturbridge, MA 01566

Contacts:

Enrique Bernal G.
Galileo Corporation
(508) 347-4291

William Tasker
Center for Advanced Fiberoptic Applications
(508) 765-0180

Number of employees:
314 at project start; 240 at the end of 1997

In addition, the technology holds further potential that might one day be realized. It is important for miniature scientific and analytical instruments — for example, a mass spectrometer on a chip. The National Aeronautics and Space Administration (NASA) recently awarded a contract to develop components for miniaturized mass spectrometers to CAFA, Galileo and the Argonne National Laboratory, under which prototypes have been delivered and are now being evaluated. While the NASA contract did not itself involve the use of the ATP-funded technology, extensions to additional contracts could easily do so, because of the need for additional miniaturization. Commercialization of the technology for this application, if it can be accomplished, could also have far-reaching economic benefits.

Hampshire Instruments, Inc. (Joint Venture)

Large-Scale Diode-Array Laser Technology for X-Ray Lithography

Today's stamp-size computer chips are made by lithography systems that project ultraviolet (UV) or deep-UV light through stencil-like masks onto silicon wafers to produce the tiny components of integrated circuits (ICs), or chips. To make higher-performing ICs, more transistors and denser circuitry will have to be packed onto each chip.

Ever Smaller, Denser Computer Chips

Today's densest chips have feature sizes of about 0.15 mm, which can barely be produced with deep-UV lithography. To make even smaller chips, the next generation of lithography equipment may use x-rays, which have shorter wavelengths than visible or UV light. Shorter wavelengths are needed to make tinier features.

An Inexpensive Laser Approach

X-ray lithography able to make chip features of 0.10 mm and smaller was demonstrated prior to the start of this project in 1991. But cost-effective x-ray lithography systems capable of large-scale IC manufacturing were not available. Research had shown that a relatively inexpensive device using a high-energy laser to stimulate x-ray emission could be used to produce x-rays. Suitable material (neodymium-doped gadolinium gallium garnet, or Nd:GGG) for this type of laser was available. However, the inability to precisely control the energy used to pump up the material's energy level was a key problem in making such a laser work.

This ATP joint venture project by Hampshire Instruments and McDonnell Douglas Corporation (MDC), with help from Lawrence Livermore National Laboratory, solved the control problem by developing methods for using powerful arrays of laser diodes to pump Nd:GGG in a laser-based x-ray lithography system. Hampshire, a small New York company, contributed its laser design expertise. MDC provided expertise in system design and the design of the critical high-power laser-diode pump. It also provided the world's largest laser-diode-module manufacturing capacity to support post-project commercialization goals.

Prior to the ATP-funded work, MDC built a prototype laser-diode-pump system with a peak power output of more than 300 kW. The system was successfully used to pump a Hampshire laser being developed for a second-generation x-ray lithography system, and its pumping was significantly more efficient than that of the flash lamps Hampshire had used in its first-generation x-ray lithography system. In addition, life testing of laser-diode-pump systems showed they lasted much longer than the longest-lasting flash lamps then available.

Soon after the ATP project was completed, Hampshire ran into serious financial problems, declared bankruptcy and was liquidated.

Doubling the Peak Power Output

During the ATP project, MDC built two prototype laser-diode-pump systems that each delivered more than 750 kW of peak power, by far the highest laser-diode power produced by any device then or now. Both met or exceeded all performance and reliability specifications. MDC kept one pump and delivered the other to Lawrence Livermore for testing in the second-generation x-ray lithography system being developed by the lab and Hampshire. The pump, however, was never integrated with the Hampshire laser. Flash lamps with longer life became available, leading Lawrence Livermore to shift its focus to flash-lamp pumping of the laser. The lab continues to develop x-ray lithography.

High Expectations Dashed by Bankruptcy

Evidence at the start of the project suggested the ATP-funded technology would be rapidly commercialized if it could be successfully developed and demonstrated. Hampshire and MDC planned to sell the new x-ray lithography system in a worldwide market expected, when the proposal was written, to exceed $1.5 billion by 1994. They also hoped to sell the technology in solid-state laser markets.

Hampshire, however, ran into serious financial problems and failed to raise the addi-

. . . MDC built two prototype laser-diode-pump systems that each delivered more than 750 kW of peak power, by far the highest laser-diode power produced by any device . . .

PROJECT:

To develop a laser-diode-pumped laser system for generating x-rays in a new generation of lithography equipment to enable a major advance in the miniaturization of computer chips while reducing manufacturing costs.

Duration: 7/1/1991 — 9/30/1992
ATP number: 90-01-0126

FUNDING (IN THOUSANDS):

ATP	$926	50%
Company	930	50%
Total	$1,856	

ACCOMPLISHMENTS:

Researchers demonstrated the feasibility of using a powerful laser-diode-array to pump up the energy level of Nd:GGG (neodymium-doped gadolinium gallium garnet) in a laser intended for use in producing x-rays. Such a laser could be scaled up to meet the technical, reliability and affordability requirements for third-generation x-ray lithography systems. All planned tasks were accomplished. The company presented some results at the Advanced Solid State Laser Conference in 1992.

COMMERCIALIZATION STATUS:

No attempt to commercialize the technology has occurred. Soon after the ATP project was completed, Hampshire ran into serious financial problems, declared bankruptcy and was liquidated. The company's demise halted the effort to develop this type of laser-based x-ray lithography and led to the collapse of MDC's laser-diode business.

OUTLOOK:

The New York Job Development Authority — which now owns practically all Hampshire assets, including intellectual property — shows no intention to commercialize the technology. Neither does MDC (Boeing). The semiconductor industry has shifted some of its attention from x-ray lithography to competing technologies such as deep ultraviolet (DUV) lithography utilizing excimer lasers. However, given the expectation that feature resolution limits of DUV lithography will be reached in a few years, x-ray lithography continues to arouse interest. If the industry comes to view the x-ray approach as a viable candidate for a new generation of lithography equipment, the technology developed in this ATP project could be revisited.

COMPANIES:

Hampshire Instruments, Inc.
(joint venture lead)
(Since April 25, 1993, no longer in business)

Other joint venture participant:

McDonnell Douglas Corporation (MDC),
now merged with The Boeing Company

5000 E. McDowell Road
Mesa, AZ 85215-9797

Contact: Henry B. Morris
Phone: (602) 891-2194

Informal collaborator:
Lawrence Livermore National Laboratory

tional funds needed to survive. The company declared bankruptcy and was liquidated. The New York Job Development Authority assumed ownership of practically all Hampshire assets, including its intellectual property. For a time, several organizations expressed interest in acquiring the technology, but none completed the acquisition. MDC intended to commercialize its laser-diode pumps for a variety of applications. With Hampshire's demise, that plan did not materialize. There is currently no effort to commercialize the ATP-funded technology, either by Boeing (MDC) or government agencies. But this may change with renewed interest in x-ray lithography in the future.

Illinois Superconductor Corporation (ISC)

Using High-Temperature Superconductivity to Improve Cellular Phone Transmission

The number of cellular phones used in the United States has mushroomed in the last decade. Estimates provided by the Cellular Telecommunications Industry Association are that the number of wireless telephone subscribers was over 50 million as of August 1997. Additional estimates are that by 2001 the cellular subscriber base is expected to grow to more than 75 million subscribers, with an additional 15.1 million subscribers using personal communications services (PCS) by the same year.

A compact one-box enclosure for *RangeMaster®* and *SpectrumMaster®*

Cellular phone users will receive clearer signals and suffer fewer dropped calls as their signals move from one base station site to the next.

Extending and Improving Cellular Phone Service

To provide cellular phone or PCS service, a communications company using a land-based approach must place base stations — towers and reception/transmission equipment — at regular intervals throughout its service area. In deciding where to locate these base stations, the company considers the strength and clarity of its communications signals and how customer service will be affected when a signal shifts from one station to the next while the customer is traveling.

All these factors depend on how well the station's equipment handles the communications signals. And that depends on how well each component of the equipment works as it attempts to distinguish the user's cellular phone signal from the surrounding electronic noise.

A High-Temperature Superconductivity Solution

This ATP project with Illinois Superconductor Corporation (ISC), a small company founded in 1990, developed technology based on high-temperature superconductivity (a phenomenon discovered in 1986) to significantly improve the quality of signal transmission.

Superconducting components offer great benefits to cellular phone communications, including improvements in range, receiver sensitivity and frequency stability. These improvements, in turn, will extend the range of base stations, reducing the number needed to cover a given area and decreasing the costs of cellular phone service. Cellular phone users will receive clearer signals and suffer fewer dropped calls as their signals move from one base station site to the next.

Despite the promise of superconducting components, little prior work had gone into developing HTS components for the radio-frequency (RF) spectrum, which is used by cellular phone systems. Difficulties in economically making the relatively large, geometrically complex structures needed for these frequencies were partly to blame. ISC solved this problem by developing the ability to use thick-film HTS coatings on inexpensive substrates.

Focus on Preselector Receive Filters

The goal of the ATP project was to develop and demonstrate consistently performing RF superconducting components in a prototype base station. During the ATP project, however, ISC narrowed its focus (with ATP approval) to preselector receive filters, which remove all extraneous RF signals and leave only those within the cellular spectrum allotted to that

. . . received the *Microwave & RF* magazine 1996 Top Product Award for "cellular phone site filters, superconducting ceramics" . . .

A ceramic torroid form, coated with thick film HTS material, designed to resonate at a specific frequency.

By September 1997, ISC had installed SpectrumMaster™ or RangeMaster™ in 22 base stations in 12 cities and had successfully completed 16 field trials in 10 cities.

PROJECT:

To develop high-temperature, superconducting thick-film materials for equipment used in the reception/transmission stations of cellular phone and other communications systems.

Duration: 3/1/1993 — 2/29/1996
ATP number: 92-01-0017

FUNDING (IN THOUSANDS):

ATP	$1,980	56%
Company	1,555	44%
Total	$3,535	

ACCOMPLISHMENTS:

ISC developed and demonstrated a robust fabrication process to produce radio-frequency (RF) components using thick-film, high-temperature superconductivity (HTS) technology. It developed a model that predicts the impact of high-performance filters on future digital wireless systems. The company also:

- received five patents for technologies related to the ATP project:
  - "Superconducting YBa.sub.2 Cu.sub.3 O.sub.7-x Produced at Low Temperatures" (No. 5,527,765: filed 8/23/1994, granted 6/18/1996),
  - "Electromagnetic Resonant Filter Comprising Cylindrically Curved Split Ring Resonators" (No. 5,616,540: filed 12/2/1994, granted 4/1/1997),
  - "Electromagnetic Resonator Comprised of Annular Resonant Bodies Disposed Between Confinement Plates" (No. 5,629,266: filed 12/2/1994, granted 5/13/1997),
  - "Resonator Mounting Mechanism" (No. 5,604,472: filed 12/1/1995, granted 2/18/1997), and
  - "Superconducting Re-entrant Resonator" (No. 5,682,128: filed 4/23/1996, granted 10/28/1997);
- applied for one additional patent for technology related to the ATP project;
- raised $17.4 million through an initial public stock offering in October 1993;
- completed construction of a plant to manufacture RF filters and related products;
- began selling SpectrumMaster® in 1996 and RangeMaster™ in 1997, both of which are based on the ATP-funded technology;
- received the *Microwave & RF* magazine 1996 Top Product Award for "cellular phone site filters, superconducting ceramics," which were selected from a field of 5,000 new products; and
- received (with subcontractor Lucent Technologies) a Corporate Technical Achievement Award for 1997 from the American Ceramic Society.

COMMERCIALIZATION STATUS:

Commercialization is in progress and products are being sold. The benefits of lower costs and higher-quality service are accruing to companies that use ISC's new technology and to their customers.

OUTLOOK:

The outlook for this new technology is excellent. Its use is expected to spread throughout the economy, lowering the costs and improving the quality of cellular phone and personal communication services.

COMPANY:

Illinois Superconductor Corporation (ISC)
451 Kingston Court
Mt. Prospect, IL 60056

Contact: Ben Golant
Phone: (847) 391-9416

Number of employees:
8 at project start, 75 at the end of 1997

particular operator. Investigation of the cellular market indicated that the superconducting preselector receive filter was of greatest interest to customers in terms of improving system performance. Given the limited resources available to ISC, the company decided to focus on this component as an initial goal and to integrate others later. The new HTS technology is useful for other RF equipment and has potential applications in antennas, magnetic resonance imaging machines and other components of communications systems.

ISC successfully incorporated the ATP-funded technology in a preselector receive filter and, in late 1996, started selling it under the name of SpectrumMaster® to companies

operating cellular phone systems. A year later, it launched RangeMaster®, which contains the SpectrumMaster® preselector receive filter and a cryogenically cooled low-noise amplifier. By September 1997, ISC had installed SpectrumMaster® or RangeMaster® in 22 base stations in 12 cities and had successfully completed 16 field trials in 10 cities. Sales at that time amounted to $1 million. The company has also modified and installed SpectrumMaster® for use in the base stations of personal communications systems.

Improved Communications Service

The future looks bright for ISC as it uses the ATP-funded technology to help communications companies serve their customers with greater-quality services at lower costs. Cellular phone service companies can reduce the number of new base station sites they install. They can also expand by up to 25 percent the range of existing sites by replacing an older filter at the station with a new one based on the ATP-funded technology. A 25 percent range increase corresponds to a 56 percent increase in the area covered and translates into a 40 percent decrease in the number of sites required to cover the area. The cost of the improved filter is around $25,000 to $60,000, depending on site configuration, whereas the cost of a new site is about $1 million to $2 million.

The future also looks bright for customers of these communications companies, as costs drop and service quality improves.

Even greater benefits should accrue to cellular and personal communications customers with the conversion from analog to digital communications. Digital stations must transmit much more data per call, so any quality improvements or cost reductions will apply to a larger volume of signal traffic. As more transmission sites install digital systems, cellular phone users will get clearer signals and fewer dropped calls. Other sectors, such as mobile communications, will experience lower costs and improved quality as the technology is extended to them. Proliferation of the new technology will provide an additional benefit in terms of aesthetics by reducing the number of signal towers installed for communications systems.

ATP Award Accelerates Development

Funding from the ATP enabled ISC to form alliances with research partners and contractors and to achieve its research and development results about 18 months earlier than it would otherwise have been able to do. Company officials say the ATP award also enabled ISC to survive as a company and gave its technology and commercialization plan significant credibility with investors. The increased credibility, in turn, directly helped the company raise private capital, especially during its initial public stock offering in 1993.

A 25 percent range increase corresponds to a 56 percent increase in the area covered and translates into a 40 percent decrease in the number of sites required to cover the area.

Light Age, Inc.

Exploiting Alexandrite's Unique Properties for a Less-Expensive, More-Reliable Tunable Laser

Lasers today drive many devices throughout the consumer and commercial worlds. There are tiny ones in printers and CD-ROM players, small ones in medical instruments and large ones in satellite communications systems. Besides coming in different sizes, lasers vary in the wavelength and strength of the light they produce. In almost all applications, the wavelength and power of the beam are fixed.

Tunable Lasers for Many Uses

This ATP project with Light Age, a small privately held company, developed a convenient, reliable, tunable, compact laser source of ultraviolet (UV) light suitable for spectroscopy, medical applications, photochemical research, electronics fabrication, and laboratory studies of atomic and molecular science. Of particular importance, the new laser can be tuned to the shorter UV wavelengths known as vacuum UV (VUV) light.

The new device is the brightest (most powerful) available tunable source of laser light over much of the UV spectrum.

Light Age was founded in 1985 by two scientists who, at AlliedSignal, had pioneered and managed the development of a tunable-wavelength laser based on the alexandrite crystal. The new light source developed in the ATP project offered improvements over the AlliedSignal technology and is less expensive, operationally simpler and more reliable than other tunable laser light sources. It uses the fundamental output of the alexandrite laser, which is broadly tunable between 700 and 800 nanometers (nm). That output is then converted to UV wavelengths of 190-200 nm, 240-270 nm or 350-400 nm. The new device is the brightest (most powerful) available tunable source of laser light over much of the UV spectrum.

The *Pal/Pro - UV*™ laser system, tunable to 248 nanometers, 193 nanometers, and other ultraviolet wavelengths.

Surgery and Photolithography

The new tunable laser is particularly promising for corneal sculpting and angioplasty because it provides the control needed for these advanced applications. Its advantage stems from the fact that laser beams of certain wavelengths affect some tissue types but not others. The laser can be tuned, for example, to the wavelength of a light beam that destroys diseased tissue while leaving healthy tissue undamaged.

The laser can be tuned, for example, to the wavelength of a light beam that destroys diseased tissue while leaving healthy tissue undamaged.

Another, quite different potential application is in photolithography equipment for the production of faster, higher-density, next-generation computer chips. Shorter-wavelength light is needed to produce the finer features on these chips. And reliable lasers that can generate shorter-wavelength light are needed to move beyond this manufacturing choke point. As recently as 1995, almost all chip photolithography used light in the near-UV range (around 350 nm) produced by UV light bulbs. Today, the industry is rapidly moving toward

PROJECT:

To develop a safe, compact, convenient, reliable, less-expensive, broadly tunable laser source of ultraviolet (UV) light — particularly at shorter UV wavelengths — suitable for use in science, medicine and photolithography.

Duration: 4/1/1991 — 9/30/1993
ATP number: 90-01-0212

FUNDING (IN THOUSANDS):

ATP	$702	41%
Company	1,010	59%
Total	$1,712	

ACCOMPLISHMENTS:

Light Age accomplished its R&D goal. The company also:

- introduced several new or improved laser products incorporating the ATP technology, including:
  - nUVo™ — a continuous-wave, diode-pumped, solid-state laser producing UV light,
  - PAL/UV™ — a solid-state laser source of 193-nanometer light, and
  - PAL/PRO™ — a narrow spectral bandwidth version of the PAL™ laser;
- increased revenues an average of 50 percent per year since the end of the ATP project in 1993, with 1997 revenues exceeding $2.8 million on sales of lasers incorporating the new technology; and
- received more than $10 million worth of product orders, which are currently being filled.

COMMERCIALIZATION STATUS:

Light Age lasers incorporating the ATP-funded tunable-laser technology are being sold and put to use in academic R&D and in clinics, hospitals and doctors' offices around the world.

OUTLOOK:

Prospects for wider use of this technology are promising, particularly in medicine for corneal sculpting and angioplasty. Products based on the ATP-funded technology may generate large payoffs to the U.S. economy in science, health care and electronics manufacturing. The company's lasers are also being used in studies to refine and extend global weather prediction methods. If atmospheric research using the new lasers leads to improved weather forecasts, the benefits in this area alone could be huge for businesses and individuals worldwide.

COMPANY:

Light Age, Inc.
2 Riverview Drive
Somerset, NJ 08873

Contact: Donald F. Heller
Phone: (732) 563-0600

Number of employees:
10 at project start, 28 at the end of 1997

deep-UV laser sources that produce light at 248 nm. Future generations of computer chips may require VUV laser sources that produce light at wavelengths of about 193 nm or even shorter.

Large Benefits to Intermediate Users and Customers

Light Age makes UV and VUV lasers costing $20,000 to $200,000. They are used in applications such as health care and scientific equipment that may generate big payoffs to the economy as a whole. In most of these markets, the company's technology faces global competition. Nonetheless, Light Age is already a significant exporter of laser systems for scientific and medical applications and expects strong, continued growth of these exports.

Light Age is already a significant exporter of laser systems . . .

Economic benefits are accruing to intermediate customers and end users of the new technology in medical applications. Many applications of the new laser technology are in environments such as medicine and weather forecasting, where the economic benefits to others besides Light Age are likely to be large.

Potential for Improved Weather Prediction

The company's lasers are being used in institutional and government research on the upper atmosphere to refine and extend global weather prediction methods. In these applications, lasers are a required technology. The research uses UV lidar (light detecting and ranging) to illuminate particular atoms in the mesosphere — about 70 miles above the earth. Specific effects of the illumination are viewed with powerful telescopes, recorded and used to determine the temperature of the environment at that altitude.

This research aims to develop methods for measuring the temperature and wind speed at very high altitudes. Current measurement systems mainly use only ground-level data. Researchers believe that data on several atmospheric strata measured at selected points around the earth could significantly improve the quality of the very large weather prediction computer models now in use. If research using the tunable laser does lead to better weather predictions, the benefits would likely be huge for businesses and individuals not just in the United States, but around the world.

The tunability of the alexandrite laser from Light Age has made this new research feasible. To show their effects, different types of atoms must each be illuminated by a lidar laser of a specific wavelength. With the Light Age laser, that wavelength can be set by a technician using conventional controls. Alternative laser sources for this research are hand-constructed for just one wave-length, which limits their use and makes them much more expensive than the mass-produced Light Age lasers.

Greater Sales and Revenues

Light Age has done well commercially. The company has expanded product offerings and increased sales each year since beginning the ATP project in 1991. The new technology helped Light Age boost revenues an average of more than 50 percent per year after completing the project in 1993. In 1997, the company generated more than $2.8 million in revenues and, at the beginning of 1998, had back orders worth more than four times its 1997 sales.

If atmospheric research using the new lasers leads to improved weather forecasts, the benefits in this area alone could be huge for businesses and individuals worldwide.

Light Age sees itself as an up-by-your-own-bootstraps company in terms of finances. A large part of its success comes from paying detailed attention to financial management, tightening its budgetary belt, retrenching temporarily when needed, pushing new technology-driven products through to market and staying in product areas where its strengths lie. The company has adopted a stringent approach to financial matters, plowing all earnings back into additional research. ATP's participation compelled Light Age to adopt rigorous financial discipline during the company's early development in order to meet the ATP requirement for cost sharing. The belt-tightening was difficult for Light Age in the short run, company officials say, but served the long-term interests of the company.

The ATP funds enabled Light Age to double its research budget during the funding period, a move that allowed the research and development work to be completed 12 to 36 months sooner than it would have been without the award. In addition, company officials say, the visibility generated by winning the ATP award helped Light Age establish agreements with research partners and, coupled with the success of the ATP project, enabled it to secure additional funding from private investors.

Lucent Technologies Inc. (formerly AT&T)

Precision Mirrors for Advanced Lithography

The personal computer revolution has been powered, in large part, by the development and production of new generations of memory, CPU (central processing unit) and other chips. With each generation, chip feature sizes shrink. However, chip feature size is reaching the limit of what can be produced with current lithography equipment. A new approach to lithography that can operate at shorter wavelengths is essential if the integrated circuit industry is to continue to advance toward more powerful computer chips.

Advanced Optics to Enable Chip Miniaturization

The ATP project with Lucent Technologies (formerly AT&T) Bell Laboratories significantly improved the accuracy of precision reflective optics — complex multilayer-coated mirrors — that are critical for extreme ultraviolet (EUV) lithography. EUV, or soft x-ray, technology is one of several possible approaches to advanced lithography for manufacturing chips.

The goal of the project was to discover whether it is possible to create ultrahigh-precision aspherical mirrors that properly reflect EUV wavelengths for use in lithography. This was a high-risk, technically challenging project. ATP cost sharing enabled Lucent to move ahead with a project that otherwise would have been difficult to justify, particularly because so much of the funding would go to collaborators outside the company. Ultimately, the ATP project showed that the technical obstacles were surmountable and that the optics can be manufactured, measured and aligned.

A new approach to lithography that can operate at shorter wavelengths is essential if the integrated circuit industry is to continue to advance toward more powerful computer chips.

Characterizing the complex shapes of these mirror surfaces with the high level of precision required for EUV lithography was well beyond the state of the art when the ATP project began. Working with Lucent, Tropel developed a specialized interferometer to measure aspheric surface characteristics, a device that it now uses in other applications. Lucent, in collaboration with Brookhaven and Sandia National Laboratories and the University of Wisconsin, developed other techniques required to characterize aspheric mirrors. The project also generated increased understanding of multilayer-coated aspherical optics and optics surface finishing, advanced techniques for multilayer coating of mirrors, improved methods for mirror alignment, and new test equipment.

To see whether this new technology would work, Lucent and its collaborators conducted a two-stage, round-robin test. In the first stage, four subcontractors fabricated prototype mirrors using the knowledge created in the project. Then each subcontractor tested mirrors fabricated by each of the four. The mirrors made by Tinsley Laboratories proved to be dramatically better than any of this type ever seen before.

Commercialization Status

When this project began, it was uncertain whether aspheric mirrors with the high level of accuracy required for EUV lithography could be made. And even if they could, it was not clear whether they could be measured with sufficient accuracy to verify that they met the extreme precision demanded by the specifications. Thus, this high-risk project aimed to find out whether the EUV approach to lithography deserved further consideration or whether the mirrors constituted a "show stopper" technical barrier that could not be surmounted. The project demonstrated that the mirror technical barrier could, indeed, be overcome.

Progress on all the advanced-lithography candidate technologies developed in parallel at industry and government laboratories during the early 1990s. As data accumulated, Lucent decided in 1995-1996 (well after the ATP project ended) to reduce its effort in EUV lithography and focus its attention on another option — scattering with angular limitation projection electron-beam lithography (SCALPEL) —

. . . this high-risk project aimed to find out whether . . . the mirrors constituted a "show stopper" technical barrier that could not be surmounted.

The high-quality Tinsley mirrors, fabricated and tested with methods discovered during the ATP project, are a key component of the EUV approach to new generations of lithography equipment.

which it deemed more promising. Lucent still monitors developments in all areas of advanced lithography, and substantial work on EUV lithography continues elsewhere, particularly at Lawrence Livermore and Sandia National Laboratories.

In 1996 Intel, AMD and Motorola formed the Extreme Ultraviolet Limited Liability Company to pursue EUV lithography. In September 1997, this consortium and the Virtual National Laboratory (a collaboration of Lawrence Berkeley, Lawrence Livermore and Sandia National Laboratories) agreed to collaborate on the development of EUV lithography. EUV systems would draw on the optics work from the ATP project and related technology developed at the national laboratories. The three chip makers intend to invest about $250 million over three years in the collaboration to determine whether the technology is commercially viable and, if it is, to pursue commercialization via lithography equipment manufacturers.

It is too early to tell whether the EUV or one of the other approaches to lithography will ultimately win in the marketplace. But it is clear that the ATP project has helped the industry understand the technical barriers to one major candidate technology and how to overcome them. The ATP project results are

PROJECT:

To develop new fabrication, testing and alignment techniques for making extremely precise aspheric (nonspherical curvature) mirrors to use for lithography in the extreme ultraviolet (EUV) portion of the spectrum. This is one of several approaches being considered for fabricating future generations of computer chips with extremely dense, compact microelectronic circuits.

Duration: 5/15/1991 — 5/14/1994
ATP number: 90-01-0121

FUNDING (IN THOUSANDS):

ATP	$2,000	36%
Company	3,525	64%
Total	$5,525	

ACCOMPLISHMENTS:

Lucent and its subcontractors developed dramatically improved techniques for fabricating, testing and aligning extremely precise aspherical, multilayer-coated mirrors essential to EUV technology, a candidate for future lithography systems. Lithography is a key step in manufacturing integrated circuits. Aspheric mirrors, whose surfaces have nonspherical curvature, are much more difficult to make and measure than mirrors with flat or spherically curved surfaces. They are particularly difficult to make for the ultrashort wavelengths used in this technology. Researchers significantly advanced the state of the art of the physics and metrology for these EUV lithography systems. Signs of the project's success are:

- Lucent contracted with Tropel to develop a new advanced interferometer for measuring the surface properties of aspheric optics. Tropel succeeded and is now using this technology for its own products.
- Tinsley Laboratories, a subcontractor, fabricated mirrors 10 times more precise than any produced before the ATP project. Tinsley has applied the improved methods learned in the project to all its products. In part, because of its improved manufacturing technology, Tinsley doubled its sales between 1991 (the start of the ATP project) and 1996.
- The researchers presented or published more than two dozen papers about precision metrology, aspheric mirror fabrication and lithography systems development.
- Three computer chip fabrication companies have agreed to invest $250 million over three years to continue the research, development and perhaps ultimate commercialization of EUV lithography technology. A critical component of this technology is the multilayer-coated mirrors that were the focus of this ATP project.

COMMERCIALIZATION STATUS:

Although Lucent has decided to concentrate on another advanced-lithography approach that appears more promising at this time to the company, some technologies developed during the ATP project have already been commercialized, and others may be commercialized in the future. Tinsley's business rose sharply as a result of manufacturing improvements the firm developed to fabricate the aspheric mirrors for this project. Tropel is using the measurement technology resulting from its involvement in the project. And several computer chip manufacturers are incorporating the project results into their lithography R&D. If the EUV approach meets the technical and economic requirements of the chip industry, the ATP-funded technology will be incorporated into equipment used to produce computer chips in the first decade of the twenty-first century.

OUTLOOK:

The high-quality Tinsley mirrors, fabricated and tested with methods discovered during the ATP project, are a key component of the EUV approach to new generations of lithography equipment. If this approach proves to be technically and commercially viable, it will enable a new generation of chip-making equipment that will generate benefits for chip manufacturers, as well as users of computers, communications equipment and other electronic devices containing the new chips.

COMPANY:

Lucent Technologies Inc., Bell Laboratories
(formerly AT&T Bell Laboratories)
Room 3C-428
600 Mountain Ave.
Murray Hill, NJ 07974

Contact: Richard P. Muldoon
Phone: (908) 582-5330

Subcontractors: Itek Optical Systems, SVG Lithography, Tinsley Laboratories and Tropel Corp.

Informal collaborators: Sandia, Brookhaven and Lawrence Livermore national laboratories and NIST.

The researchers presented or published more than two dozen papers about precision metrology, aspheric mirror fabrication and lithography systems development.

important to this effort because the kind of aspheric mirrors that Tinsley learned to make under contract to Lucent will be a critical component of the EUV lithography equipment.

ATP-Project Benefits Could Be Huge

Benefits have already started accruing to Tinsley, which produced the best aspheric mirrors, and to its customers who use the mirrors. Tinsley attributes much of its recent success to the ATP project, because the company was able to apply the improved manufacturing processes — developed to supply aspheric optics for the project — to all its products. Tinsley's sales have approximately doubled since the ATP project. Furthermore, in just 27 months the value of Tinsley's stock increased 600 percent, indicating the value the market places on the company's enhanced capabilities. Tropel and its customers are also continuing to reap benefits from the interferometer.

If EUV lithography equipment incorporating the new aspheric mirror technology becomes the technology of choice for the next generation of chip-making equipment, the benefits of the ATP project would be far broader. The new technology would have a huge economic impact on the semiconductor industry and generate spillover benefits to companies that use the improved computer chips in a wide variety of products, as well as to consumers who use these products. Even if another lithography approach becomes the technology of choice, benefits to companies like Tinsley and Tropel and to their customers will continue to accrue.

This project illustrates the important fact that a lack of immediate commercialization after an ATP project ends does not mean that the new technology will not eventually be commercialized and yield large benefits.

Information gathered in this project helped Lucent better understand the technical issues related to EUV lithography. Publication of numerous technical papers resulting from the project has advanced the state of the art for everyone in this technical community. And although Lucent later decided to pursue an alternative lithography approach, other companies have incorporated the ATP-funded technology into research and development work that could lead to systems that are commercialized in the future.

. . . in just 27 months the value of Tinsley's stock increased 600 percent, indicating the value the market places on the company's enhanced capabilities.

Multi-Film Venture (Joint Venture, formerly The American Scaled-Electronics Corporation)

Joining Several Chips Into One Complex Integrated Circuit

In the race to boost the performance and decrease the size of the integrated circuits (ICs) used in computers, one limitation gets a lot of notice: the two-dimensional (2D) nature of ICs. An IC, or chip, is flat. Its operating speed depends greatly on the length of the wires interconnecting its tiny components. Chip designers spend enormous resources to make the longest wire as short as possible and to reduce component size so they can be placed closer together. But as long as chips are 2D devices, wire length constrains how fast they can operate.

New Capabilities From Interconnected Chips

On a seemingly unrelated front, the need frequently arises for large electronic displays — in hospital operating rooms, military command centers, industrial applications and even sports bars. Sometimes the display must also be flat. For home use, a display that mounts flat on the wall like a picture is ideal and is much sought after by technology leaders. Large CRT (cathode-ray tube) displays are available. But a 35-inch CRT display may be 30 inches deep and weigh 150 pounds. Flat-panel displays, like those in notebook computers, are also widely available. But they are typically small, since the display usually has just one panel consisting of a single, broad, light-emitting IC. Attempts to greatly increase the scale of single-IC fabrication have been accompanied by commercially unacceptable levels of defects. Interconnecting several chips introduces other problems.

. . . raised $26.6 million from a second public stock offering in March 1993 . . .

One Technology for Two Major Needs

The Multi-Film Venture (MFV) — a partnership between MCC and Kopin Corporation (a small company spun off in 1984 from Lincoln Laboratory at the Massachusetts Institute of Technology) — used ATP funding to speed by two years the development of technology to address the needs for larger flat-panel displays and for shorter IC component connectors. The new technology can be used to join several broad light-emitting ICs into a single large display with no visible seam. It can also be used to join small ICs, stacked like a deck of cards, so that wire lengths can be shortened. ATP funding made this joint venture possible, and the project's success attracted further research and development funding from outside sources.

The new technology is based on ATP-funded development of advanced methods for positioning IC components with micron-scale alignment and for connecting individual ICs, as well as new adhesives procedures for bonding chips together. It is also based on proven IC fabrication methods and proprietary thin-film-transfer technology previously developed by Kopin. MCC contributed its expertise in adhesives, bonding and positioning.

During the ATP project, MFV researchers proved the feasibility of transferring thin-film, single-crystal silicon ICs to a substrate and interconnecting them to form a functioning multifilm module (MFM). They designed, built and successfully demonstrated a large-area, flat-panel display to show seamless joining of several panels (single, broad, light-emitting ICs) arranged side by side like floor tiles, to form the display.

Giant Flat Screens and 3D Microprocessors

The earliest commercial use of the new MFM technology is likely to be in military, medical and industrial flat-panel displays and large high-resolution displays. The tiled displays would replace conventional CRT displays. When cost considerations make it profitable, they would replace large single-panel displays based on relatively expensive technologies such as liquid crystal display. The new technology also has potential applications in desktop computer displays and — with volume production and lower prices — in wall displays for the home. In addition, the ATP technology should be competitive for very high resolution screens, those with resolutions of 2,000 by 2,000 pixels per inch up to 10,000 by 10,000 pixels.

. . . researchers proved the feasibility of transferring thin-film, single-crystal silicon ICs to a substrate and interconnecting them to form a functioning multifilm module . . .

The MFM process is expected to be useful for making devices with directly joined layers

PROJECT:

To show the feasibility of interconnecting thin-film integrated circuits (ICs), packed side by side or in layers, to form a complex, multifilm module (MFM), and to demonstrate this technology in a large flat-panel display.

Duration: 9/15/1992 — 9/15/1995
ATP number: 91-01-0262

FUNDING (IN THOUSANDS):

ATP	$2,776	48%
Company	2,973	52%
Total	$5,749	

ACCOMPLISHMENTS:

MFV developed the MFM technology and demonstrated it in a large, flat-panel display. In actions related to the project, Kopin:

- received two patents for project-related technology:

  "Single Crystal Silicon Tiles for Liquid Crystal Display Panels Including Light Shielding Layers"

  (No. 5,377,031: filed 8/18/1993, granted 12/27/1994),

  "Method for Forming Three-Dimensional Processor Using Transferred Thin-Film Circuits"

  (No. 5,656,548: filed 9/19/1995, granted 8/12/1997);
- raised $8.1 million from private sources during the ATP project;
- raised $26.6 million from a second public stock offering in March 1993;
- received (with Northeastern University) $2 million from the Office of Naval Research in June 1996 for R&D work, based directly on the ATP-funded MFM technology, to design and fabricate a 3D microprocessor;
- received (with Northeastern and Polaroid) $5 million from the Defense Advanced Research Projects Agency in June 1996 for R&D work — using the ATP-funded MFM technology — on 3D computational image sensors for compact low-power video cameras;
- raised $31.8 million via private equity investments since the end of the ATP project.

COMMERCIALIZATION STATUS:

Commercialization is expected within one or two years for products incorporating the 3D microprocessor technology. Large-area flat-panel displays based on the MFM technology are expected to be commercialized when their market develops.

OUTLOOK:

The outlook is very promising. Products based on the ATP-funded technology are being developed by Kopin and are expected to be introduced to the market soon.

COMPANIES:

Multi-Film Venture
(MFV; formerly The American Scaled-Electronics Consortium)

Kopin Corporation (joint venture lead)
695 Myles Standish Blvd.
Taunton, MA 02780

Contact: Ollie Woodard
Phone: (508) 870-5959

Number of employees:
70 at project start, 100 at the end of 1997

Other joint venture participant:
MCC, Inc. (formerly Microelectronics & Computer Technology Corporation.

of ICs that perform different functions. In one application, Kopin is collaborating with Northeastern University (using $2 million from the Office of Naval Research) to design, fabricate and demonstrate a three-dimensional (3D) microprocessor.

In a second application, Kopin is working with Northeastern and Polaroid in a five-year project, begun in June 1996, to develop a 3D computational image sensor for compact low-power video cameras. The sensor will be a stack of three chips: a sensor IC, a computation IC and a read-out IC. The chips will be connected using the ATP-funded MFM technology. This project is supported by $5 million from the Defense Advanced Research Projects Agency.

. . . potential applications in desktop computer displays and — with volume production and lower prices — in wall displays for the home.

Although products incorporating the ATP-funded technology are not yet on the market, they are likely to arrive soon.

Kopin Succeeds in Capital Markets

Although products incorporating the ATP-funded technology are not yet on the market, they are likely to arrive soon. Kopin has shown that it can carry out commercialization plans, as evidenced by its introduction of other products after more than a decade of work on the underlying technology. Also, Kopin's success at raising funds in the private-capital market reflects investor confidence in the company's ability to commercialize its technology. Kopin has raised an additional $31.8 million via private equity investments since the end of the ATP project.

When the new products — flat-panel displays and 3D microprocessors — are introduced, intermediate companies (which purchase components produced by Kopin), final-product manufacturers and consumers are expected to reap large benefits from the ATP-funded technology.

Nonvolatile Electronics, Inc. (NVE)

Computer RAM Chips That Hold Memory When Power Is Off

Conventional random access memory (RAM) computer chips record information written or copied into them by a computer, and they hold that data as long as electricity flows through the chips. Once the power is turned off, the information is lost unless it has been "saved" to a floppy disk or to the computer's hard disk, which hold data even when the power is off. Many computer users have learned this fact only after a power outage or other mishap suddenly erases the data they were working on. Program manuals and technical support staff repeatedly advise computer users to "save often."

The clean room at Nonvolatile Electronics in which GMR sensors and other devices are fabricated.

RAM That Remembers Without Power

If a memory chip could store data permanently, it would prevent these accidental loses of information. And if it could be produced in small sizes at competitive costs, the new chip would greatly affect how computers are configured and used. For example, an insertable card containing memory chips (which have no moving parts) could be substituted for a hard disk drive.

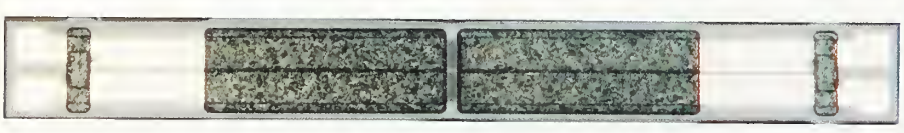
Civilian Use of MRAM Technology

This ATP project with Nonvolatile Electronics (NVE), founded in 1989 (and operated from the founder's house until the ATP award), aimed to develop such a memory chip. The founder co-invented "magnetoresistive" RAM (MRAM) technology for defense applications while at Honeywell, which subsequently licensed the technology to NVE for civilian uses. For these applications, the technology had to achieve greater density, signal strength and production yield to meet cost considerations, which are more important in consumer markets than in the military market.

A metal is magnetoresistive if it shows a slight change in electrical resistance when placed in a magnetic field. In 1988, scientists discovered that a sandwich of metals shows a much larger change in resistance than a single metal of the same size. This effect was named "giant magnetoresistance," or GMR.

GMR sensors have many applications . . .

Researchers at NVE saw the use of GMR materials as a way to achieve advances in signal strength, and they made important advances in the producibility of GMR materials. They also achieved the project's circuit density goals and made substantial improvements to production throughput, or yield. These developments are all important for lowering barriers to commercializing the technology for civilian applications. The researchers



Photomicrograph of a GMR magnetic field sensor, with actual dimensions of 436 x 3370 microns.

PROJECT:

To develop magnetoresistance technology for use in making computer random access memory (RAM) "nonvolatile" — data will not be lost when power is turned off.

Duration: 4/1/1991 — 3/31/1994
ATP Number: 90-01-0166

FUNDING (IN THOUSANDS):

ATP	$1,785	67%
Company	869	33%
Total	$2,654	

ACCOMPLISHMENTS:

In its quest to develop magnetoresistive RAM (MRAM), NVE made significant advances in producibility, circuit density and signal strength by using giant magnetoresistance (GMR) materials. In the process, the company developed an important spinoff application of the technology in sensors. Indicative of progress, NVE:

- started producing an initial commercial product, a GMR magnetic bridge sensor, in 1994, selling about 50,000 by the end of 1997 to other companies for examination purposes and earning revenues of more than $150,000 that year alone;
- entered into an agreement with Motorola in 1995 to develop MRAMs (development is still under way, with sales possible in 1999);
- entered into an agreement with Microtrace in 1996 to use a GMR-based procedure to make counterfeiting of aircraft parts much easier to detect (development work is under way);
- licensed the ATP-funded technology to Honeywell (for use in military and avionics applications), which incorporated it into computer systems placed in government agencies; and
- transferred knowledge about GMR materials to members of an ATP joint venture working on technology for magnetic disk storage based on the GMR effect.

COMMERCIALIZATION STATUS:

NVE is successfully making and selling — with a recent growth rate of about 3,000 percent — GMR-based sensing products, a spin-off from its MRAM technology development project. It is also pursuing commercialization of MRAMs through an agreement with Motorola, an endeavor that could lead to a substantial share of a $45 billion/year market.

OUTLOOK:

The outlook is excellent for expanded use of GMR sensors, which have many applications, including pace makers, engine control, shock absorbers, antilock brake systems, current monitoring, cylinder position sensing and automatic meter reading. The outlook for commercialization of the nonvolatile memory chips is potentially bright. But with several more years of development, the extent of use remains uncertain. Spillover benefits are potentially large.

COMPANY:

Nonvolatile Electronics, Inc. (NVE)
5805 Amy Drive
Edina, MN 55436

Contact: James M. Daughton
Phone: (612) 996-1607

Number of employees:
10 at project start, 56 at the end of 1997

made prototype high-quality MRAM cells that were successfully demonstrated at Honeywell.

A Promising Spinoff Application

As NVE focused on GMR materials advances, it saw a potential spin-off application that received only marginal attention when the company started its ATP project: GMR sensors. A major application for sensors based on the new technology is possibly in antilock brake systems in automobiles and trucks. These systems use a clamp to grip the edge of a steel disk attached to the wheel. If the clamp grabs too tightly, the brake "locks," the wheel stops rotating, and the tire slides on the road surface instead of gripping it. In an antilock brake system, a sensor detects the rotation of the disk and feeds that information into a computer. If the computer detects overly rapid deceleration — indicating the brake is about to lock — it directs the braking mechanism to reduce clamp pressure to keep that from happening.

The new NVE sensors are substantially more sensitive than conventional sensors. They can be farther from the monitored object while performing equally well. Their magnets can be smaller, so the cost is less. And the NVE sensors can detect rotational speeds closer to zero, which means the computer receives more-accurate data to use in controlling the brake mechanism. In a vehicle equipped with an antilock brake system incorporating NVE sensors, the driver will have better skid and stopping control.

In a vehicle equipped with an antilock brake system incorporating NVE sensors, the driver will have better skid and stopping control.

Product Sales and Commercialization Agreements

NVE expects to apply its sensor technology in several other industries, too, including medical devices, consumer products and machine tool manufacturing. Production for these markets is planned for the near future. According to NVE, it is the first to make and sell GMR-based sensing products for the general market, and it has established a new company division for this purpose. Its sales of GMR-based sensors have grown by about 3,000 percent recently, from around $5,000 in 1994 to more than $150,000 in 1997. The company has also generated revenues from engineering contracts, as well as royalties from companies that license its technology.

NVE entered into an agreement with Motorola in 1995 to develop MRAMs, and the development work is under way. Production could begin in 1999. If this effort succeeds, NVE expects to capture a sizable share of the $45 billion annual market for memory and hard-disk-drive products. The company also signed an agreement with Microtrace in 1996 to use a procedure based on GMR techniques to make counterfeiting of aircraft parts much easier to detect. The development work is under way, and products for this application are also expected in 1999.

For GMR applications beyond its own pursuits, NVE has offered its knowledge to other companies, universities and national

NVE entered into an agreement with Motorola in 1995 to develop MRAMs . . .

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laboratories. This was done through another ATP project (#91-01-0016: "Ultrahigh-Density Magnetic Recording Heads") conducted by a large joint venture led by the National Storage Industry Consortium. NVE officials consulted on fabrication methods for making GMR films and supplied samples of the films made by NVE.

Benefits From the Technology

Because NVE is selling only sensors, all benefits will initially come from that product. When the sensors actually begin appearing in commercial products — some time after the year 2000 — end users will have access to competitively priced devices that operate at much greater temperature extremes than do conventional sensors. Additional benefits will accrue from GMR sensors as more are used in a variety of applications.

GMR sensors will likely generate substantial economic benefits beyond those realized by NVE. A sensor is a small part of an antilock brake system, which is a small part of a much larger device — an automobile. Several manufacturing and subassembly stages lie between the development of the sensor and the final product, and the sensors add value to the product at each stage. According to NVE, the total of this spillover benefit will likely be more than 10 times greater than what the company earns for the use of its new technology. And the aggregate benefit will increase as more cars are equipped with antilock brake systems incorporating NVE sensors. Spillover benefits promise to be even larger when the sensors are used in other applications.

In addition to these applications, the company's GMR sensors are being used for portable traffic monitoring instruments, and they may be very useful for instruments used to detect land mines. Geometrics, Inc., in Denver, Colorado, has contracts to design and test devices to detect anti-personnel mines for the U. S. military, and it has subcontracted with NVE to supply GMR sensors for the detectors. If the design and testing lead to workable detection instruments, a much better job of finding and removing unwanted land mines will be the result. There are 100-200 million such land mines throughout the world in areas that were formerly areas of warfare, and they kill and maim tens of thousands of innocent people each year.

The market for MRAMs — the application initially targeted by NVE — may eventually be important, but it is still in the future. If MRAMs ultimately reduce accidental loss of information to computer users, benefits will be large.

ATP Project Saves Company

Before the ATP project, NVE was a tiny, undercapitalized company facing significant technological risks in developing the technology for commercial uses. Funding from the ATP, however, enabled the project to be done and prevented the company from failing, NVE officials say. In addition, the ATP award improved the company's ability to attract capital from other sources.

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Spire Corporation

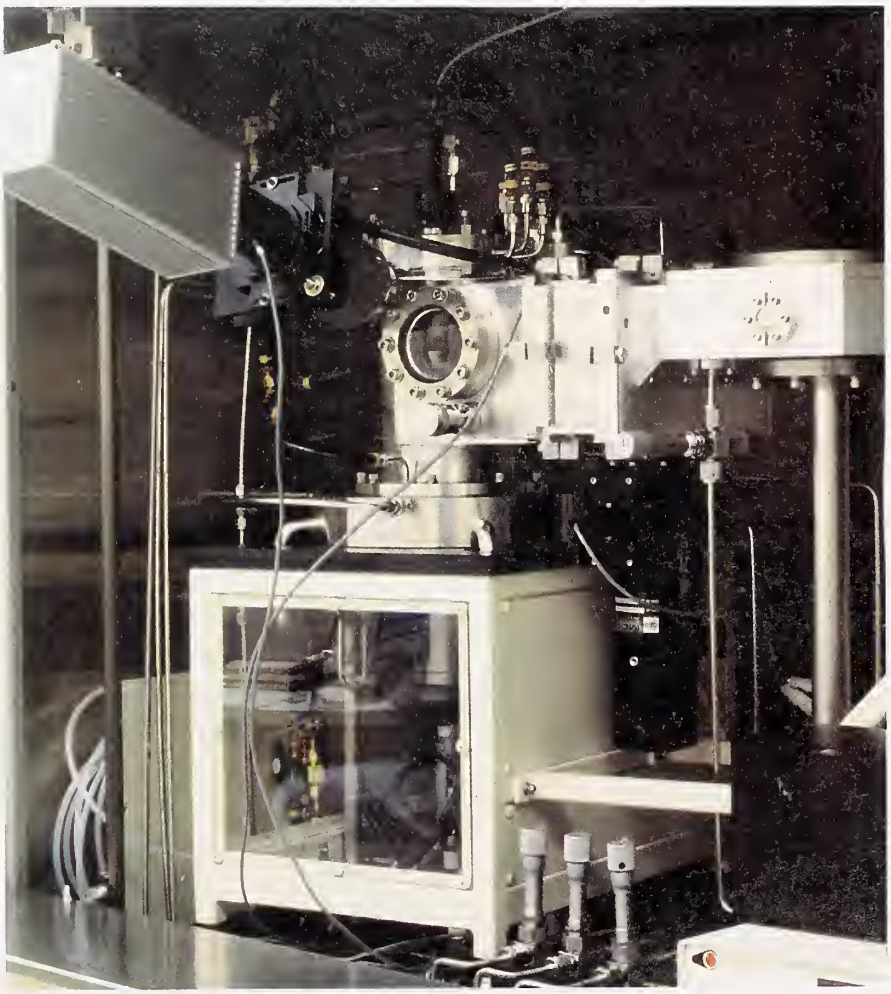
A Feedback-Controlled, Metallo-Organic Chemical Vapor Deposition Reactor

Laser diodes are the tiny workhorses in many industrial and consumer products. Every CD-ROM player has at least one, and many printers and photocopiers have a large array of them. More than 20 million laser diodes are needed each year for this market alone, and the number is growing.

Advanced Fabrication Control for Improved Electronic Devices

This ATP project with Spire Corporation developed a new way to make laser diodes and other optoelectronic devices. Founded in 1969, Spire is a specialty manufacturer of semiconductor wafers and metallo-organic chemical vapor deposition (MOCVD) equipment. The company's new method makes possible the manufacture of individual lasers and laser arrays at lower cost and with higher performance characteristics.

Spire built and demonstrated an advanced MOCVD reactor designed for the fabrication of laser diodes. Laser diodes are intricate multilayer structures generally grown by MOCVD on compound semiconductor wafers. Researchers developed in-process sensors to monitor the development of layers on the substrate, as well as control systems to automatically adjust the many process parameters. They demonstrated that the new technology can control the growth rate of the layers. They also showed that the new reactor performed better than conventional reactors in terms of epitaxial layer uniformity over the entire wafer, as well as run-to-run consistency. These two factors can contribute significantly to reducing the cost of making laser diodes.



The advanced metallo-organic chemical vapor deposition reactor constructed with funding from the ATP.

Potential for Commercial Products

The project did well technically, and limited commercialization is under way. Spire is pursuing its original plan to produce and sell reactors and license the technology to other manufacturers, and it is in discussions with several potential customers. The company also planned to produce low-cost laser diode arrays

. . . planned to produce low-cost laser diode arrays in competition with foreign producers, but that market did not develop.

A wafer populated with arrays of vertical cavity surface emitting lasers.

The company's new method makes possible the manufacture of individual lasers and laser arrays at lower cost and with higher performance characteristics.

in competition with foreign producers, but that market did not develop.

Spire has successfully used the prototype reactor to perform customer-specific research and development and to produce epitaxial laser wafers of a demanding structure. One customer has invested more that $250,000 with Spire to develop vertical cavity surface emitting laser (VCSEL) wafers and plans to invest another $450,000 in the effort in the near future. A VCSEL emits light in a cylindrical beam vertically from its surface and may offer significant advantages over edge-emitting lasers in some applications. This customer may also buy an MOCVD reactor from Spire in the next two years, following completion of the initial development project.

Spire is focusing on use of the new feedback-controlled reactor for growing laser wafers for VCSELs and edge-emitting lasers. VCSELs would be used in high-speed laser printers and in optical interconnects for computer links, and edge-emitting lasers would be used in solid-state laser pumps and in measurement and material processing applications. The company contracted with another large manufacturer in late 1997 to develop VCSEL arrays for advanced optical computer interconnects. Spire has already been paid $106,000 for the project and could potentially receive another $300,000. If the development work succeeds, Spire believes it will enable the company to enter the huge market for optical interconnect components.

ATP Project Opens Doors

If the ATP funds had not been available, Spire would not have done the project, company officials say. The ATP award enabled Spire to overcome technical barriers to volume production of VCSEL wafers, some of which contain more than 650 epitaxial layers. These complex structures had been previously grown only in a few laboratories and in small lots and sometimes virtually by hand. Spire's new capability, in turn, has attracted an entire new line of customers.

The potential for alliances with research and development partners is now high, and Spire is already working on advanced device development projects with several companies. The benefits to users of new devices made from these complex wafers can be significant. The ATP-funded reactor enables production of many kinds of wafers at lower costs. It also enables the production of some devices, made from VCSEL wafers, that could not be fabricated any other way. The benefits, however, can occur only if the company's limited commercialization expands into full-scale success, and it is still too early to tell whether that will happen.

PROJECT:

To develop an advanced feedback-controlled, high-throughput, metallo-organic chemical vapor deposition (MOCVD) reactor for fabricating low-cost, high-quality laser diode arrays.

Duration: 6/15/1992 — 3/31/1995
ATP number: 91-01-0263

FUNDING:

ATP	$1,223	56%
Company	973	44%
Total	$2,196	

ACCOMPLISHMENTS:

Spire achieved the project's research goal and afterward conducted additional, company-funded development to commercialize the technology. A prototype reactor is being used for commercial wafer production and customer-specific development work. Signs of the project's success include the fact that the company:

- published four papers and presented several others at professional conferences during the award period;
- demonstrated the ability to grow epitaxial wafers with high-quality uniformity of composition and thickness over an entire wafer 2.25 inches in diameter;
- demonstrated the ability to fabricate vertical cavity surface emitting lasers (VCSELs) with state-of-the-art performance characteristics;
- published a 1997 update on use of the ATP-funded reactor, "In Situ Monitoring and Control for MOCVD Growth of AlGaAs and InGaAs," in the *Journal of Electronic Materials*;
- received $356,000 from two large manufacturers for development of advanced VCSEL epitaxial wafers and wafer production processes, with an additional $450,000 to $750,000 expected in the near future; and
- expanded sales of commercial epitaxial wafers (mostly for lasers and light-emitting diodes), with sales revenue of about $200,000 in 1998.

COMMERCIALIZATION STATUS:

Limited commercialization has been under way since 1996. The ATP-funded technology has been incorporated into an MOCVD reactor being used for commercial production of optoelectronic epitaxial wafers. These include VCSEL epitaxial wafers that are being developed for high-speed laser printing. Spire is also using the reactor for two development projects funded by other companies.

OUTLOOK:

Spire expects to produce substantial numbers of VCSEL devices in the future. Because the market is growing rapidly, the company is positioned to exploit its superior in-house epitaxial wafer growth capability, based on the ATP-funded technology, to produce large quantities of whole epitaxial wafers, as well as wafers processed into optoelectronic devices ready for packaging.

COMPANY:

Spire Corporation
1 Patriots Park
Bedford, MA 01730-2396

Contact: Harvey B. Serreze or Kurt J. Linden
Phone: (781) 275-6000

Number of employees:
180 at project start, 150 at the end of 1997

Thomas Electronics, Inc.

Flat Fluorescent Lamps for Displays

Every cockpit in a large airplane contains small windows that are mainly used when the plane is on the ground. While flying, pilots "see" the world not by looking out the windows, but by looking at the text and images shown by instrument displays mounted on the walls of the cockpit. The quality of these images bears directly on the quality of the flying.

More-Visible Instrument Displays for Safer Flying

Today, almost every cockpit display uses cathode ray tube (CRT) technology. CRTs are a proven technology, have a long history and are fabricated by Thomas Electronics — which undertook this ATP project — for use in the manufacture of cockpit displays. CRT displays have a well-known drawback, however: the surface is glass, and the view one gets through it depends on the amount of light in the cockpit and the direction the light is coming from. In some circumstances, such as bright sunlight, visibility of displays may be seriously diminished.

Creating a Flat Fluorescent Lamp

Liquid-crystal displays (LCDs) — the flat-panel displays used in notebook computers — would be a good alternative to CRT displays. The drawback to LCDs, however, is that their light source is not nearly bright enough for use in airplane cockpits. This ATP project addressed that problem by developing the technology needed to make a flat, bright fluorescent lamp for backlighting an LCD. The new lamp would be about a quarter of an inch thick, have the same length and width as the LCD, and be attached to its back.

In conventional fluorescent lamps, a cathode discharges electrons that excite mercury vapor to emit ultraviolet light that, in turn, induces the phosphor coating on the interior of the lamp to glow white. Flat fluorescent lamps were not developed earlier because of the diffi-

In some circumstances, such as bright sunlight, visibility of displays may be seriously diminished.

Flat fluorescent lamps for flat panel display back-lighting, in a variety of sizes, ranging from 1.5 inches to 12.5 inches on the diagonal.

Flat fluorescent lamps were not developed earlier because of the difficulty in generating a bright plasma in the thin space between wide, flat sheets.

PROJECT:

To develop a high-efficiency electron source for fluorescent lighting to enable a new class of efficient, bright, flat lamps with wide applications in computer and instrument displays, high-definition TV displays and wide-area ultraviolet light sources for industrial use.

Duration: 2/1/1994 — 1/31/1997

ATP number: 93-01-0109

FUNDING (IN THOUSANDS):

ATP	$718	77%
Company	215	23%
Total	$933	

ACCOMPLISHMENTS:

Thomas developed the high-efficiency electron source needed to construct flat fluorescent lamps, which was the goal of the project. The company achieved the following:

- entered pilot production of flat lamps for key customers in the U.S. display industry;
- received orders for further evaluation and field testing of the new technology in cockpit applications from Optical Image Systems, AlliedSignal, Honeywell, Litton Industries, Kaiser Electronics and five other companies; and
- placed prototypes with three military contractors for rugged displays in tanks and other ground vehicles.

COMMERCIALIZATION STATUS:

Current sales of prototypes and pilot models of flat fluorescent lamps to avionics customers range from 30 to 50 units per month. If customer tests prove the technology works for them, regular commercial sales are expected to begin after the flat-panel displays have been certified by the Federal Aviation Administration for use in cockpits.

OUTLOOK:

Full commercialization is expected after refinements to the technology based on feedback from customers using prototype units. If the technology is commercialized, its users — aircraft manufacturers, airlines and their passengers — will benefit from brighter, more reliable and cheaper backlights for flat-panel displays in airplane cockpits.

COMPANY:

Thomas Electronics, Inc.
100 Riverview Drive
Wayne, NJ 07470

Contact: Douglas Ketchum
Phone: (973) 696-5200

Number of employees:
251 at project start, 324 at the end of 1997

Informal collaborator:
Princeton University

culty in generating a bright plasma in the thin space between wide, flat sheets. Conventional cathodes are too inefficient to create enough light for the color LCDs used in avionic displays. And although barium dispenser cathodes (BDCs) are efficient enough for the task, they were never used in the presence of mercury, which is believed to "poison" the barium and quickly reduce both the efficiency and life span of the device. Thomas solved the mercury problem with BDCs by using a new hollow-cathode design that enabled the company to construct a truly flat fluorescent lamp.

In addition, Thomas introduced new materials to flat fluorescent lighting. The front of the lamp is glass. But the back is hardier ceramic material and has all the light-producing components embedded in it. The ceramic back enables the lamp to withstand severe shock and vibration much better than if both sides were glass. In addition, the thermal properties of the ceramic material allow the lamp to operate at significantly higher temperatures than comparable lamps made solely of glass. As a result, these new lamps can be used for rugged flat-panel displays in applications such as military tanks.

Field Testing Underway

Follow-on research and development work is on track to meet the project's commercialization goal — the introduction into commercial and military airplane cockpits of flat-panel displays containing the new fluorescent lamp. To date, Thomas has invested more of its own money in the effort than it received from ATP, and the work is beginning to pay off. The com-

pany is completing a pilot production plant and has received orders for further evaluation and field testing of the new technology from Optical Image Systems, AlliedSignal, Honeywell, Litton Industries, Kaiser Electronics and five other companies. The field testing must yield positive results before the Federal Aviation Administration will certify the flat-panel displays for use in cockpits.

About 10,000 displays are installed in airplane cockpits each year. Compared with CRT devices, the new flat-panel displays will be more effective (they produce more light), more reliable (the ceramic material is hardier than glass) and less-costly (the ceramic material can be machined more easily than glass). Ultimately, their use is expected to benefit aircraft passengers, who will enjoy safer air travel because pilots have more-effective, more-reliable instrument displays. It is also expected to benefit flat-panel display manufacturers, aircraft manufacturers and airlines through cost reductions and quality improvements.

Potential uses for the flat-lamp technology include displays in military ground vehicles, such as tanks. Displays in these applications must withstand greater extremes in vibration, temperature and other operating conditions than ordinary displays. Three companies specializing in such displays have ordered flat-lamp prototypes from Thomas.

ATP Bolsters U.S. Technology

Without the ATP award, Thomas officials say, the company would not have done the research and development work for this project. The company would have struggled along with its conventional CRT technology and would have stood virtually no chance of competing with other display-component suppliers, all of which are foreign companies. In addition, the award helped Thomas establish connections with scientists at Princeton University and form alliances with contractors.

. . . these new lamps can be used for rugged flat-panel displays in applications such as military tanks.

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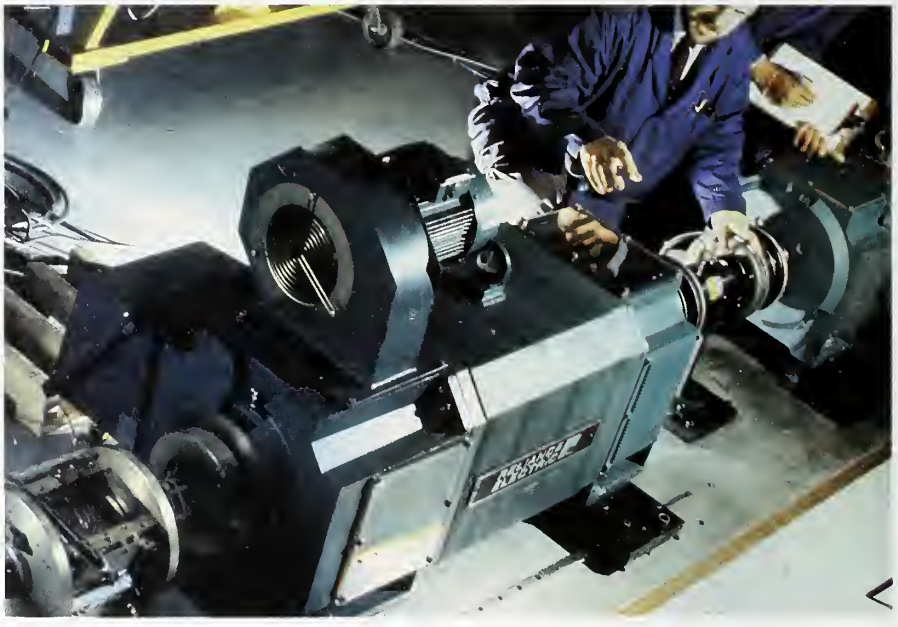
Chapter 6

Energy and Environment

American Superconductor Corporation (ASC)

High-Temperature Superconducting Coils for Electric Motor Efficiency

Large electric motors of 1,000 horsepower (hp) or more are used in many applications across the U.S. economy. If more-efficient motors could be developed and replace older ones, the savings would be substantial. The new motors would consume less electricity than older motors. In addition to cutting electricity bills, the switch to more-efficient motors would decrease the need for electricity production, with concomitant reductions in the burning of fossil fuels and in the resulting air pollution.



A 286 hp demonstration motor constructed by Reliance Electric with HTS windings supplied by ASC.

Harnessing Superconductivity to Increase Electric Motor Efficiency

American Superconductor Corporation (ASC), a young development-stage company, was eager to undertake the long-term research and development needed to capture the advantages offered by high-temperature superconductivity for large electric motors. But it lacked the necessary financial resources to do it. At the time of the ATP award in 1992, there was little competitive pressure in the electric power-generation industry, so few incentives existed to reduce costs. And, although the Department of Energy followed the ATP award with a contract to ASC, that source of funding was unavailable for the initial research the company proposed to do. ASC reports that the ATP award made the research project possible. Without the award, the company would have been unable to do the research and development on the new technology, even on a delayed-development schedule.

Superconductivity Reduces Energy Losses

The most significant energy losses in motors come from resistive heating in the windings, so superconducting motors with almost no electrical resistance in the windings could realize important efficiency gains. To be able to build such motors required significant advances in the design, fabrication and winding of HTS wires in geometries required for motor winding.

In addition to industrial motors, the new technology would be useful in generators, transmission cables and superconducting magnetic energy storage systems. It also has potential applications in x-ray lithography, ion implantation, medical cyclotrons, magnetically levitated trains, magneto-hydrodynamic ship propulsion systems, and magnetic separation for materials processing and ore recovery. Indeed, opportunities abound for reducing electric energy use via applications of the ATP-funded technology.

. . . opportunities abound for reducing electric energy use via applications of the ATP-funded technology.

PROJECT:

To develop high-temperature superconducting (HTS) wire fabrication and winding techniques that will enable the development of large HTS electric motors with almost no electrical resistance. This advance will reduce the motors' electricity consumption and save the country hundreds of millions of dollars in energy costs each year.

Duration: 7/1/1992 — 6/30/1995
ATP number: 91-01-0146

FUNDING (IN THOUSANDS):

ATP	$1,883	42%
Company	2,579	58%
Total	$4,462	

ACCOMPLISHMENTS:

ASC achieved its goal of developing HTS wire fabrication and winding techniques. It demonstrated the use of racetrack-shaped HTS coils in a 5-hp motor early in the project and in a 200-hp motor soon after project completion. The company also:

- received six patents for technologies related to the ATP project:
  - "Current Limiters in Power Utility Applications"
  - (No. 5,390,064: filed 7/7/1992, granted 2/14/1995),
  - "Superconducting Rotor"
  - (No. 5,482,919: filed 9/15/1993, granted 1/9/1996),
  - "Method of Making Superconducting Wind-and-React Coils"
  - (No. 5,531,015: filed 1/28/1994, granted 7/2/1996),
  - "Superconducting Magnetic Coil"
  - (No. 5,525,583: filed 2/7/1994, granted 6/11/1996),
  - "Magnetostrictive Superconducting Actuator"
  - (No. 5,585,772: filed 1/11/1995, granted 12/17/1996), and
  - "Variable Profile Superconducting Magnetic Coil"
  - (No. 5,581,220: filed 10/10/1995, granted 12/3/1996);
- applied for eight additional patents for technologies related to the ATP project;
- won *Industry Week* magazine's Technology of the Year Award in 1996;
- won the 100 Award in 1996 from *R&D* magazine, which selects the 100 most important innovations of the year, for its development of CryoSaver current leads, a spin-off product related to the ATP project;
- received (with partner Reliance Electric) $10.2 million in Department of Energy Strategic Partnership Initiative awards in 1996 for cost-shared development of high-horsepower, commercial-scale motors;
- received a $10-million investment from Électricité de France, the French power company, in April 1997; and
- raised $27 million via a second public stock offering in February 1994.

COMMERCIALIZATION STATUS:

Commercialization is in progress. A partnership with Reliance Electric will help commercialize the large-motor technology in the form of 1,000- and 5,000-hp motors. In the meantime, ASC has introduced a related product, CryoSaver current leads, in 1996. Users of this product have already achieved better operating efficiencies in magnetic resonance imaging and commercial energy storage systems.

OUTLOOK:

The project has progressed as planned, and the outlook for achieving significant energy savings from HTS motors is excellent. Large electric motors account for about 65 percent of all electricity consumption in the United States, so even small efficiency gains in this application are likely to translate into cost savings of several hundreds of millions of dollars for the nation. In the future, large users of electric power will be able to construct new facilities with smaller, more-efficient and reliable motors based on HTS technology. Other applications of the technology could help residential electricity users in the United States save millions of dollars in energy costs each year.

COMPANY:

American Superconductor Corporation (ASC)
2 Technology Drive
Westborough, MA 01581

Contact: Joe Sollecito
Phone: (508) 836-4200

Number of employees:
59 at project start, 146 at the end of 1997

Informal collaborators:
Reliance Electric Company (acquired by Rockwell International in 1995), Oak Ridge National Laboratory

. . . received six patents for technologies related to the ATP project . . .

Larger and Larger Motors

Researchers from ASC and its partner, Reliance Electric Company (now part of Rockwell International), built a 5-hp HTS motor as proof of concept. This team and researchers at Oak Ridge National Laboratory then fabricated and tested a series of racetrack-shaped HTS coils of a type needed for motors. This effort included studies of mechanical and electrical properties that affect performance, as well as the development of fabrication techniques for producing flexible, durable wires in increasing lengths. Soon after the project ended in June 1995, ASC built a 200-hp HTS motor for testing and demonstration. The company is planning to complete development work on a laboratory model 1,000-hp HTS motor in late 1998 or early 1999 and then begin development of a 5,000-hp motor. Each increment in motor size represents substantial advances in the underlying technology.

This advance will reduce the motors' electricity consumption and save the country hundreds of millions of dollars in energy costs each year.

A Long-Term Endeavor on Track

ASC has viewed this endeavor from the outset as requiring a long-term commitment and substantial infusions of capital along the way to reach full commercial deployment of the HTS technology in huge electric motors. The effort is on track. In the meantime, ASC has launched its first commercial product related to the ATP-funded technology, the CryoSaver current leads, which carry power into HTS devices from external electricity supplies. Although this is not the ultimate commercial-

Placing 1000 horsepower HTS motor coils into a cryogenic cooling system.

. . . electricity users are likely to benefit from lower electricity costs enabled by electricity producers' use of the new HTS motors.

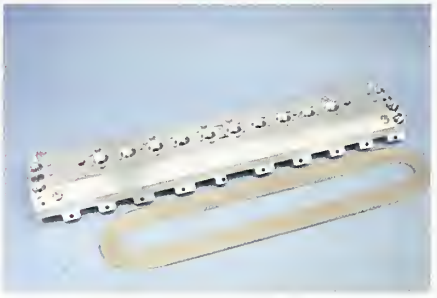
. . . won *Industry Week* magazine's Technology of the Year Award in 1996 . . .

ization goal envisioned for the technology, CryoSaver current leads provide revenue and help maintain investor interest in the company.

The CryoSaver product has received technical recognition as well as early commercial success. In 1996, it won *Industry Week* magazine's Technology of the Year award and the 100 Award from *R&D* magazine, which selects the 100 most important innovations of the year.

An HTS motor of at least 1,000 hp is needed to achieve efficiencies and cost savings in line with the project goals. ASC is deliberately waiting until it proves the concept at the 5,000-hp level before moving the HTS motor into commercialization. The company expects to demonstrate a commercial-scale 1,000-hp motor in 1999.

Following the ATP award, ASC received funding from the Department of Energy as part of a $21 million motor program with Reliance Electric and several other companies to complete the development work. In addition, it raised $27 million via a second public stock offering and attracted another $10 million in private investment from the electric utility industry. It is actively protecting its intellectual property position through patent filings.



Pole set and double pancacke HTS coils for 1000 horsepower Reliance Electric motor.

Potential for Huge Benefits

Users of ASC's CryoSaver current leads have achieved better operating efficiencies by improving the transmission of electricity for cryogenic devices. In the future, users of large electric motors (electric utilities, steel mills, water pumping stations) will be able to have motors that are smaller, more reliable and more efficient than today's motors.

This may be particularly important when competition is introduced into the electric power industry, which ASC has selected as its first commercial target. Companies in that industry have generally operated as regulated monopolies. With competition in the production of electricity, cost savings will be far more important in the electric power generation marketplace. Some of those cost savings are likely to be achieved by electric power generation companies switching from conventional large electric motors to HTS motors from ASC.

Lower costs for power generation companies, together with pricing pressure as several companies compete for the right to supply commercial and residential customers, is likely to result in cost savings at the power generation level being passed on, at least partially, to customers. The end result of this chain of events, which is still in the future, is that electricity users are likely to benefit from lower electricity costs enabled by electricity producers' use of the new HTS motors.

The possibility exists for a large return to the economy as a whole from the implementation of this new technology, since even small gains in motor efficiency translate into large energy savings to the companies and to the nation.

The company expects to demonstrate a commercial-scale 1,000-hp motor in 1999.

Armstrong World Industries, Inc.

New Materials for New-Generation Thermal Insulation

Armstrong researchers planned to investigate the microstructure of insulation material and the air cells, or pores, within it. The project aimed to learn how to control the molecular morphology — structure — of the solid material (to reduce its thermal conductivity), the geometry and orientation of air cells (to optimize pore morphology), and the size and distribution of air cells (to reduce the thermal conductivity of air within a cell).

Developing Super Insulating Materials

Though they were not able to fully achieve their goals, the researchers made important progress in the development of super insulating materials as a result of their study of materials with high porosity and of nonspherical pores that are nanometer in size. The technical work followed two major tracks: the fabrication of polyethylene and polystyrene foams with carbon dioxide blowing while attempting explicitly to control the formation of the air pores, and the development of new process technology for the synthesis of aerogels for use in insulation products.

The blowing of polyethylene and polystyrene foams with carbon dioxide entailed substantial challenges in attempting to optimize the mechanics to achieve the foam without a pressure drop leading to collapse of air cells. The researchers ran into problems working with polyethylene and, in addition, concluded that modification to extruder equipment would be necessary to achieve success with carbon dioxide as the blowing agent. Both changes raised production costs. Armstrong subsequently shifted away from polyethylene to other thermoplastics and began blowing with butane, in addition to carbon dioxide, but costs could not be lowered enough to justify commercialization. No patents or papers resulted from this track of the ATP-sponsored research.

Researchers achieved more technical success in their work on process technology for the synthesis of aerogels.

Researchers achieved more technical success in their work on process technology for the synthesis of aerogels. The aerogels and xerogels produced by the process have both a high porosity and small pores; that is, the resulting material is microporous, with about 25 percent of the pore volume in pores less than 50 nanometers in diameter. The process also promises to substantially lower the costs of aerogel production. Armstrong received three patents for its technical advances in aerogel synthesis.

Company Shifts

At the time the project was awarded, Armstrong saw the ATP project as providing an opportunity to broaden the company's capabilities along lines that it otherwise would not have pursued. By developing new forms of insulation with superior performance, Armstrong saw the opportunity to broaden its focus from the technical insulation market (insulation for heating, refrigeration, plumbing and specialty applications) to the structural insulation market (insulation for buildings and other large structures). Armstrong officials expected their first aerogel application to be for rigid technical insulation, with eventual opportunities in structural applications.

Later company reorganizations and strategy shifts changed the company's plans for applying its new technical know-how. Armstrong officials concluded that — despite the remarkable insulating properties of the aerogels and the new process technology, which dramatically reduced production costs — the unit costs were still too high to penetrate the structural insulation market. The company's initial excitement over the potential of aerogels for the structural market dimmed. Armstrong scaled back its estimated demand for aerogels and decided to procure what it needed through suppliers rather than produce them in-house.

The company has decided to license the three aerogel process patents to potential suppliers, and not to be in the aerogel manufacturing business itself. To the extent that suppliers who obtain the licenses can use technology to produce aerogels more cheaply, Armstrong will benefit from its research in terms of a lower-cost supply. Other buyers may also benefit from lower-cost aerogels, depending on the specific licensing arrangements negotiated by the suppliers with Armstrong.

The company's initial excitement over the potential of aerogels for the structural market dimmed.

PROJECT:

To develop process technology for a new-generation insulation material based on controlled morphology (structure) in order to achieve superior insulating properties and associated energy savings.

Duration: 8/1/1992 — 7/31/1995
ATP Number: 91-01-0025

FUNDING (IN THOUSANDS):

ATP	$1,868	41%
Company	$2,650	59%
Total	$4,518	

ACCOMPLISHMENTS:

Armstrong researchers performed research in two major areas: process technology for aerogels and carbon dioxide blowing of polyethylene foams. The company received three patents for technologies related to the ATP project:

"Preparation of High Porosity Xerogels by Chemical Surface Modification"

(No. 5,565,142: filed 4/28/1993, granted 10/15/1996);

"Thermally Insulative, Microporous Xerogels and Aerogels"

(No. 5,525,643: filed 7/28/1995, granted 6/11/1996); and

"Wet Silica Gels for Aerogel and Xerogel Insulation and Processes for the Wet Gels"

(No. 5,762,829: filed 3/5/1997, granted 6/9/1998).

COMMERCIALIZATION STATUS:

Armstrong has decided to license its low-cost aerogel synthesis patents to suppliers, rather than to manufacture aerogels directly, but the licensing has not yet occurred.

OUTLOOK

Despite extremely good insulating properties of the aerogels and lowered processing costs, early applications of the aerogel are expected to be limited to niche markets, such as rigid technical insulation for heating, refrigeration and plumbing, or to speciality applications such as superconductivity insulation. Even with lowered costs, the aerogels do not at this time appear to be cost-competitive with conventional insulation materials for structural applications. Armstrong is continuing its research on the use of carbon dioxide foaming of thermoplastics, and this approach may hold promise for the future.

COMPANY:

Armstrong World Industries, Inc.
Innovation Center
2500 Columbia Ave.
Lancaster, PA 17603

Contact: Stephen C. Davis
Phone: (717) 396-5643

Thus far, no licensing agreements have been achieved. But, according to company officials, Armstrong stands ready to negotiate licensing agreements for its aeorogel process technology.

In fall 1996 Armstrong combined, with another unit, the research unit where the ATP project was carried out, a consolidation that also entailed personnel changes. The principal investigator on the ATP project left Armstrong and set up a separate business that is reportedly working in areas related to the ATP project. This movement of people who worked on the research project and the establishment of a new business pursuing related technological goals may provide yet another possible path of technology diffusion.

The company has decided to license the three aerogel process patents to potential suppliers, and not to be in the aerogel manufacturing business itself.

Over time, Armstrong's primary interest has shifted away from the aerogel technology and toward the foam blowing technology, as indicated by the company's continued involvement in this area. Here, too, Armstrong's research effort shifted away from the initial ATP project focus towards techniques and materials that now are seen to offer more promise of achieving the high-performance foam insulating products that were the ultimate goal of the ATP-funded research.

E.I. du Pont de Nemours & Company

Thallium/Lead Thin Films for Advanced Superconducting Electronic Devices

Superconductivity holds great promise for reducing energy consumption in practically any process that uses or transports electricity. Radar components, power transmission lines, communications satellites, and a host of electronic and electrical devices, for example, are good candidates for superconductor applications.

New Technology for Making Superconducting Components

At the time of its proposal to the ATP, DuPont had carried out a three-year research program to develop high-temperature superconducting (HTS) materials and was debating whether to disband the effort because of its high technical uncertainty. The properties of HTS materials were still not well understood, fabrication processes had not been developed, and the technical and commercial viability of the materials had not been proven. DuPont said later that continuation of its HTS research hinged on receiving an ATP award, which the company considered an indicator of the promising nature of the work.

With its ATP award, DuPont developed thin-film HTS fabrication technology. It is generic enough to use with a variety of HTS materials that have form, structure and performance properties similar to those of thallium/lead. The technology is particularly useful when using thallium/barium or thallium/lead in the fabrication of HTS electronics components. The company developed two thin-film fabrication processes — a two-step approach using sputtering and post-annealing and a single-step approach with simultaneous sputtering and annealing. Photolithographic and ion-milling techniques are used to form circuits and other electronic features in the films. The viability of the two processes was demonstrated by constructing and testing several basic electronic components, including oscillators, filters, mixers and coplanar-designed transmission lines.

. . . continuation of its HTS research hinged on receiving an ATP award . . .

. . . HTS component technology recognized as one of the "Top Products of 1993" by *Microwaves & RF* magazine . . .

Many New and Potential HTS Products

DuPont has developed six electronic-component products: thin films of two or three inches in diameter made on HTS substrates of erbium/barium, thallium/barium or thallium/lead. All six of these products use the new HTS thin-film fabrication technology developed in the ATP-funded project. In addition, the company usually fabricates electronic components on the thin-film wafers, cuts the wafers into discrete components and encases them in metal casings, all according to customer specifications.

The company has begun substantial marketing efforts and is successfully selling products. Most of these are made with erbium/barium and thallium/barium rather than thallium/lead. Applications requiring the higher operating-temperature capabilities of thallium/lead HTS components have not yet developed significantly, due in part to improved cryogenics technology that has increased the number of application areas where the two other HTS materials are useful.

DuPont has maintained its long-term vision and continues to develop HTS electronics components based on erbium/barium, thallium/barium and thallium/lead. The payoffs may be coming soon, especially in magnetic resonance imaging (MRI) equipment and possibly in terrestrial and satellite communications. HTS materials also have potential use in nuclear magnetic resonance instruments, superconducting quantum interference devices and a variety of microwave applications.

For superconductor technology to realize its full potential, however, more advances have to be made in the technology. DuPont continues to fund its HTS research program at significant levels.

. . . this technology . . . could make magnetic resonance imaging and terrestrial and satellite communications less expensive and more efficient to operate . . .

. . . published more than 20 research papers on the technology in professional journals . . .

. . . a small equipment supplier, the Kurt J. Lesker Company . . . improved fabrication equipment . . .

PROJECT:

To develop thin-film fabrication processes needed to produce high-temperature superconducting (HTS) electronics components at reasonable cost.

Duration: 4/1/1991 — 3/31/1994

ATP number: 90-01-0064

FUNDING (IN THOUSANDS):

ATP	$1,590	67%
Company	784	33%
Total	$2,374	

ACCOMPLISHMENTS:

DuPont accomplished the R&D goal and has demonstrated several component products that directly use the new technology. It has also marketed products based in part on procedures developed by the project, but using thallium/barium as a key ingredient instead of thallium/lead. Indicators of successful development of the technology are that the company:

- published more than 20 research papers on the technology in professional journals;
- had its HTS component technology recognized as one of the "Top Products of 1993" by *Microwaves & RF* magazine in December 1993;
- introduced HTS thin-film products that, when built into larger systems such as magnetic resonance imaging machines and communications satellites, can lead to higher performance at lower overall cost; and
- worked with a small equipment-supplier company to develop improved HTS thin-film fabrication equipment.

COMMERCIALIZATION STATUS:

The market for new products based on the fabrication technology developed in the project is well established, even though applications that use thallium/lead as the HTS material have been slow to develop. Several products made with the new HTS technology are being marketed. The company has invested large sums to scale up for production in anticipation of increased demand in the near future.

OUTLOOK:

Use of the new process technology can substantially reduce the cost and improve the quality of superconductors in many applications. Applications based on this technology could, for example, make magnetic resonance imaging and terrestrial and satellite communications less expensive and more efficient to operate, generating widespread benefits valued at tens of millions of dollars.

COMPANY:

E.I. du Pont de Nemours & Company
P.O. Box 80304
Wilmington, DE 19880-0304

Contact: Dennis J. Kountz
Phone: (302) 695-4256

Less-Costly, More-Efficient Electronic Equipment

HTS processes developed in the ATP project could make superconductivity-based equipment less costly and more efficient to operate. HTS-based signal coils, for example, permit the use of a low-cost permanent magnet for MRI, an arrangement that could reduce the installation cost of this MRI machine to as little as one-tenth that of a standard MRI device. In addition, the use of HTS electronics enables equivalent or better MRI performance at much lower cost. IGC, an MRI manufacturer that uses DuPont HTS electronics in its products, reports that operating costs for its MRI machines are expected to be about one-sixth those for currently available competitor machines that use low-temperature superconducting technology. Thus, the new technology helps reduce MRI capital and operating costs while improving diagnostic effectiveness.

The benefits of the new HTS technology are likely to be substantial and widespread. In MRI and satellite communications, for example, the chain of events leading from the manufacturer of the components to the end users has many steps. At each step, some benefits from the technology are likely to accrue to intermediate customers and end-users, who pay for only a small part of the value they receive from the technological advance. Given the large number of end users for MRI and satellite services, the aggregate value of those spillover benefits is likely to be in the tens of millions of dollars.

During this project, DuPont worked with a small equipment supplier, the Kurt J. Lesker Company, to develop improved fabrication equipment for depositing HTS material on a wafer. Lesker is now making these improved machines available to other companies, as well as to DuPont.

Michigan Molecular Institute (MMI)

Recycling Mixed Plastics

Like turning swords into plowshares, the idea of turning waste plastics into fenceposts, park benches, building blocks and other useful, long-lasting items holds tremendous promise for the welfare of society. Wood rots, iron rusts and stones weather, but plastic endures. You can tear, bend or break plastic. But words like "rot" or "rust" simply do not apply — a blessing when durability is at issue; a curse when plastics are dumped into landfills.

Wood rots, iron rusts and stones weather, but plastic endures.

Technology to Recycle Much More Waste Plastic

The U.S. economy produces about 75 million pounds of plastic products each year, and the idea of recycling them is appealing. A problem with reusing plastics, though, is that the many kinds do not mix well in recycling processes. Recycling today requires sorting of plastics, many of which still get dumped because they are not compatible with the others. This ATP project with Michigan Molecular Institute (MMI) aimed to develop a technology that would dramatically increase the proportion of plastics that can be recycled. The new technology would "compatibilize," or alter, various plastics so they mix well in recycling. They could then be formed into pellets with essentially the characteristics of virgin plastics. These pellets would be mixed into a slurry fed into a continuous flow process that puts out a mixed plastic strong enough for construction materials.

. . . a curse when plastics are dumped into landfills.

A key technical goal of the project was to develop the science and technology of polymer compatibilization, which would enable polymers in the commingled plastic-waste stream to be recycled into commercially useful products. Collaborating researchers from Eastman Kodak, Eastman Chemical and the University of Florida (UF) accomplished that goal by establishing the fundamentals of compatibilization of multiphase polymer blends, including new knowledge about the "morphology" — the shape and structure — of polymer blends. The team also prepared compatibilizers using a variety of chemical approaches and produced and tested prototype compatibilized materials. Researchers found effective methods to compatibilize commingled-plastic waste.

New Recycled-Plastic Products

Results of the ATP project are being used by Eagle Plastics Systems of Florida to produce compatibilized plastic panels for housing parts, in collaboration with UF researchers who were involved in the ATP project. Large 4-inch-thick panels are fabricated by sandwiching fiberglass insulation between thin plastic sheets attached to galvanized steel studs. These wall units are then used for the construction of low-cost modular houses, many of which are used following a fire or other disaster, when temporary housing must be built quickly. The company plans to construct full-scale compatibilized plastic-panel manufacturing plants in the near future.

Eagle constructed an assembly plant in Kentucky and began manufacturing modular houses there in late 1996. It uses recycled plastics brought from a pilot plant to the site by railroad cars that left the state loaded with coal. Because of the extremely low cost of the recycled plastics, the company can manufacture its houses for about $6 per square foot, much lower than the cost of conventional housing, which runs as high as $50 per square foot. During its first year producing the modular houses, Eagle generated more than $100 million in contracts.

Results of the ATP project are being used by Eagle Plastics Systems of Florida to produce compatibilized plastic panels for housing parts . . .

In addition, attempts to commercialize the technology are under way via the development of two new MMI research and development projects in the auto industry that focus on recycling plastics from auto parts such as dashboards and door panels. Both projects rely on the knowledge of polymer blend morphology discovered in the ATP project. If these projects generate applications in the auto industry, the ATP technology will be commercialized via that route, as well.

Commercialization efforts did not proceed as quickly as anticipated when the proposal was submitted. One obstacle to the speed of commercialization was a change in ownership and direction of Waste Alternatives, one of the initial collaborators on the project and the company that was planned to play a key role in commercializing the technology.

ATP Funding Critical for Recycling Research

Without the ATP award, MMI officials say, the project would not have been undertaken. The funding helped MMI forge relations with research partners at the University of Florida, Eagle, Eastman Kodak and Eastman Chemical. Research on post-consumer plastics packaging recycling, based on the ATP-funded technology and substantial funding from Eagle, is continuing at the university. In addition, researchers there have extended the ATP technology to develop new virgin plastics alloys that are expected to lead to further commercialization. A 30-acre plastics recycling industrial park is being constructed on land owned by the UF Foundation, and continuing support for research amounting to about $100 million over the next 15 years is anticipated.

In addition, the use of knowledge developed by the ATP project may have advanced the two succeeding studies at MMI for recycled plastics parts in the auto industry by as much as two years. The scientific information generated by the ATP project has also been made generally available, via published technical papers, to the plastics and recycling industries.

PROJECT:

To develop methods for polymer compatibilization — adding small amounts of a substance to a blend of different plastics to make them chemically compatible so that the material fabricated from them has good mechanical and physical properties. This technology would greatly increase the amount of waste plastic that can be recycled.

Duration : 8/15/1992 — 8/14/1995
ATP number: 91-01-0088

FUNDING (IN THOUSANDS):

ATP	$1,642	30%
Company	3,808	70%
Total	$5,450	

ACCOMPLISHMENTS:

MMI researchers and their collaborators established the fundamentals of polymer compatibilization, which enables polymers in a waste stream of different kinds of plastics to be recycled into commercially useful products. Indicators of this accomplishment are that MMI and its collaborators:

- published more than 10 papers on the technology in professional journals;
- made the technology available to Eagle Plastics Systems to develop and test materials for the housing construction industry; and
- made the technology available through MMI to two on-going R&D projects in the automobile industry that focus on recycling plastics from auto parts such as dashboards, door panels and tail lights.

COMMERCIALIZATION STATUS:

One collaborating company has begun to use the technology in the construction of low-cost modular houses. Information on the technology generated by the project is now available to the plastics and recycling industries via published technical papers, and some of it is being used in additional research projects.

OUTLOOK:

Commercialization is underway and is expected to increase substantially in the construction of modular housing. The technical base developed in this project is also being used in two new projects that focus on recycling plastic auto parts.

ORGANIZATION:

Michigan Molecular Institute (MMI)
1910 W. St. Andrews Road
Midland, MI 48640-2696

Contact: Conrad F. Balazs
Phone: (517) 832-3882 ext. 590

Informal collaborators:
University of Florida; Eagle Plastics Systems; Eastman Kodak Company; Eastman Chemical Company; Inter Recycling, Inc.

One obstacle to the speed of commercialization was a change in ownership . . .

Chapter 7

Information, Computers and Communications

Communication Intelligence Corporation (CIC)

Computer Recognition of Natural Handwriting

Since the beginning of the computer age during World War II, virtually all data have been entered into computers via the keyboard. Teletype machines were adapted so that typing created a punched paper tape, which was read by a second device attached to the computer. Later, the key-punch machine was developed; it created holes in cards that were read by a card reader connected to the computer. In time, keyboards were used to enter data directly into computers, first via terminals connected to main-frame computers, and then for desktop computers as well.

A computer user entering information into her PC with a pad and stylus. Company software in the PC converts the data from the pad into letters and words.

Handwriting: An Easier Way to Enter Computer Data

Each development advanced the science of data entry, but keyboards have continued to be problematic. Some people cannot use them because of physical limitations, such as arthritis or carpal tunnel syndrome, or because they do not know how to type. Others find them difficult to use in particular settings and circumstances, such as conducting inventory on the shop floor or a geology survey in the wilderness, where using a keyboard is cumbersome. Difficulty in using keyboards and their inappropriateness in certain situations were seen as two of the obstacles limiting computer use to only about 5 percent of the U.S. population when this project was proposed in ATP's first competition in 1990.

Software That Recognizes Cursive Writing

Communication Intelligence Corporation (CIC), a small California company spun off from SRI International (formerly Stanford Research Institute), has addressed these keyboard problems by using technology created in its ATP project for a reliable, cost-effective alternative: a stylus and pad that can be used by the computer to "read" handwriting. The hardware was simple to implement, since touch-sensitive pads already existed. The difficult part was perfecting techniques for software that would effectively recognize fully cursive handwriting.

CIC researchers accomplished this technical goal during the project by collecting a database with thousands of cursive handwriting samples and developing new recognition algorithms. After analyzing the handwriting-sample database and developing the recognition methods, they also developed procedures that permit fast computation with modest computer memory requirements.

. . . received, in early 1997, the "Ease-of-Use Seal of Commendation" from the Commendation Program of the Arthritis Foundation . . .

PROJECT:

To develop a natural handwriting data-entry system for computers for applications where pen-based entry works best and for use by people who do not or cannot use a keyboard.

Duration : 4/1/1991 — 9/30/1993
ATP number: 90-01-0210

FUNDING (IN THOUSANDS):

ATP	$1,264	58%
Company	912	42%
Total	$2,176	

ACCOMPLISHMENTS:

CIC developed new data-entry software technology that recognizes each user's natural handwriting without "training" the computer or the user. The company:

- incorporated some of the ATP-funded technology into an existing software product, Handwriter®, giving it the ability to recognize connected letters in cursive writing in limited circumstances (previously, it recognized only handprinting);
- licensed the Handwriter® software to more than a dozen computer manufacturers around the world, generating $360,000 in revenue from sales of 30,000 units in 1997;
- launched a new product in 1996 called Handwriter® Mx™, a stylus-and-tablet data-entry device using the upgraded Handwriter® software;
- sold 11,000 copies of Handwriter® Mx™ in 1997, with sales totaling more than $2.2 million; and
- received, in early 1997, the "Ease-of-Use Seal of Commendation" from the Commendation Program of the Arthritis Foundation, for the company's Handwriter products — indicating their value to disabled people who have trouble with keyboard entry.

COMMERCIALIZATION STATUS:

The ATP-funded software technology is widely licensed, and a new product fully incorporating the software is due on the market soon. Both are generating revenue.

OUTLOOK:

The outlook for this technology is strong, since it opens up possibilities for much wider use of computers and expanded market opportunities for U.S. producers of hardware and software. The potential is likely to increase further as languages other than English are incorporated into the approach. The company is actively seeking additional market opportunities for further distribution of its products.

COMPANY:

Communication Intelligence Corporation (CIC)
275 Shoreline Drive, Sixth Floor
Redwood Shores, CA 94065

Contact: Russ Davis
Phone: (650) 802-7757

Number of employees:
33 at project start, 93 at the end of 1997

New and Upgraded Products

Prior to its ATP project, CIC was marketing a software product called Handwriter®, which could recognize handwritten printing but not cursive writing. The company has now incorporated some components of the ATP-funded technology into Handwriter®. Even though the technology for recognizing fully cursive handwriting has been developed, the upgraded software currently available commercially cannot yet read fully cursive handwriting. It is able to recognize connected letters in cursive writing in limited circumstances, however. CIC has licensed Handwriter® to most of the PC manufacturers in the world, and the upgraded Handwriter® software is now incorporated in a number of pen-based, hand-held computer devices on the market.

. . . this technology . . . opens up possibilities for much wider use of computers and expanded market opportunities for U.S. producers of hardware and software.

The company also developed two new consumer products based on the ATP-funded technology. One product is Handwriter® Mx™, which includes a stylus and pad, as well as the upgraded Handwriter® software. In late 1996, CIC began marketing Handwriter® Mx™ in a large computer chain, with a retail price of about $200. The other product, Handwriter® fx™, also contains the upgraded software but has a larger writing pad and other features useful to graphics artists. In early 1997, CIC began marketing it in the same computer chain. During that year, the company sold more than 11,000 units of these two products, generating revenues in excess of $2.2 million.

Company officials say the Handwriter® software will be upgraded again in the near future to fully recognize cursive handwriting. One barrier to complete implementation of the ATP-funded technology has been the need for tuning the software system to operate with the standard amount of memory available in modern desktop computers and to run fast enough to keep up with a typical person's handwriting speed. That obstacle is now being addressed.

Broadening Access to Computers

CIC's handwriting-recognition system should prove extremely beneficial. Computer users are now able to enter data via the digitizer tablet, as well as by keyboard or other means. This advance makes computers more useful for more people, especially those whose keyboard use is limited by physical problems or other circumstances. Other computer users may find a note-taking stylus a useful adjunct to the keyboard. For some jobs, particularly those that involve field work, the pen-based computer is the only reasonable solution, and the benefits of having it may be quite high for the user.

As more languages besides English are added to the software, users who write in these languages will benefit from using a handwriting input device that readily accepts all manner of handwriting styles. Markets for hardware and software should expand in response to wider use of computers and related products.

. . . thousands of cursive handwriting samples . . . new recognition algorithims . . . fast computations . . .

CIC projected at the start of the project in 1991 that the overall research, development and marketing effort needed to get to market would take four to five years.

ATP Partnership Speeds Technology Development

ATP's participation in this project advanced development of the technology by 18 to 24 months and improved the company's credibility with commercial partners. This credibility was important in establishing the licensing and manufacturing relationships needed for rapid commercial deployment of the technology.

The history of this ATP project offers a good example of the amount of time needed by a well-run program to both develop and commercialize a new technology. CIC estimated at the start of the project in 1991 that the overall research, development and marketing effort needed to get to market would take four to five years. In 1996, three years after completing the two-and-a-half year ATP research project, the company launched Handwriter® Mx™, and in 1998, seven years from the time the project began, the company was nearing release of a new software version that fully met the original goals.

Help for Victims of Arthritis

In early 1997 the Arthritis Foundation awarded CIC its "Ease-of-Use Seal of Commendation" for the company's Handwriter products. The Foundation's Commendation Program, founded in the late 1980's, recognizes products and packaging that are particularly accessible and easy to use. The award followed a favorable review by health professionals and arthritis patients.

Communication Intelligence Corporation (CIC)

Chinese Character-Recognition Methods for Computer Data Entry

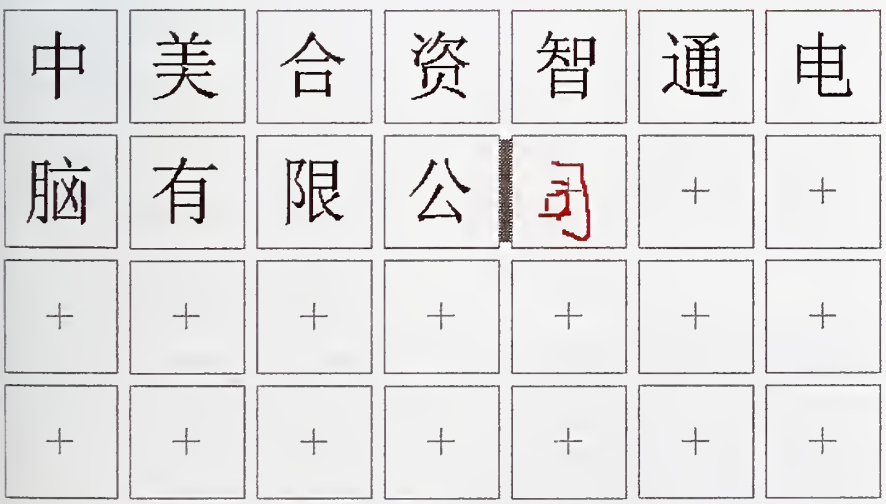
China is the world's most populous country, and in the last decade its economy has begun to mushroom. Because modern economies rely heavily on computers, the potential market for computers in China has grown along with its economy.

Accessing China's Giant Computer Market Potential

A major technical problem, however, impedes the widespread use of computers in China: the Chinese language is ideographic, using symbols to form characters representing things or ideas rather than letters to form words. Written Chinese employs thousands of symbols, as opposed to the 26 letters used in written English. Some keyboard methods exist for entering Chinese characters into a computer, but they are laborious. This technical barrier means that the large potential Chinese market is not readily accessible to U.S. computer businesses.

This ATP project enabled Communication Intelligence Corporation (CIC), a small California company, to develop a stylus-and-tablet method for writing Chinese directly into a computer. CIC is a spin-off from SRI International (formerly Stanford Research Institute) and was founded in 1984 to commercialize English handwriting recognition technology. In its first ATP project, CIC developed technology for a digitized stylus-and-pad system that can be used to enter cursive handwriting in English into a computer. In this second ATP project, CIC applied several techniques from its earlier work: using a tablet and stylus to record pen strokes, getting tablet sensory data into the computer and using algorithms to convert graphics signals to digital form. In addition, the company created a way to recognize handwritten Chinese characters.

. . . the large potential Chinese market is not readily accessible to U.S. computer businesses.



A screenful of Chinese characters, with one in the process of being composed. They were entered into the computer after being written on a pad using a stylus.

A System That Recognizes Nonalphabetic Writing

For the foundation of its system, CIC developed a high-quality database of about 750,000 characters penned by 2,800 Chinese writers. It also developed an algorithm that recognizes 6,763 Guojia Biaozhun characters, the standard set of characters determined by the Chinese government to be used by schools, publishers and other institutions. The technology can be applied to personal computers in the People's Republic of China, the Republic of China, Taiwan and countries such as Japan and Korea, where Chinese characters are part of the written language.

The technology will also be useful in applications for other languages that use nonalphabetic writing. Most important is Japanese, which uses symbols to represent the syllables of words and employs two different syllable sets — hiragana (made with more-flowing strokes) and katakana (made with more-angular strokes). Application to handwritten Japanese is also complicated by the interspersion of Chinese characters and English words in Japanese writing.

. . . entered into discussions with several major U.S. computer companies about incorporating the CIC character recognition technology into their computers for sale in China.

Entering the Chinese Market

The company has entered into a joint venture, which is called CICC and has 50 employees, with the Ministry of Electronic Industries of Jiangsu (the coastal province that includes Shanghai). Under the agreement, CIC will perform system integration services and market its pen-based business computer systems (incorporating the ATP-funded technology) to Chinese business and government users. The goal of the venture is to develop and market a "Chinese computer" designed specifically to meet Chinese business requirements.

Part of the agreement specifies that the company will package U.S. hardware and office automation software as part of the Chinese computer. To implement this agreement, CIC is in discussions with several major U.S. computer companies about installing the CIC character-recognition software in their products before selling them in the Chinese market.

The sale of its products in the Chinese market will open a huge opportunity for CIC, as well as many other U.S. sellers of personal computer hardware and software in China. For a country with a population of about one billion (few of whom now use computers), the potential market is vast. But solving the technical barrier to entering data in Chinese was a necessary step in actualizing the market and making it accessible to U.S. producers of computers and computer products.

ATP Accelerates Technology Development

CIC officials say the company was able to accomplish this technology development 18 to 24 months sooner than it could have without the ATP funds. Moreover, the ATP award helped the company develop licensing agreements and secure a joint-venture partner.

PROJECT:

To develop a Chinese character-recognition system to be used in place of a keyboard for computer entry of information in Chinese, opening Chinese markets to U.S. computer products.

Duration: 12/20/1993 — 3/19/1996
ATP number: 93-01-0211

FUNDING (IN THOUSANDS):

ATP	$1,480	62%
Company	911	38%
Total	$2,391	

ACCOMPLISHMENTS:

CIC fulfilled its goals by developing a recognition system for Chinese characters. The company's progress is indicated by the fact that it:

- collected a high-quality database of about 750,000 Chinese characters penned by 2,800 Chinese writers;
- developed a recognition algorithm that supports 6,763 Guojia Biaozhun characters, the standard set of characters determined by the Chinese government to be used by printers, schools and so forth;
- entered into a joint venture with the Ministry of Electronic Industries of Jiangsu Province, China, to perform system integration services and to market the company's pen-based business computer systems to Chinese businesses and government agencies;
- released the first major product version of its character-recognition software in September 1997; and
- entered into discussions with several major U.S. computer companies about incorporating the CIC character recognition technology into their computers for sale in China.

COMMERCIALIZATION STATUS:

Commercialization is in progress. CIC recently closed its first major deal with a Chinese company to incorporate the ATP-funded technology into its products. CIC is also in discussions with major U.S. computer companies to incorporate the technology into their products for China.

OUTLOOK:

Benefits from this project are expected to accrue to U.S. companies through U.S. leadership in China's computer market, the development of computer standards in China based on U.S. technology and large direct sales of U.S. computer components into China's markets.

COMPANY:

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Redwood Shores, CA 94065-1413

Contact: Russ Davis
Phone: (650) 802-7757

Number of employees:
66 at project start, 93 at the end of 1997

. . . the ATP award helped the company develop licensing agreements and secure a joint-venture partner.

Engineering Animation, Inc. (EAI)

Three-Dimensional Anatomy of Human Body, With Animation, for Medical Training

Every day, surgeons operate on thousands of patients around the country. For each operation, the surgeon and support staff have trained in some way to perform the delicate surgical procedures, some of them training on cadavers in medical school and others learning by doing. For each operation, the patient has gone through a learning experience as well, via conversations with doctors and nurses, while first considering and then preparing for the surgery. Occasionally, patients get to see a video of another person undergoing the procedure to be performed on them.

Animated 3D Anatomy

This ATP project enabled Engineering Animation, Inc. (EAI) — a small company founded in 1988 in Ames, Iowa, and specializing in three-dimensional (3D) visualization — to develop a new set of computer-based technologies for making training tools to help surgeons and patients better understand important aspects of surgical procedures before they are performed. The technology was developed for use in health care, medical research, medical education, surgical planning, rehabilitation equipment design and patient education prior to surgery.

EAI was established to create software that can show animated 3D objects, and its initial products were used in court cases to present "re-enactments" of car crashes and other events. The company sought ATP funding to develop new methods that would enable it to extend its technical capabilities to depict the inner parts of the body, not just the exterior. In the process, the company hoped to extend understanding of human anatomy. Its attempts would be path-breaking, since there were then no other known efforts to gather digital anatomical data from different sources into one uniform database or to present that data in 3D motion.

The breathing patterns of asthma patients are demonstrated with a computer-generated dynamic model of the lungs. This is one of a sequence of images — the next one in the sequence has the ribs removed.

The 3D aspect is critical, because flat pictures do not provide enough information for a good understanding of anatomy and surgical procedures.

"Walk-Through" Surgery

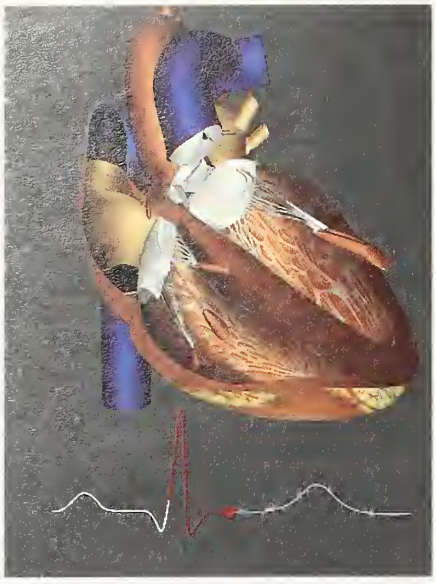
During the ATP project, EAI researchers developed algorithms for a system that can show realistic 3D images of human body parts and their motion. The pictures of tissues and organs can be manipulated to present a "walk-through" of surgery. The 3D aspect is critical, because flat pictures do not provide enough information for a good understanding of anatomy and surgical procedures. Dynamics, or animation, is also important because joints bend, the heart beats and the lungs contract and expand. Seeing these motions is extremely useful to surgeons planning an operation. Realism, too, is critical so that the images look like natural anatomy.

The realism of these images was achieved by using new databases with digitized, two-dimensional (2D) images showing cross-sections of human cadavers from head to toe. Several organizations provided these databases, including a highly detailed one from the National Library of Medicine. Using newly developed methods to combine 2D images, the researchers put together a complete 3D representation of the human body, including the exterior and all distinct interior parts.

With its ATP award, EAI developed large databases with detailed, digitized images of a generic human body and the associated technologies for storing and accessing the information. The project succeeded in depicting the whole body (male and female versions) as a 3D computer-generated image, as well as separately showing each interior part — bones, muscles, heart, lungs, brain and so forth.

Software Tools Commercialized

Substantial commercialization has been achieved and further effort is under way. After making sufficient progress on the research and development work of the ATP project, EAI used



A snapshot of the beating human heart shown with the output of an EKG, at one point in time. In use, both are dynamic — the heart beats in time with the EKG, so medical students can visualize the relation of the beating heart to electrical impulses captured by the EKG.

its own funds to combine the new technology and databases with its existing software in a new product — the Virtual Human — for use in medical training. The company began offering the Virtual Human at the end of the ATP funding period but was unable to sell a single copy of it because the hardware was so expensive. The costs for setting up the system using a Silicon Graphics workstation and the Unix operating system ran as high as $100,000. The company delayed commercialization of that product to modify the software and databases to operate on lower-cost personal computers running the Microsoft NT operating system. The company has recently successfully converted other products to run on the lower-cost systems, and is on track to do the same for products derived from the Virtual Human product.

In the meantime, much of the ATP-funded technology that went into the Virtual Human has been adapted to three CD-ROMs (The Dissectable Human™, The Dynamic Human™ and CardioViewer 3D™) and two medical books which use unique prints show-

. . . 20 employees at project start, 400 at the end of 1997 . . .

PROJECT:

To develop computer visualization and computational dynamics technology for presenting animated 3D images of the human body and its parts in order to improve medical education and surgical simulation.

Duration: 7/1/92 — 6/30/95
ATP number: 91-01-0184

FUNDING (IN THOUSANDS):

ATP	$1,947	76%
Company	625	24%
Total	$2,572	

ACCOMPLISHMENTS:

EAI developed core algorithms to enable the creation of 3D images from sets of 2D cross-sectional images of the human body. Researchers organized and integrated these digitized images in a large database and developed the technology to present them as animated visualizations of human anatomy. The company also:

- received the Smithsonian Award from *Computerworld* magazine in 1994, for the use of information technology in the field of medicine;
- received the Award of Excellence in Animation from the Association of Medical Illustrators in 1995;
- was a finalist, together with Walt Disney Studios, in the International ANNIE Awards category in 1995, for best animations in the film industry;
- produced and started offering the Virtual Human software, to run on a Silicon Graphics workstation, in June 1995;
- adapted the Virtual Human technology for three CD-ROMs using dynamic 3D visualization and for two publications, all of which are now on the market;
- incorporated the ATP-funded technology in the tools EAI uses to provide custom modeling in biomedicine, health education and custom animation;
- raised $30.5 million via an initial public stock offering in February 1996;
- opened international offices in 1997 and 1998, in England, France, Germany, Italy, and Malaysia;
- received one of the 25 Technology and Innovation Awards from *Industry Week* in 1996;
- entered into an agreement in January 1997 to develop software that supports Endovascular Technologies' Endovascular Grafting System — a less-invasive, less-costly alternative to open vascular surgery that should lead to lower mortality, fewer complications, shorter hospital stays and quicker recoveries;
- raised another $26.6 million via a second public stock offering in June 1997;
- was named one of "America's Fastest Growing Companies" by *Individual Investor* magazine, September, 1997;
- had its CEO, Matthew Rizai, recognized as one of the best entrepreneurs of 1997 by *Business Week* magazine, January 12, 1998; and
- was recognized as one of the 100 most dynamic technology companies in the US — with a rank of number eight — by *Forbes ASAP* magazine, Feb. 23, 1998.

COMMERCIALIZATION STATUS:

The new computer visualization and computational dynamics technology developed in this project has been successfully commercialized. Though an early product called the "Virtual Human" was not commercially successful because it could only be run on a very expensive work station, much of the technology was adapted for three CD-ROMs and two print publications and has also been used to create CD-ROMs that supplement medical books and are sold as a bundled package. Increased sales of medical books are attributed to the CD-ROMs. Software to support open vascular surgery is being tested and has shown promising results. This rapidly expanding company is now active in a multiplicity of applications featuring 3D animations which utilize computer visualization and computational dynamics.

OUTLOOK:

Further potential applications of the technical capabilities developed in the ATP project — and extended by subsequent research and product development — appear abundant. When a reduced-price hardware/software system to support the Virtual Human technology becomes available, potential economy-wide benefits should be large as a result of likely wide-spread use of the technology in health care.

COMPANY:

Engineering Animation, Inc. (EAI)
2625 N. Loop Drive
Ames, IA 50010

Contact: Mike Sellberg
Phone: (515) 296-9908

Number of employees:
20 at project start, 400 at the end of 1997

Informal collaborators: The Mayo Clinic, Biomechanics Laboratory; Johns Hopkins University

. . . much of the ATP-funded technology has been adapted to three CD-ROMs (The Dissectable Human™, The Dynamic Human™ and CardioViewer 3D™) and two medical books . . .

ing layers of body parts. All five products are now being marketed by Mosby-Year Book, a subsidiary of Times-Mirror. In addition, EAI has formed an alliance with Elsevier Science to create 3D multimedia titles in the neuroscience area. These products have achieved several of EAI's original marketing objectives and have been used successfully in training medical students. One professor who used The Dynamic Human™ as a teaching aid reported that her students "seem to retain more information after using this visual tool" and "are more excited about anatomy and physiology when the material is viewed with 3D animation and graphics on a computer screen."[1] The company has also incorporated its ATP-funded technology, both the anatomical database and the motion capability, in the tools it uses to provide custom modeling in biomedicine, health education, human body animation, and entertainment.

EAI is especially interested in offering its software as training tools for surgery via laparoscopy (for example, using a laparoscope to look into the abdomen) or other less-invasive surgical procedures. One candidate for this type of treatment is abdominal aortic aneurysm, which afflicts 1.5 million people in the United States each year. If left untreated, the aorta can rupture, usually causing death. This type of open-surgery repair has a morbidity rate of 15 percent to 40 percent.

In January 1997, EAI entered into an agreement to develop software that will support Endovascular Technologies's Endovascular Grafting System, a less-invasive, less-costly alternative to open vascular surgery that should lead to lower mortality, fewer complications, shorter hospital stays and quicker patient recoveries. The software will automatically calculate key aortic measurements, based on actual CT (computerized tomography) data, and enable doctors to "walk through" a patient's anatomy on the computer. The software allows doctors to identify structures, discern damaged and healthy tissue, and determine a patient's condition without performing invasive procedures. This application is directly dependent on the technology developed by the ATP project.

A person's body is more than just the "dry bones" of the skeleton; here the heart and major arteries and veins are shown in their proper places within or along-side the bones.

Better-Trained Doctors

The CD-ROMs and books developed or bundled with the new technology and databases have benefited anatomy and physiology students. The successful modification of the Virtual Human product for less-expensive computers, which will bring down the cost of the complete system, has the potential for creating large economy-wide benefits. In many areas of surgery, less-physically invasive procedures are replacing traditional techniques. Angioplasty, for example, can often be used instead of open surgery to repair blood vessels. If the Virtual Human proves valuable in training for these and other surgical techniques, then less-invasive procedures would likely be used more often in surgery. And by reducing the need for painful, highly invasive surgeries, the ATP-funded technology would lower the costs and improve the quality of health care. If this happens, the value of the resulting benefits will be counted in the hundreds, possibly thousands, of dollars for each patient treated by a doctor trained with the system — and could amount to life itself.

One professor who used The Dynamic Human™ as a teaching aid reported that her students "seem to retain more information after using this visual tool" . . .

Transition from Consulting to Software Products

At the beginning of the ATP award period, June 1992, the company had 20 employees. By the end of 1997 it had 400 employees, and near the end of 1998 it had more than 900. Total revenues in 1992 were $1 million. By 1994 they had grown to $5.5 million, and in 1996 they were $20.4 million. By 1997, after accounting for mergers, revenues had grown to $49.7 million.

EAI reports that the ATP project was a huge part of this commercial success. "This cost sharing enabled us to assemble technology," said Dr. Martin Vanderploeg, EAI executive vice-president, in 1994 during the ATP project. "The award was a major event that launched us into this growth phase," he added.[2] In 1994, EAI's total expenditures on research and development were $869,000, and in that year it received $564,000 from its ATP grant, about 65% of its total research and development budget.

When it applied for the ATP grant in 1991, EAI's only revenues were from consulting fees for providing support in court cases, and it had no software products on the market. By 1997, it was no longer reporting this line of business separately, and its computer animation software products had become its major activity.

The company has since its inception sought to exploit synergies among all its technological assets, continually seeking ways for

Awards for technical achievements roll in.

the company's product lines to benefit from and build upon each other. For instance, it utilizes its 3D visualization software products internally, to improve its ability to deliver high-quality, interactive animation software products, such as CD-ROM medical education products, in a timely manner. But the flow of technology works in the other direction as well, according to company publications, because it is continuously modifying and enhancing the 3D visualization software as it develops new interactive software products.

Awards for Technical Achievements Roll In

EAI began to receive awards for its technical achievements in 1994. In that year, it received the Smithsonian Award from *Computerworld* magazine for the use of information technology in the field of medicine. The next year, it received the Award of Excellence in Animation from the Association of Medical Illustrators, and was a finalist, together with Walt Disney Studios, in the International ANNIE Awards category for best animations in the film industry. And in 1996, EAI was one of 25 recipients of the Technology and Innovation Award from *Industry Week*, specifically for its interactive 3D visualization and dynamics products used in the manufacturing sector for product development.

ATP Funding Plays a Crucial Role

According to EAI officials, the company would not have been able do its research and development work without the ATP funds. The award enabled EAI to establish collaborations with the Mayo Clinic and Johns Hopkins University, and work performed during the ATP project facilitated collaboration with the National Library of Medicine on a later project. And it enabled the company to significantly extend its capabilities in computer visualization and computational dynamics, providing new technology that could be applied to other areas of the company's activities.

The award enabled EAI to establish collaborations with the Mayo Clinic and Johns Hopkins University, and work performed during the ATP project facilitated collaboration with the National Library of Medicine on a later project.

Having the award and doing the project also made EAI more attractive to potential investors. This was crucial in the early years of the company. In a 1995 interview with a reporter from *The Wall Street Journal*,[3] Matthew Rizai, CEO of the company, noted that winning the ATP award — which was for $1.9 million — gave him leverage with private investors, from whom he raised an additional $1.5 million. And the company says the ATP grant continued to be important to investors as it conducted its initial public stock offering in February 1996, a few months after the ATP project ended, raising $30.5 million.

Outstanding Commercial Performance

The company's recent rapid growth, accomplishments, and recognition received are impressive. Over the past 10 years it has emerged from the ranks of start-up to a company employing nearly 1,000 people. It has made the transition from a company heavily dependent on consulting revenues to one which relies on high-value software products. Its success has depended substantially on the internal integration of all its technical assets to develop new products in a variety of fields that draw on its technologies for very large database manipulation and visualization of motion, and on its belief that the company can succeed only if it brings those new products into the market.

In the September, 1997 issue of *Individual Investor* magazine, EAI was named one of "America's Fastest Growing Companies." And, early in 1998, two additional magazines recognized the company's achievements. *Business Week* magazine, in its January 12, 1998 issue, recognized Matthew Rizai, the company CEO, as one of the best entrepreneurs of 1997, and *Forbes ASAP* magazine, in its Feb. 23, 1998 issue, recognized the company as one of the 100 most dynamic technology companies in the US — with a rank of number eight.

ETOM Technologies, Inc.
(formerly Optex Communications, Inc.)

Packing More Data Into Optical Data-Storage Disks

Optical data-storage devices, typically CD-ROMs (compact disk, read-only memory), have taken the desktop computer market by storm, becoming a standard part of almost every computer sold. Just five years ago they were included in such equipment only by special order. Now, millions of these devices are manufactured and installed every year.

A Rewritable, Higher-Capacity Compact Disk

Optical disks hold much more data than conventional magnetic hard or floppy disks, the alternative data-storage technology. The optical devices employ the same technology used with music CDs: a laser stores the data by pitting the disk surface in a pattern that can be read by another laser. When it was introduced, a conventional plastic CD-ROM could hold 650 megabytes of data, whereas typical hard disks then held fewer than 50 megabytes. Optical disks, however, could be written only once, and the drive mechanism was much slower than magnetic hard disk drives.

New technology is addressing both deficiencies. Optical-disk-drive speeds have increased substantially, and several techniques for enabling the device to write new data are now commercially available. This project with ETOM Technologies, a small start-up company, developed technology that greatly increases the amount of data that can be stored on optical disks.

Large Jump in Storage Capacity

The ETOM technology uses a glass, rather than plastic, disk onto which is laid a light-sensitive substrate that can be written and read by the lasers in conventional CD-ROM drives. The core technology is called electron-trapping optical memory (ETOM). Data are "written" to the substrate by a low-power laser tuned to a specific frequency. The laser light raises individual electrons in the substrate to an elevated energy level, where they are trapped indefinitely. The data are "read" by a second laser, which releases the trapped electrons to return to their lower energy state, emitting a light signal in the process.

In addition to being a write-and-read device, the ETOM disk is able to store data at multiple energy levels, giving it the ability to use "multiple-ary" digits, as opposed to the binary digits (having two energy levels) used in conventional magnetic data storage. This capability greatly increases the amount of data that can be placed on the disk. For example, a byte (group of eight digits) using binary digits can store 256 different numbers. A byte using a multiple-ary digit with three energy levels, however, can store 6,561 numbers. Thus, the use of just three different energy levels instead of two increases the disk's storage capacity more than 25 times.

. . . barriers arose that made it impossible to offer a cost-effective video CD-ROM.

. . . ceased operations in January 1998 and filed for bankruptcy two months later.

Unforeseen Obstacles Block Commercialization

The company planned to manufacture and sell ETOM-based digital video recording products if the technology could be successfully developed. The technology was developed. But barriers arose that made it impossible to offer a cost-effective video CD-ROM. The company needed a green laser, but a commercial supply of them did not materialize as expected. Nor did the market materialize for a video-on-demand device, which would have used the video CD-ROM to temporarily store movies and other videos downloaded by viewer request from a cable-TV company.

After attempting to develop additional technologies to enable it to survive, ETOM ran into severe financial problems in late 1997. Private investors in ETOM decided it could not continue to operate without the business from a partnership to commercialize one of these technologies — a deal that ultimately fell through — so they decided to close ETOM. It ceased operations in January 1998 and filed for bankruptcy two months later.

. . . received 12 patents for technologies related to the ATP project . . . applied for 14 additional patents . . .

ATP Critical to Developing New Technology

ETOM reports that if it had not received the $1.4 million ATP award, it could not have performed the research and probably would not have survived as a company long enough to conduct the research. It encountered difficulties in bringing to market an optical disk device incorporating its new technology. Even though the company is no longer in business, the new approaches developed in this ATP project may eventually be picked up and used by some other company.

. . . the new approaches developed in this ATP project may eventually be picked up and used by some other company.

PROJECT:

To develop new optical disk data-storage technology capable of recording digital video information on an ETOM (electron trapping optical memory) optical disk, a development that could substantially reduce the cost of storing digital information.

Duration: 2/15/1993 — 12/31/1994
ATP number: 92-01-0122

FUNDING (IN THOUSANDS):

ATP	$1,433	56%
Company	$1,118	44%
Total	$2,551	

ACCOMPLISHMENTS:

ETOM demonstrated the ability to store data in a radically new optical data-storage mode. The company completed header pattern definition, mask fabrication and software for reading and writing M-ary (multiple-ary, as opposed to binary) data and developed specialized test equipment. It also:

- received 12 patents for technologies related to the ATP project:
  - "Partial Response Coding for a Multilevel Optical Recording Channel"
  - (No. 5,537,382: filed 11/22/1994, granted 7/16/1996),
  - "M=7 (3,7) Runlength Limited Code for Multilevel Data"
  - (No. 5,657,014: filed 5/12/1995, granted 8/12/1997),
  - "M=5 (0,2) Runlength Limited Code for Multilevel Data"
  - (No. 5,659,310: filed 5/12/1995, granted 8/19/1997),
  - "M=6 (2,4) Runlength Limited Code for Multilevel Data"
  - (No. 5,659,311: filed 5/12/1995, granted 8/19/1997),
  - "M=10 (3,6) Runlength Limited Code for Multilevel Data"
  - (No. 5,663,722: filed 5/12/1995, granted 9/2/1997),
  - "M=7 (1,3) Runlength Limited Code for Multilevel Data"
  - (No. 5,663,723: filed 5/12/1995, granted 9/2/1997),
  - "M=6 (3,6) Runlength Limited Code for Multilevel Data"
  - (No. 5,668,546: filed 5/12/1995, granted 9/16/1997),
  - "M=5 (3,7) Runlength Limited Code for Multilevel Data"
  - (No. 5,670,956: filed 5/12/1995, granted 9/23/1997),
  - "M=5 (4,11) Runlength Limited Code for Multilevel Data"
  - (No. 5,675,330: filed 5/12/1995, granted 10/7/1997),
  - "M=6 (3,8) Runlength Limited Code for Multilevel Data"
  - (No. 5,680,128: filed 5/12/1995, granted 10/21/1997),
  - "M=4 (1,2) Runlength Limited Code for Multilevel Data"
  - (No. 5,682,154: filed 5/12/1995, granted 10/28/1997), and
  - "M=6 (4,11) Runlength Limited Code for Multilevel Data"
  - (No. 5,682,155: filed 5/12/1995, granted 10/28/1997);
- applied for 14 additional patents for technologies related to the ATP project;
- prepared several technical papers for publication or presentation at professional conferences; and
- entered into preliminary negotiations with potential users of its patented M-ary coding algorithms.

COMMERCIALIZATION STATUS:

Commercialization of the original data storage device employing the ATP-funded technology faltered because not all necessary technical components were available for the system, and the expected market did not materialize. The company encountered severe financial problems in late 1997 and declared bankruptcy in March 1998.

OUTLOOK:

Although ETOM's recent bankruptcy precludes its commercialization of this technology, substantial knowledge was gained, as reflected in the patent applications and grants. The possibility exists that other companies will license and commercialize the technology.

COMPANY:

ETOM Technologies, Inc.
(formerly Optex Communications, Inc.)
2 Research Court
Rockville, MD 20850

Number of employees:
30 at project start, 3 at the end of 1997

Mathematical Technologies Inc. (MTI)

Mathematical Technology to Restore or Enhance Movies

Many old movies are extremely valuable. If they were made for entertainment, reviving them for current showing can earn sizable profits in addition to providing viewing pleasure to consumers. The film archives of some movie studios, in fact, are worth hundreds of millions of dollars. Documentary movies with footage of important people, industrial processes, and current or historical events have great value, too, for educational and archival purposes.

A frame from the movie Amacord, shown first with several areas that are damaged, and then shown after digital restoration automatically removed the damaged spots and replaced them with the original images.

Old Movies: a Resource Too Valuable to Waste

Movies mean reels of film. Commercial movie-making uses a master film from which others are copied. Film is a physical thing that can be damaged, soiled or broken like any other object. But unlike a scratch on a single car, a scratch or other artifact on an old movie master can affect the film's usefulness to viewing audiences and the fortunes of the company that owns it. If the master film is marred, each copy will also be marred. Even if the master film is converted to digital form for making video copies, the artifacts will persist. Everything on the old film, trash and all, is converted to electronic data that go onto the video copy.

Another difficulty with movies and other videos is the existence of several formats. It would be useful for film companies to be able to change films from one format to another so that current films could be easily converted to video, and older films could be made to fit today's video and film equipment. Format has to do with the technicalities of converting movies to digitized videos that can be shown on TV. One format problem involves resolution. The U.S. standard for TV is 525 scan lines and 60 hertz (Hz) — the frame rate. The European standard is 625 scan lines and 50 Hz. High-definition TV will have a different pair of numbers.

A second format problem concerns how to preserve the natural speed of motion depicted in a film when translating, for example, from a format that requires a speed of 24 frames per second to one that calls for 30. Because of the need to compensate for these differences in

Viewers of many films, both current and archival, are benefiting from what they do not see: defects removed by the technology.

Researchers developed mathematical algorithms to create data for filling in damaged areas . . .

. . . the 1958 film "A Night to Remember" . . . Fellini's "Amarcord" . . . DeMille's "Ten Commandments" . . .

PROJECT:

To develop generic software technology that can repair, enhance or reformat movie and video sequences, enabling the restoration of damaged movies, enhancement of military images and conversion between digital image formats.

Duration: 5/1/1993 — 8/31/1995

ATP number: 92-01-0053

FUNDING (IN THOUSANDS):

ATP	$989	88%
Company	136	12%
Total	$1,125	

ACCOMPLISHMENTS:

MTI developed technology to remove artifacts (unwanted defects) from movies, whether archived or newly created. It made progress in developing the reformatting technology, but this work is still experimental. The company also:

- formed MTI Digital Restoration Services early in 1996, a division now actively marketing software and restoration services in video post-production;
- received jacket-cover credit for restoration work on the laser disc version of the 1958 film "A Night to Remember," about the sinking of the Titanic;
- participated, via MTI Digital Restoration Services, in acclaimed restorations of recent re-releases of Federico Fellini's "Amarcord" and Cecil B. DeMille's "Ten Commandments;" and
- had its software used in the perfection or restoration of hundreds of new and old films for new video releases since 1995.

COMMERCIALIZATION STATUS:

Commercialization is in progress. Film-restoration software and services are being sold by MTI Digital Restoration Services, and MTI has other products under development. Viewers of many films, both current and archival, are benefiting from what they do not see: defects removed by the technology.

OUTLOOK:

In the restoration of old movies and the polishing of new releases, there are excellent expectations for the mathematical algorithm technology. It also has potential applications in forward-looking infrared imagery and in medical imaging areas like ultrasound and fluoroscopy. Completion of the technology for conversion between formats will widen applications further, particularly in high-definition TV.

COMPANY:

Mathematical Technologies Inc. (MTI)
1 Richmond Square
Providence, RI 02906-5139

Contact: Donald E. McClure
Phone: (401) 831-1315

Number of employees:
4 at project start, 6 at the end of 1997

resolution and film speed, translation from one format to another is not a trivial process.

A Mathematical Approach to Repairing and Converting Films

This ATP project with Mathematical Technologies Inc. (MTI), a small company formed in 1981, has solved many of the problems of reformatting and removing defects from films. MTI specializes in bringing mathematical theory to commercial applications via new programming technologies, and its defect-removal research during the ATP project was particularly successful. Researchers developed mathematical algorithms to create data for filling in damaged areas of the digitized versions of movie-frame images, a process that essentially restores the images to their original quality. Texture matching is an important problem that had not been anticipated but had to be solved in order to repair severe, wide scratches and other defects involving substantial amounts of missing data.

The MTI technology can remove tears, splotches, scratches, dust motes, liquid-spill marks and other unwanted visual defects from movies. Methods for using the new technology, as well as a specialized user-friendly screen display from MTI, have been integrated into post-production processing at a number of facilities in Hollywood and elsewhere.

MTI researchers succeeded in developing some components needed for format conversion. Work on other components is still experimental. The researchers thoroughly investigated motion compensation (which concerns the way moving objects are detected in a movie) and determined how to make adjustments for motion so that the new technology does not create new artifacts. Specifically, they estimated the frame-to-frame motion of objects and developed technology for the rapid calculation of the most significant motions. This technology is critical both for restoration of damaged images and for translating between film and video recording standards.

New Products and Services for Film and Video Industries

Commercialization is under way. Near the end of the ATP project, MTI established a division called Digital Restoration Services that sells movie-restoration software and services, and the company is developing other products that would use the ATP-funded technology, too. MTI has invested heavily in the development of new software for film and video post-production since the ATP project was completed. A new state-of-the-art algorithm for converting from ordinary video resolution to high-definition-TV resolution was demonstrated at the National Association of Broadcasters trade show in April 1998.

The new MTI offerings face competition from several other products — virtually all of them from abroad. Competitor products, however, tend to focus on the "artistic" end of the of the movie restoration business rather than on the "technical" end. MTI's products focus on the technical end, and the company reports it is currently the only one to provide such software technology for automated restoration.

MTI initially intended to develop applications for motion-compensated reformatting and standards conversion, as well as restoration. After the ATP project began, the company decided to focus almost exclusively on restoration, based on a reassessment of the market for conversion software and services. It planned to offer film-restoration software running at commercially viable speeds (perhaps three to four times slower than real-time) on graphics workstations or high-performance personal computers costing well under $100,000. MTI succeeded, and it is offering the software for use with contemporary and archived movies. In addition, the company says it is about two years ahead of where it would have been without the ATP funds.

Restored "Ten Commandments"

Viewers of the many films, both contemporary and archival, restored with MTI's technology have benefited. When Cecil B. DeMille's "Ten Commandments" was restored with the ATP-funded technology and re-released, a commentator on the television program "Entertainment Tonight" reported that "the difference between the original and this new vibrant version is a revelation. . . . Digital technology is the modern miracle that's made it possible."

As MTI's mathematical algorithm technology is applied to more films, more viewers will benefit. Further benefits will emerge if the technology is used in other areas. It has potential applications, for example, in forward-looking infrared imagery, which is used by the military to detect objects at night, and may also be useful in medical imaging procedures such as ultrasound and fluoroscopy. Additional benefits will materialize if the technology for standards conversion is completed.

The film-restoration technology already commercialized promises spillover economic benefits to the viewing public and to owners of films with defects. Many films of historical interest, once they are restored with the new technology, will be available to viewers. The number of viewers will grow over the years as the restored or enhanced films are shown again and again, so spillover benefits will grow, as well. If the reformatting technology is completed and commercialized, additional benefits will accrue.

A new algorithm for converting from ordinary video resolution to high-definition-TV resolution was demonstrated . . . in April 1998.

Torrent Systems, Inc. (formerly Applied Parallel Technologies, Inc.)

A User-Friendly Programmer's Tool for Writing Parallel-Processing Software

Parallel computers — especially so-called "massively parallel" machines with hundreds or thousands of individual processors — hold great promise for solving many formerly intractable computing problems in government and industry. Estimates suggest that parallel processing would save the U.S. airline industry alone more than $1 billion annually through more efficient scheduling of flight crews. It could enable U.S. oil companies to reduce exploration costs and increase oil reserves. Analysis of massive transaction databases using parallel processing could recover much of the tens of billions of dollars lost annually to health care and credit card fraud.

Easy-to-Do Programming for Parallel Processing

A difficulty with parallel processing, though, is that writing its software is more art than science, an art practiced well by a relatively small number of programmers. Torrent Systems, founded as a two-person company in 1993, had an idea for solving this problem but was unable to find venture capital to finance the research to develop the technology. The company then sought and won ATP funding that enabled it to proceed. Torrent ultimately developed a component software system that allows programmers to build parallel-processing software systems without needing to explicitly understand how the system exploits the underlying parallel-processing hardware. To accomplish this project, researchers studied the actual application needs of typical users — to assure that the results would be widely applicable and useful.

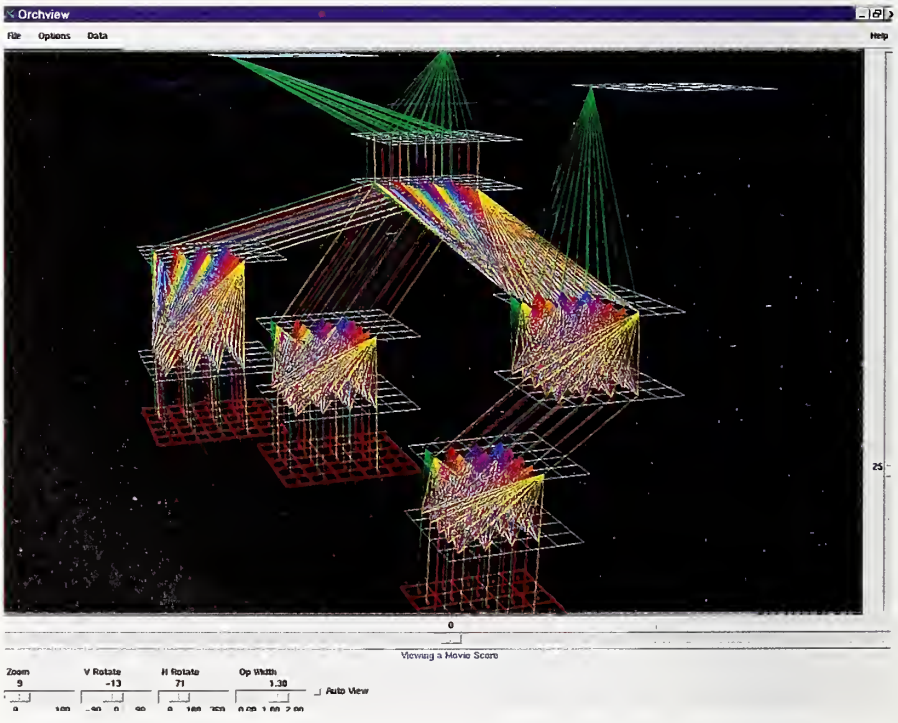
Quick to Market

Torrent produced a research prototype of a parallel-software component framework, created its basic components and performed limited testing on them. It also planned to develop a library of reusable code — containing components for a parallel-processing system. If such a library were available for other developers, then even more applications could come on line sooner. However, the company did not complete this research task. Torrent closed the project before its anticipated completion date in order to commercialize early technical results and generate needed revenue.

Torrent incorporated the ATP-funded component-based technology in a product called Orchestrate™, which the company describes as a "parallel application environment that insulates you from the complexities of parallel programming while delivering scalable applications." United Airlines and Citicorp were two of the first corporations to license it.

Strategic Marketing Alliances

The company has been quick to form strategic marketing alliances. It formed a partnership with IBM in July 1997, under which IBM will promote Orchestrate™ as a standard compu-



A graphic illustration of a 16 processor system under the control of Orchestrate — three sources of input data (shown at the top of the screen in green) are split into many parallel data streams, each to be manipulated by a sequence of software components (the grids at the bottom in red) which apply the same logic to each stream.

PROJECT:

To develop component-based tools for writers of parallel-processing software, as well as a library of reusable parallel-processing software components.

Duration: 12/1/1994 to 7/31/1996
ATP number: 94-06-0024

FUNDING (IN THOUSANDS):

ATP	$1,117	77%
Company	325	23%
Total	$1,442	

ACCOMPLISHMENTS:

Torrent accomplished most of the project goals, including development of a software environment for building parallel data-processing applications. The company did not develop as extensive a library of reusable components as originally anticipated. It halted the project sooner than originally planned to exploit the excellent commercial opportunities for technology developed early in the project. Torrent's outstanding progress toward commercialization is indicated by the following:

- The company applied for a patent on parallel training of neural networks, as well as patents on several other innovations.
- Torrent incorporated the ATP-funded technology in a product called Orchestrate™, introduced to the market in 1996. The company describes it as "a parallel development environment that insulates you from the complexities of parallel programming while delivering scalable applications."
- Orchestrate™ was described in a December 1996 *Datamation* article, "Build Your Warehouse on MPP," as one of a number of approaches to use in data warehousing.
- Orchestrate™ was selected in 1997 for use by KO1, IBM, Citicorp, Autozone, Sears Roebuck and United Airlines.
- Torrent entered into a strategic partnership in July 1997 with IBM, which will promote Orchestrate™ as a standard computer application. IBM is focusing on rapid development and deployment of a parallel-processing software system that can be enlarged without needing to be replaced by a new version, because expansion of the system is built into its architecture. Orchestrate™ plays a key role in the expansion capability of the IBM system. Torrent extended the partnership in September 1997, with IBM agreeing to resell Orchestrate™.
- Torrent entered into partnerships in September 1997 with three new vendors: The MEDSTAT Group, i.d.Centric and Knowledge Discovery One.
- The company also negotiated bundling arrangements (selling two or more separately produced products as a unit) with independent software vendors and manufacturers including Emergent, Knowledge Discovery One, Lockheed Martin IS&T and MRJ Technology Solutions.
- During 1997, several commercial software vendors chose Orchestrate™ for building their software products. The first such product, produced by the SAS Institute, reached the market in late 1997.
- At the end of 1997, *Computerworld* magazine recognized Torrent as one of the "100 Hot Emerging Companies."
- Torrent had attracted investments of $3.8 million by the end of the ATP project in July 1996, and it increased the total to $10 million over the next 18 months.
- United Airlines, an early customer, is using Orchestrate™ and an IBM parallel-processing computer to design a system for managing airplane seat assignments. United expects the new system to generate between $50 million and $100 million per year in increased revenue. The company is spending only about $17 million on the system, which would not work without Orchestrate™.

COMMERCIALIZATION STATUS:

The ATP-funded programmer's tool for writing parallel processing software has been commercialized. It is embodied in Orchestrate™, as well as in derivative products.

OUTLOOK:

The outlook for further commercialization and economic benefits is excellent. The strong market interest in Orchestrate™ indicates its usefulness in processing immense amounts of data. Since government and many industries — retail, health care, energy and transportation — use massive databases, new tools that can dramatically increase processing efficiency stand to yield billions of dollars in savings across the economy. The benefits from this project will accrue mostly to users of the technology, rather than to Torrent.

COMPANY:

Torrent Systems, Inc.
(formerly Applied Parallel Technologies, Inc.)
5 Cambridge Center, Seventh Floor
Cambridge, MA 02142

Contact: Robert Utzschneider
Phone: (617) 354-8684 ext. 1162

Number of employees:
2 at project start, 32 at the end of 1997

. . . halted the project sooner than originally planned to exploit the excellent commercial opportunities for technology developed early in the project.

ter application. IBM's focus is rapid development and deployment of a parallel-processing hardware/software system that can be enlarged without needing to be replaced by a new version, because expansion is built into its architecture. Orchestrate™ plays a key role in that expansion capability. The IBM system is specifically designed to make full use of customer sales and other data across an entire company, regardless of the type of business. Torrent extended that partnership a few months later, with IBM agreeing to resell Orchestrate™.

United Airlines, an early customer, reported in a November 1997 *Chicago Tribune* article that it had installed a new IBM RS6000/SP2 parallel-processing computer. The software supplied by IBM included Orchestrate™ under a licensing agreement between Torrent and IBM. United paid $3.5 million for the hardware and planned to spend another $13.5 million to get the computer running. The system is expected to generate between $50 million and $100 million per year in increased revenue by doing a better job of matching potential fliers with available airplane seats. Orchestrate™ is a critical component that enables United personnel to program the computer, which United would not otherwise have bought. This advance is important, since the RS6000/SP2 has been on the market for several years.

. . . new tools that can dramatically increase processing efficiency stand to yield billions of dollars in savings across the economy.

. . . a component software system that allows programmers to build parallel-processing systems without needing to explicitly understand how the system exploits the hardware.

. . . this technology . . . is embodied in "industrial strength" computer programs used in diverse industries and by government agencies.

Torrent also formed a marketing partnership with Sun Microsystems in 1997. An early outgrowth of this alliance was a joint demonstration showing the advantages of using Orchestrate™ in a typical data warehousing application. Orchestrate™ was used to integrate the basic Torrent components and specialized components from three other vendors into a single test application. The test involved data cleaning of a name-and-address file of about 13 million records, which was then merged with a demographics file of about 16 million records. When the test was run without using parallel processing, the application took 32.5 hours on a machine using four processors. With Orchestrate™, the application took only 9 hours. When the number of processors was increased to 12, the Orchestrate™-based application finished in just 3 hours.

Torrent also entered partnerships in September 1997 with three new software vendors: The MEDSTAT Group, i.d.Centric and Knowledge Discovery One. And it negotiated bundling arrangements (selling two or more separately produced products as a unit) with independent software vendors and manufacturers including Emergent, Knowledge Discovery One, Lockheed Martin IS&T and MRJ Technology Solutions.

Potential for Huge Benefits

Torrent has succeeded in marketing its technology, and substantial broad-based benefits can be expected to flow from the use of the new technology incorporated in its software. Users of Orchestrate™ have benefited from the removal of the need to pay attention to programming details for C/C++ (the most common language used to write programs for parallel processing), because Orchestrate™ handles them. As more applications of the new technology are implemented through the use of Orchestrate™ and other Torrent products, more analyses of large databases will be done. Another product that uses the ATP-funded technology is Orchestrator for the SAS System™, recently released by the SAS Institute.

Economic benefits are likely to be large and widespread for this technology. It is embodied in "industrial strength" computer programs used in diverse industries and by government agencies. Users in these areas say they anticipate dramatic savings. Consumers will also benefit from these savings, as lower operating costs are passed on to them. Torrent, a small company, will be able to collect only a small percentage of the total additional value created by its technology, while the rest will spill over to others in the economy.

The benefits from the ATP project would likely be even greater if Torrent had been able to fully develop and make available the library of reusable components as originally planned. However, as is often the case with small, near-startup companies, cash-flow concerns related to ensuring company survival dictated a fast move to generate revenue. In this case, given its limited resources, Torrent felt it had to stop the research project early and commercialize the technology. As customers suggest needs for other components, they will be developed and integrated into the company's products.

ATP Project Speeds Exploitation of Parallel Processing

ATP funding for this project allowed Torrent to research and develop a prototype of a component software system that allows programmers to create parallel-processing software in a user-friendly way. Without the ATP funds, Torrent officials say, it is doubtful that the technology could have been successfully developed at all. Venture capital funding had been sought but was unavailable. ATP funded the project to enable U.S. industry to broadly and rapidly exploit parallel processing, expecting that it would generate significant benefits throughout the economy. The speedy adoption of Torrent's first commercial products confirms that expectation.

Venture capital funding had been sought but was unavailable. ATP funded the project to enable U.S. industry to broadly and rapidly exploit parallel processing.

Chapter 8

Materials

AlliedSignal, Inc.

A Process for Making Ceramic Parts

Many types of industrial and commercial equipment contain parts that revolve at very high speeds, under great stress and in extreme heat. Jet engines, power generation turbines and automobile engines are a few examples. In the past, metal has been accepted as the only material for making such parts.

Safe, Low-Cost Fabrication of High-Performance Ceramic Parts

With the recent development of high-performance structural ceramic materials, this ATP project with AlliedSignal asked whether it was possible to develop a process for fabricating ceramic parts inexpensively enough to allow them to be substituted for metal parts, thereby significantly improving equipment performance and reliability.

Ceramic substitutes for metal have performed well in certain critical situations. Space flight is one. Ceramic tile coverings on spacecraft form heat shields that protect astronauts re-entering earth atmosphere. Atmospheric friction heats the tiles to a fiery glow. But the tiles stay in place and dissipate enough heat for safe re-entry. Metal surfaces would melt under these circumstances, with disastrous results.

A 16-blade silicon nitride turbine wheel for use in small turbogenerators.

Cost and Safety Issues Hinder Use

Despite such performance advantages, the application of advanced ceramics has been held back by the high cost of fabrication. Whereas metal can be melt-processed or plastically deformed using molding, extruding, stamping or other standard metalworking techniques, many ceramics cannot be processed by these methods. Ceramic parts must be made by forming ceramic powder into a desired shape at room temperature and then "reacting" the powder compact at various temperatures to densify it. This process is much more limited in the shapes it can achieve than melt-processing or plastic deformation approaches.

This ATP project offered a novel approach to ceramics production via a relatively new process called gelcasting, a technology developed at Oak Ridge National Laboratory. In gelcasting, powdered ceramic precursors are mixed with a polymer precursor (monomer) and solvent (usually water) to make a slurry that is poured into a mold. The gel is then polymerized, locking the ceramic powder in a polymer matrix. The solvent is removed, and the part is heated to burn out the polymer. At this point, if necessary, the "green" part can be machined to some degree. Finally, the part is fired to produce the ceramic. The process is capable of making very complex parts such as turbine wheels. Some shapes made with this technique cannot be made any other way.

A major drawback to the original gelcasting technology was its reliance on acrylamide as the gelling additive. Acrylamide is highly sensitive to oxygen, which inhibits polymerization. So the process must be done in an inert environment, which raises the cost. Acrylamide gel is also very difficult to remove if an inert environment is used, raising costs even more. Most important, however, acrylamide is a cumulative neurotoxin, and safety concerns had prevented the technology's widespread use.

. . . a novel near-net-shape . . . process for making high-performance ceramic parts for automobile and aircraft engines.

PROJECT:

To develop a low-cost, near-net-shape gelcasting process for making structural ceramics in a safer, less-costly way than conventional gelcasting based on acrylamide, a cumulative neurotoxin. Successful development of this process would open the door to commercial gelcasting production of these high-performance ceramics.

Duration: 7/1/1992 — 6/30/1995
ATP number: 91-01-0187

FUNDING (IN THOUSANDS):

ATP	$1,136	56%
Company	884	44%
Total	$2,020	

ACCOMPLISHMENTS:

AlliedSignal achieved its R&D goal. The company also:

- presented the new technology at several professional conferences;
- invested after the ATP project another $3 million of its own money on additional gelcasting R&D aimed at the development and installation in 1998 of an automated gelcasting system that can fabricate ceramic automotive turbogenerator wheels at a rate of 10,000 per year; and
- received funding from the Department of Energy and the Defense Advanced Research Projects Agency to further advance gelcasting technology, with the specific goal of establishing viable manufacturing processes.

COMMERCIALIZATION STATUS:

Commercialization is in progress, and the first gelcast parts made with the new technology are expected to reach the market very soon. Opportunities exist for commercialization in a variety of fields.

OUTLOOK:

The company is making excellent progress toward its commercialization goals and is expected to start producing gelcast parts in large volume in the near future. Users of vehicles or equipment made with gelcast ceramic parts will benefit from lower cost and better performance, with potentially huge benefits accruing in areas like auto engines, commercial aircraft and industrial applications such as stationary power generation.

COMPANY:

AlliedSignal, Inc., Ceramic Components
(formerly Garrett Ceramic Components Division, AlliedSignal Aerospace)
2525 W. 190th St.
Torrance, CA 90504

Contact: John Pollinger
Phone: (310) 512-5654

Informal collaborator:
Oak Ridge National Laboratory

AlliedSignal's innovation in this ATP project was to develop a low-cost, nontoxic alternative that retains acrylamide's excellent process characteristics. During the project, AlliedSignal researchers developed and demonstrated a novel near-net-shape (requiring almost no machining) process for making high-performance ceramic parts for automobile and aircraft engines. In addition, the new gelcasting process has potential applications in energy, chemicals, aerospace, electronics, advanced materials and telecommunications.

Early Commercialization Expected

Development of the technology is continuing. In 1995, under the "Partnership to Productionize and Commercialize a Manufacturing Process for Silicon Nitride Turbomachinery Components," AlliedSignal began receiving funds from the Defense Advanced Research Projects Agency for work that grew directly out of the ATP-funded gelcasting project. The company received additional funding for this effort from the Department of Energy in 1997, and it has made substantial progress toward a commercially viable manufacturing process. Marketable products have yet to be sold. But commercial production is expected to begin in the very near future, with annual sales projected to be several million dollars.

AlliedSignal has constructed a new plant for manufacturing ceramics parts, including those made with the gelcasting technology. Since the close of the ATP project in June 1995, the company has invested $3 million to further develop the technology for particular commercial applications. In addition, based explicitly on the successful completion of the ATP project, it received funding from the Department of Energy and the Defense Advanced Research Projects Agency to advance gelcasting technology into commercialization.

. . . potential applications in energy, chemicals, aerospace, electronics, advanced materials and telecommunications.

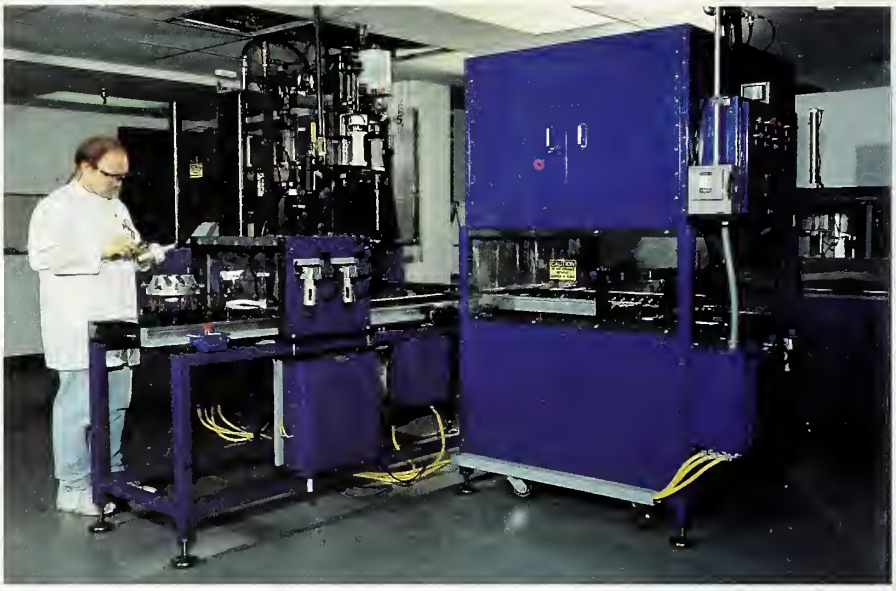
. . . acrylamide is a cumulative neurotoxin, and safety concerns had prevented the technology's widespread use.

Cost Reductions and Improved Performance

Users of vehicles and other equipment using gelcast ceramic parts instead of metal ones will benefit from cost reduction and improved performance — in the case of some applications, to a considerable degree. Since Oak Ridge National Laboratory holds the underlying intellectual property for gelcasting, additional spillover benefits are likely to accrue. As a national laboratory, Oak Ridge offers its technologies to the public, and other companies are likely to realize considerable spillover benefits from the AlliedSignal/ATP-funded gelcasting technology. Oak Ridge has already licensed gelcasting technology to two other U.S. companies — a magnetic ferrite manufacturer and a small manufacturer of ceramics for automotive and fuel cell applications — and is working with a number of other companies evaluating the technology.

Future benefits are also expected to come from applications of the new gelcasting process in a number of sectors, including large aircraft engine parts. In addition, there may be applications in small parts for jet engines, small turbine generators for hybrid electric/fossil fuel cars and auxiliary power systems for aircraft.

. . . invested . . . another $3 million of its own money . . . aimed at the development and installation in 1998 of an automated gelcasting system . . .



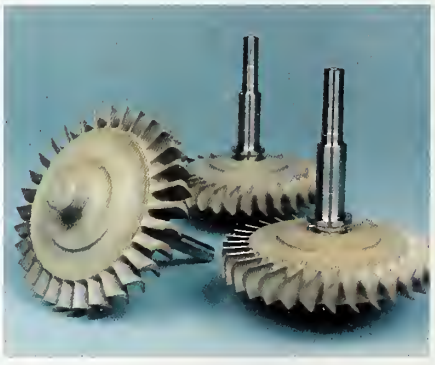
An automated gelcasting machine capable of forming 10,000 ceramic turbine wheels per year.

Progress Accelerated by Five Years

Because of its success in developing the new gelcasting technology, AlliedSignal has also succeeded in developing the manufacturing technology and component fabrication projects that allow commercialization to progress. The company says that without the ATP funds, it would have needed another five years to reach this stage of development. And it would have been that much further behind its major competitor, Kyocera of Japan. Instead, AlliedSignal believes that with the help of the ATP funds, it has now pulled even with Kyocera in most applications and is able to make superior-quality products in several areas.

Another clear benefit made possible by the ATP grant was the establishment of a technology-development relationship between AlliedSignal and Oak Ridge National Laboratory. Relations have continued through a scientific exchange agreement for an Oak Ridge scientist who co-invented the original gelcasting technology to work at AlliedSignal for two years.

. . . made possible by the ATP grant was the establishment of a technology-development relationship between AlliedSignal and Oak Ridge National Laboratory.



Near-net-shape turbine wheels for use in commercial or military jet engine starters.

Geltech Incorporated

Making Low-Cost, High-Quality Glass Microlenses at Low Temperature

Tiny lenses and other micro-optical components appear in many industrial products such as sensors, laser systems, detector arrays and fiberoptic data links. Tens of millions of these components are produced every year. Many are made of plastic, are of low quality and cost little. Others made of silica glass are higher-quality, but they cost much more than plastic lenses.

Technology for Making Small, Complex Silica Micro-Optics

This ATP project with Geltech, a small Florida company, developed a novel method for producing low-cost, high-quality silica-glass microlenses based on "sol-gel" technology pioneered by the company. Geltech was founded in 1985 to commercialize micro-optics technology (dealing with light wavelengths in the range of nanometers to hundreds of microns) discovered at the University of Florida, and it holds exclusive licenses for patents assigned to the university.

Casting Silica at Room Temperature

Silica cannot be used with traditional molding techniques because of its very high melting temperature. In addition, conventional grinding and polishing processes limit how small and complex the silica micro-optics can be. Geltech overcame these problems by developing methods to cast net-shape (no grinding necessary) silica-glass micro-optics at room temperature using sol-gel technology.

In the sol-gel process, silicon alkoxides are formed into larger molecules (polymerized) and combined with a liquid in a suspension, or sol, that is cast in a mold at room temperature to make a rigid, wet gel. The gel, in turn, is dried, strengthened and densified at high temperature into a pure, highly homogeneous, silica-glass structure. The ATP project demonstrated that fully dense silica glass — hard, transparent, nonporous glass with a density of two grams per cubic centimeter — can be produced by this process with a quality similar to that of the best fused silica glass.

Signs of Initial Technical Success

Near the end of the ATP project, five of the company's prototype refractive lens devices were tested by a customer and found to perform satisfactorily. In addition, the Army recently gave Geltech a Small Business Technology Transfer Research Phase II award for research using technology partly developed with the ATP funding. Under the contract the company will build prototype windows molded in silica using the sol-gel process. The windows are designed to protect military personnel from intense laser pulses.

Secondary Products

Although the ATP-project demonstrated that high-quality, silica-glass micro-optics can be produced by the sol-gel process at low temperature, the technology could not produce refractive microlenses at a cost low enough to penetrate this market. Therefore, the company has been as yet unable to commercialize microlenses produced by the new process.

. . . the technology could not produce refractive microlenses at a cost low enough to penetrate this market . . .

. . . used some of the ATP-funded technology to develop a porous-glass product, which has been introduced to the market as a component of a home sensor for toxic gases.

The company, however, succeeded in using the new technology to produce diffraction gratings, its second major product, with acceptably high surface quality and at reasonable cost. A diffraction grating is a band of equidistant parallel lines (usually more than 5,000 per inch) ruled on a glass or polished metal surface and used to break a beam of light into components of different wave lengths. The company has just begun to offer parts to customers for use in conjunction with lasers in optical systems. It is too early to tell whether commercialization of its diffraction gratings will succeed. Acceptance for this product in the marketplace has taken longer than anticipated.

Geltech also used some of the ATP-funded technology — materials processing and mold fabrication methods — to develop a porous-glass product, which has been introduced to the market as a component of a home sensor for toxic gases. The details of this application are still confidential. The company is also using some of the technology to develop plastic micro-optics, which are lighter and less expen-

The ATP project demonstrated that fully dense silica glass . . . can be produced by the sol-gel process with a quality similar to that of the best fused silica glass.

sive than glass micro-optics, with hopes for commercialization in consumer products in the near future.

Geltech officials say the ATP funding helped the company form alliances with research partners and enabled it to conduct research it would otherwise have been unable to do. The funding was also critical in helping Geltech survive as a company. Geltech more than doubled its revenues over the ATP grant period, and the new technology played a significant role in boosting the company's revenues from less than a quarter million dollars in 1992 to about $5 million three years later.

. . . ATP funding helped the company form alliances with research partners . . . enabled it to conduct research . . . critical in helping Geltech survive . . .

PROJECT:

To develop a method of casting net-shape (no grinding necessary) pure silica glass micro-optics at room temperature.

Duration: 4/5/1993 — 7/4/1995

ATP number: 92-01-0074

FUNDING (IN THOUSANDS):

ATP	$1,323	48%
Company	1,456	52%
Total	$2,779	

ACCOMPLISHMENTS:

Geltech demonstrated that high quality, silica glass micro-optics can be produced by a manufacturing process that includes a room-temperature, net-shape casting method. Also, in activities related to the ATP project, the company:

- had five prototype refractive lens devices tested by a customer and found to perform satisfactorily;
- used the technology to develop diffraction gratings, for use in conjunction with lasers in optical systems, with market introduction just beginning;
- used some of the ATP-funded technology (materials processing and mold fabrication methods) to develop a porous-glass product, which has been introduced to the market;
- used the procedures for making optical-quality molds, developed in the ATP project, as initial steps toward commercialization of plastic micro-optics;
- increased revenues from less than a quarter million dollars in 1992 to $5 million in 1995, with the new technology playing a significant role in the company's revenue growth; and
- recently received a Small Business Technology Transfer Research Phase II award from the Army for research using technology developed in the ATP project.

COMMERCIALIZATION STATUS:

Commercialization of refractive microlenses, one of the major products envisioned in the ATP project, has not occurred because the technology did not produce microlenses with a high enough surface quality to penetrate this market. Geltech began using the ATP-funded technology in 1994 to produce a porous-glass product for a home sensor application, with production reaching a peak of about 500,000 parts per week at the end of 1995 and sales achieving significant levels. Although today the sales of products derived from the ATP technology are relatively small, sales of diffraction gratings — the second major micro-optics product envisioned in the project — have just begun.

OUTLOOK:

Despite the successful commercialization of other products using the ATP technology, it is too early to tell when refractive microlenses will enter the commercial marketplace or whether commercialization of diffraction gratings will succeed. However, if the cost per piece of diffractive gratings continues to drop and Geltech succeeds in selling large volumes of them, producers and users of systems that contain optical components such as printers will benefit from parts that are smaller than their refractive counterparts or that perform functions not possible with refractive parts. Users of one device already on the market, a home sensor product for detecting toxic gases (details are still confidential), are already benefitting from the technology.

COMPANY:

Geltech Incorporated
3267 Progress Drive
Orlando, FL 32826

Contact: Jean-Luc Nogues
Phone: (407) 382-4003 ext. 302

Number of employees:
7 at project start, 65 at the end of 1997

Potential Broad Applications

If the unit-cost of diffraction gratings continues to drop and Geltech succeeds in selling large volumes of them, producers and users of systems that contain optical components will benefit from components that are smaller, lighter and less expensive than their refractive (light-bending) counterparts. In addition, diffractive parts may perform functions not possible with refractive parts. Geltech's sales are small at this point, and specific applications are still in the testing stage, but the potential broad applications and benefits are there.

The new gelcasting process technology can be used in manufacturing microlenses, microlens arrays, beam splitters and other micro-optics, and the company anticipates moving into these markets when it is economically feasible to do so. The technology has already been applied to refractive lenses, diffraction gratings and porous glass optics. It might also be used for producing ceramic packages (casings for chips in computers and communications equipment) in electronics manufacturing and for applications in the global surveillance and communications fields.

IBM Corporation

Methods for Making New Optical Switches

Information is transmitted in a variety of ways in a developed economy: by surface mail, telephone, facsimile, e-mail, radio and TV broadcast, and data downloading. Several technologies are useful for each type of transmission, and in some instances, both electrical and optical methods can be used. Optical transmission has a signal-quality advantage over electrical transmission in cable TV, telephone trunk lines, undersea cables and other cable applications.

Faster, Cheaper Optical Transmission of Data

Optical fiber is rapidly replacing metal wires in terrestrial and oceanic transmission, both for voice and data, because of cost savings and improved performance. Optical methods also have a potential advantage for transmitting information from component to component within computers. If optical signals could replace electrical signals in this context, bandwidth could be multiplied many fold, while heat generation and cross-talk — significant problems in computers — could be greatly reduced.

New Optoelectronic Polymer and Prototype Switches

IBM's ATP project aimed to develop optical switches to link the optical fibers running between components in computers. Current-generation switches convert data from an optical to an electrical signal, do the necessary switching and then convert the data back to an optical signal, a process that involves expensive components and significantly limits the speed of the system. IBM's proposed technology would help achieve the technical advantages of optical signals over electrical signals in computers.

IBM researchers succeeded in developing high-speed, inexpensive optoelectronic switches using nonlinear optical polymeric waveguides suitable for use in the data communications industry. Specifically, the project developed a general method for identifying and synthesizing particular dipolar molecules, known as chromophores, that are chemically stable at temperatures exceeding 300 C. Researchers were able to incorporate these molecules into thermally stable polymers, producing the desired optoelectronic polymer.

. . . bandwidth could be multiplied many fold, while heat generation and cross-talk . . . could be greatly reduced.

Market Fails to Materialize as Expected

Commercialization by IBM is not expected in the foreseeable future, even though IBM completed working prototypes of polymeric switches. The need for such switches in the envisioned application changed, and a broad market opportunity did not materialize. Technological change in this industry is rapid, and trends can suddenly switch directions.

New Opportunities Arising

The rapid expansion of digital data transmission, however, is likely to open up opportunities for low-cost, high-speed optoelectronic switches in the future, and devices based on polymeric materials are viable candidates. Thus, chances are good that this technology will ultimately be used in important applications. Of the six key researchers on the project, five have left the company for other jobs. Knowledge spillover may occur elsewhere, as these researchers use their knowledge of the technology in new applications. They conjecture that the technology may be useful in the near future in telecommunications, rather than in computers. One potential application, according to project researchers, is in wavelength division multiplexing (sending light of more than one wavelength through a single optical fiber), where the technology might provide significant enhancements for high-speed, broad-band telecommunications. Another possible application is in microprocessor chip-to-chip interconnects, but semiconductor industry experts suggest that the need for those interconnects may not become apparent for 10 or more years or might not ever arise.

. . . this technology . . . may . . . be useful in telecommunications, rather than computers.

PROJECT:

To develop high-speed, inexpensive optoelectronic switches using nonlinear optical polymeric waveguides suitable for use in the data communications industry.

Duration: 8/1/1992 — 7/31/1995
ATP number: 91-01-0017

FUNDING (IN THOUSANDS):

ATP	$1,787	44%
Company	2,235	56%
Total	$4,022	

ACCOMPLISHMENTS:

Researchers reduced the size and cost and improved the speed and efficiency of switches for computers and communications systems. IBM produced working prototypes of polymeric switches. Technical progress is indicated by the fact that IBM:

- received a patent for technology related to the ATP project:

  "Optical photorefractive article"

  (No. 5,607,799: filed 4/21/1994, granted 3/4/1997);

- published more than 20 papers in professional journals in areas related to the project goals; and
- presented technical results at several professional society meetings and conferences.

COMMERCIALIZATION STATUS:

The technology has not yet been commercialized by IBM or others. The market opportunities for the polymer-based switches has yet to materialize.

OUTLOOK:

While predicting the future of this technology is difficult, it may possibly be useful in telecommunications, rather than computers. One potential application is in wavelength division multiplexing (sending light of more than one wavelength through a single optical fiber), where the technology may find cost-effective use in switches and other components.

COMPANY:

IBM Corporation, Almaden Research Center
650 Harry Road, K13/E1
San Jose, CA 95120-6099

Contact: Mike Ross
Phone: (408) 927-1283

Informal collaborator:
University of Colorado

The support enabled company researchers to publish more than 20 papers in professional journals, enabling the technology to be disseminated among other researchers.

No broad market benefits have emerged yet, because there are no commercial products incorporating the technology, either in the intended or other applications. It is likely, however, that the rapidly expanding use of digital data communication will lead to opportunities for low-cost, high-speed optoelectronic switches in the future. The ATP-funded technology is a core technology for the polymeric materials and devices that IBM demonstrated, and these products have potential in a number of future applications.

Through its research under ATP funding, IBM was able to gain access to cutting-edge work being done on optoelectronic devices at the University of Colorado. The support enabled company researchers to publish more than 20 papers in professional journals, enabling the technology to be disseminated among other researchers. The knowledge gains are well documented.

Appendices

Appendix A

Development of New Knowledge and Early Commercial Products and Processes

Technical achievements are listed in Column B - "Technology Developed." And products being sold in the market or processes being used in production are given in Column C - "Product or Process Commercialized." For projects where there is no product or process under current commercialization, a short note concerning the author's opinion about prospects is given in Column C, in italics.

There are seven tables below, one for each of the seven chapters where results for the individual projects are presented.

Table A1. Biotechnology (Chapter 2)

Awardee Name (A)	Technology Developed (B)	Product or Process Commercialized (c)
Aastrom Biosciences, Inc.	Bioreactor technology for expansion of stem and other cells outside the patient's body — used in tests and clinical trials for more than 60 cancer patients.	*Commercialization likely.*
Aphios Corporation	Viral deactivation procedures based on critical fluid technology — demonstrated in cleaning contaminated blood supplies.	*Commercialization possible.*
Molecular Simulations, Inc.	Incorporation of density functional theory (DFT) into easy-to-use software — targeted toward the clinical and biotechnology communities for calculating molecular structures and energies.	Enhanced Turbomole™, a software tool that enables researchers to design new target molecules for drugs and other substances at much lower costs.
Thermo Trilogy Corporation	Genetic engineering processes — demonstrated in the production of pyrethrin, a natural insecticide that is nontoxic to mammals.	*Commercialization not likely.*
Tissue Engineering, Inc.	Techniques and procedures for enhancing tissue growth, including processing tissue, extracting and storing collagen, and spinning and weaving collagen fibers into fabrics for rebuilding lost tissues — demonstrated in production of human protheses.	*Commercialization likely.*

Table A2. Chemicals & Chemical Processing (Chapter 3)

Awardee Name (A)	Technology Developed (B)	Product or Process Commercialized (C)
BioTraces, Inc.	Multiphoton detection (MPD) technology — demonstrated in enhanced immunoassay, chromatography and nucleic acid analysis.	Licensee PetroTraces: applications of the technology in the petrochemical field. Marketed directly by BioTraces: ssMPD™, for clinical diagnostics applications.

Table A3. Discrete Manufacturing (Chapter 4)

Awardee Name (A)	Technology Developed (B)	Product or Process Commercialized (C)
Auto Body Consortium (Joint Venture)	Measurement and process control technology — demonstrated in reduction of dimensional variation in auto body assembly to two millimeters or less.	New measurement and process control systems in auto assembly plants that cut dimensional variation to a world-class standard of two millimeters and below, being implemented in 22 assembly plants in the United States and Canada.
HelpMate Robotics, Inc.	Specialized lidar (light direction and range) scanner and related locating technologies — demonstrated in the development of an intelligent, autonomous mobile robot capable of maneuvering around on a factory or hospital floor.	HelpMate Robots in use as delivery devices in about 100 hospitals in the United States and Canada.
PreAmp Consortium (Joint Venture)	A knowledge-based software system that can extract process "rules" from manufacturing process data — demonstrated in test automations for designing and manufacturing electronics components.	STEP Tools, Inc., an informal participant in the project, has incorporated the project's data application interface in its ST-Developer™ software tool. *Commercialization possible for the complete system.*
Saginaw Machine Systems, Inc.	Intelligent thermal-error correction technology, based on a generic mathematical model of thermal errors — demonstrated in high precision machine tool applications.	Accu-System™ — a new intelligent process controller for increasing the accuracy of machine tools.

Table A4. Electronics (Chapter 5)

Awardee Name (A)	Technology Developed (B)	Product or Process Commercialized (C)
Accuwave Corporation	A process for producing photorefractive materials based on holographics technology — demonstrated in fiber optics telecommunications applications.	Wavelength division multiplexing components: wavelength controllers, wavelength lockers and fiber-optic collimators.
AstroPower, Inc.	Improved liquid-phase epitaxial growth methods and a high-throughput manufacturing technology — demonstrated in the fabrication of high-performance optoelectronic devices such as ultra-bright light-emitting diodes (LEDs).	New epitaxy technology incorporated in all company production processes, including the Silicon-Film™ solar cell.
Cree Research, Inc.	Methods for increasing the quality and size (to 2 inches or more) of silicon carbide single crystals — demonstrated in the fabrication of LEDs and other electronic and optoelectronic devices.	Less expensive blue light-emitting diodes, and improved silicon carbide wafers that permit fabrication of electronic devices that deliver more power, last longer and can withstand very high temperatures.
Cynosure, Inc.	A fault-tolerant optical system — demonstrated for a diode-laser array in a laser surgical application.	*Commercialization possible.*
Diamond Semiconductor Group, LLC	Compact high-current broad-beam ion-implantation technology for altering the electrical properties of materials — enabling production of larger semi-conductor wafers and also useful for other applications.	A new high-current ion implanter, produced by Varian Associates, which incorporates the new techniques developed in the ATP project for implanting dopants on large silicon crystal wafers measuring 300 mm or more in diameter.

Table A4. Electronics (Chapter 5) — continued

Awardee Name (A)	Technology Developed (B)	Product or Process Commercialized (C)
FSI International, Inc.	A dry gas wafer cleaning method — demonstrated in the cleaning of computer-chip wafers during manufacturing (which traditionally has used wet chemical processing), and suitable for the ever smaller features on new generations of chips.	*Commercialization possible.*
Galileo Corporation	New processes for fabricating micro-channel plates (MCPs) using photon detectors and other types of electron multipliers — demonstrated in night vision applications.	*Commercialization possible.*
Hampshire Instruments, Inc. (Joint Venture)	Techniques for laser pumping of high-power laser systems — demonstrated using a laser-diode array to pump a neodymium-doped gadolinium gallium garnet laser for producing low-cost x-rays.	*Commercialization not likely.*
Illinois Superconductor Corporation	Fabrication process for thick-film, high-temperature superconducting materials — demonstrated in the production of radio-frequency components for wireless applications.	Two products — SpectrumMaster™ and RangeMaster™ — installed in 22 cell phone base stations in 12 cities.
Light Age, Inc.	Broadly tunable laser source of ultraviolet (UV) light based on alexandrite laser technology — aimed at applications in science, medicine and photolithography.	Three laser products — nUVo™, PAL/UV™ and PAL/PRO™ — for laser surgery and potentially for other applications, including next-generation chip fabrication and investigation of weather conditions in the upper atmosphere (70 miles above earth).
Lucent Technologies Inc.	Fabrication, testing and alignment techniques for extremely precise aspherical, multilayer-coated mirrors — essential for extreme ultraviolet (EUV) technology, a contender for future lithography systems.	Subcontractor Tinsley Laboratories: application of improved fabrication methods learned in the project to all its aspherical mirror production. Subcontractor Tropel: a specialized interferometer it now uses in other contract work. *Commercialization possible for lithography systems.*
Multi-Film Venture (Joint Venture)	Procedures for interconnecting thin-film integrated circuits — targeted at complex, multi-film module (MFM) electronic device applications and suitable for use when the films are arranged either side by side for flat-panel displays or in layers for compact processor units.	*Commercialization possible.*
Nonvolatile Electronics, Inc.	New procedures that enhance the producibility, circuit density and signal strength of giant magnetoresistance (GMR) materials — demonstrated in random access memory (RAM) and highly sensitive sensor applications.	Highly sensitive sensors based on giant magnetoresistance materials that could be used in brakes, pacemakers, and many other applications.
Spire Corporation	Feedback-controlled, chemical vapor deposition processes — demonstrated in a reactor in a high-throughput mode for fabricating low-cost, high-quality metallo-organic laser diode arrays and other optoelectronic devices.	A prototype reactor being used for limited production of epitaxial wafers.
Thomas Electronics, Inc.	A high-efficiency electron source to enable development of new classes of efficient, bright, flat fluorescent lamps — with wide applications in computer and instrument displays and in high-definition TV screens.	Prototypes and pilot models of flat fluorescent lamps placed with more than a dozen companies for further evaluation and field testing of the new technology in cockpit and other applications.

Table A5. Energy & Environment (Chapter 6)

Awardee Name (A)	Technology Developed (B)	Product or Process Commercialized (C)
American Superconductor Corporation	Wire fabrication and winding techniques for high-temperature superconducting materials — with primary applications in the development of extremely efficient large motors.	CryoSaver™ — electrical wires that carry current into and out of cryogenically cooled devices, which reduces electrical resistance and helps users achieve better operating efficiencies.
Armstrong World Industries, Inc.	Process technology for controlling the microstructure of aerogel insulation materials — targeted toward cost-effectively enhancing its thermal insulating properties.	*Commercialization possible through licensing.*
E. I. du Pont de Nemours & Company	Thin-film fabrication processes for high-temperature superconducting materials — targeted toward low-cost electronics components.	New thin-film components, incorporated into magnetic resonance imaging equipment for use in hospitals and clinics.
Michigan Molecular Institute	Fundamentals of polymer compatibilization — targeted at demonstrating that mixed plastics (either from waste streams or virgin) can be successfully combined into materials with high performance characteristics.	Prefabricated wall units using compatibilized plastic panels, made by Eagle Plastics Systems of Florida in collaboration with University of Florida researchers.

Table A6. Information, Computers and Communications (Chapter 7)

Awardee Name (A)	Technology Developed (B)	Product or Process Commercialized (C)
Communication Intelligence Corporation #1	New data-entry software technology that recognizes each user's natural handwriting without "training" the computer or the user — intended to allow a pen and tablet to be used instead of a keyboard.	Enhanced Handwriter® MX™ — a stylus-and-pad system that recognizes hand-printed text.
Communication Intelligence Corporation #2	A recognition system for hand-written Chinese — intended to replace a cumbersome data-entry system that uses a keyboard.	*Commercialization likely.*
Engineering Animation, Inc.	Core algorithms to enable the creation of 3D images from sets of 2D cross-sectional images — with an initial application targeting animated visualization of the entire human body.	Three CD-ROMS (The Dissectable Human™, The Dynamic Human™ and CardioViewer 3D™), plus two medical textbooks that are used to train medical personnel.
ETOM Technologies, Inc.	Techniques for writing and reading more than one bit of information at the same spot on an optoelectronic disk — and new optoelectronic disk materials.	*Commercialization not likely.*
Mathematical Technologies Inc.	Mathematical methods for managing successive digitized video images — with the purpose of removing defects from one or more individual frames of new or archived movies.	Digital Restoration Services™, integrated into postproduction movie processing at a number of facilities in the entertainment industry.
Torrent Systems, Inc.	Component-based software and user interface for building parallel processor applications — a tool for the professional programmer.	Orchestrate™ — an innovative component software prototype system that enables a variety of hardware systems to handle massive amounts of data and increase processing efficiency.

Table A7. Materials (Chapter 8)

Awardee Name (A)	Technology Developed (B)	Product or Process Commercialized (C)
AlliedSignal, Inc.	Near-net-shape gelcasting process that is safer and less costly than conventional gelcasting based on acrylamide, a cumulative neurotoxin — demonstrated by making structural ceramic parts for very high-temperature applications.	*Commercialization likely.*
Geltech Incorporated	Room temperature net-shape gelcasting method — demonstrated in the production of high-quality, silica glass micro-optics.	Materials processing and mold fabrication methods used to develop a porous-glass product which is a component of a home sensor for toxic gases.
IBM Corporation	Nonlinear optical polymeric waveguides — demonstrated in the development of inexpensive optoelectronic switches for computers and communications systems.	*Commercialization not likely.*

Appendix B

Terminated Projects

A few ATP projects that are announced are not carried through to completion. Some of them never actually start. Others are stopped significantly short of completing their proposed research agenda.

Announced projects may not start or may be stopped prior to completion, for a variety of reasons. But the main reason observed to date centers on difficulties with joint venture agreements. Sometimes companies that plan to collaborate may find last-minute obstacles to signing a joint venture agreement and decide to disband their planned partnership.

A project may also be derailed because technical challenges are found to pose too high a risk from the company's perspective, even with the ATP award. Or, a company—particularly a small company—may encounter cash-flow difficulties and have to drop its research activities to pursue short-term survival. In addition, the technology and business climate may change in ways that obviate the need for a project, or alter participants' willingness to proceed. Sometimes, companies simply change their strategic directions and get out of research areas they formerly wished to pursue. Over the multi-year span of ATP-research projects, a variety of personal, business, and technical circumstances can develop that alter original plans. Such change is to some extent inevitable.

From the beginning of the program in 1990 through March 1997, the period covered by this report, 12 ATP-announced projects that were scheduled to complete during this period did not complete, and, therefore, are not included in the group of projects addressed in the body of this report. Of the 12, four were announced but then were canceled without ever getting underway; eight went some distance in their research agenda, but were stopped without completing substantial portions of their planned research. The ATP contributed a total of $9.4 million to the eight projects that went part way, and $0 to the four that were stopped up front.

The following analysis identifies the major factor that contributed to the termination of each of the 12 projects, while providing anonymity to the companies to preserve their rights regarding proprietary information:

Case 1: The company, a single-company awardee, found it necessary to reassign key R&D personnel in order to pursue critical short-term objectives that were unanticipated at the time it submitted the proposal. The company requested that the project be terminated before any costs had actually been incurred, and the ATP agreed.

Case 2: ATP chose not to renew this single-company project after the first year of performance because it was not demonstrated that the company could successfully carry out the technical effort proposed.

Case 3: The company, a single-company awardee, requested that the project be terminated following its acquisition by another firm which did not wish to pursue the ATP project's area of technology development, and the ATP agreed.

Case 4: As a result of financial trouble, which entailed severe restructuring, this single-company awardee decided to end its research in the technical area of its ATP project in order to concentrate its limited resources in other areas with more immediate prospects for generating needed revenue.

Case 5: Members of the joint venture wished to stop the project due to changes in market trends in the relevant technology areas, and the ATP agreed.

Case 6: The company requested that the project be discontinued when results produced from its early work on the project were not as promising as had been expected, and the ATP agreed.

Case 7: A key member of the planned joint venture membership withdrew from the project during the negotiating phase, and ATP determined that, as a result, the project was no longer competitive against the ATP's selection criteria, and canceled it before it got underway.

Case 8: The single-company awardee ran into financial trouble, and needed to stop its research effort in order to focus on short-term survival.

Case 9: The joint venture members were unable to correct organizational deficiencies identified by the ATP, and the ATP canceled the award before research work began.

Case 10: The ATP elected not to renew this joint venture award because it determined that the project was unlikely to achieve its technical objectives in a number of different areas and that the joint venture organization was not functioning effectively either managerially or administratively.

Case 11: The companies failed to negotiate with one another the terms of their joint venture agreement, and subsequently proposed significant changes to their plan and joint venture team. The ATP rejected the revisions as not competitive against ATP selection criteria, and the project was never started.

Case 12: The companies were unable to reach agreement among themselves on the terms and conditions of their joint venture project, and it was never started.

End Notes

Introduction

1 The selection criteria in effect from 1990 through 1998 are as follows: 30% for scientific and technical merit; 20% for potential net broad-based economic benefits; 20% for adequacy of plans for eventual commercialization; 20% for level of commitment and organizational structure; and 10% for experience and qualifications. The criteria are simplified for 1999 competitions: 50% scientific/technical merit and 50% potential broad-based economic benefits. A detailed description of the earlier criteria are contained in Advanced Technology Program Proposal Preparation Kits published on or before December 1997 (the kit is updated periodically). The current edition of the kit and other program materials may be obtained by calling 1-800-ATP-FUND, or viewed at the ATP Web site, http://www.atp.nist.gov.

2 For a description of the ATP evaluation plan, see Ruegg (1998).

3 EAO's published economic studies are generally available at the ATP Web site, http://www.atp.nist.gov, or can be requested by calling 301-975-4332.

Chapter 1

1 Nonprofit institutes are no longer eligible to apply as single applicants. Two nonprofits, one of which is in this grouping of 38 projects, received single-applicant awards during the early years of the program, before this change in eligibility by Congress.

2 Does not add to 100%, due to rounding.

3 Under a recent change in the ATP cost-share rules, companies as large as the Fortune 500 companies who apply as single applicants are required to cover at least 60% of total project costs, but none of these first completed projects are affected by the change.

4 Proposers to the ATP are asked to identify potential markets for products that might one day incorporate the new technology to be developed in the project. They are also asked to discuss plans and pathways for commercializing and diffusing downstream products or processes based on the technology, assuming that their proposed research objectives are achieved and commercialization becomes technically feasible. But the ATP's funding contribution to the project is restricted to research activities and may not be used for product development.

5 "New" in this context means that the product or process is new in fundamental terms or that it is significantly improved over earlier versions. The 38 completed projects under study here have commercialized products or processes of both kinds. And the term "product" is also used, where there is little chance of confusion, to include both products and processes.

6 Figure 2 and the explanatory text are taken from Ruegg (1999). An earlier version of Figure 2 may be found in Ruegg (1994).

7 See Powell (1997).

8 See Laidlaw (1997).

9 The Torrent Systems project was funded in ATP's Component Based Software Focused Program Competition in 1994.

10 As noted above, ATP funding and the research and development work it supports typically are part of a larger picture. A recipient frequently will have started some related research and development work before receiving ATP funds and may continue with additional efforts after the ATP project has been completed. It is unusual to find a project in which there is an exact one-to-one matching between technical achievements of the ATP-funded project and an award citation. For all of the entries in the table, company officials confirmed that the award was for achievements that were at least partly the result of the ATP-funded project.

11 For two projects, the company response to the question about patent applications that had been filed but for which the grant had not yet been received was "several" instead of a precise number. For tabulation purposes, the number four has been used; it is the simple

average of the number for the ten projects for which a precise answer was given.

12 Includes projects reporting "several" papers.

13 For a detailed treatment of the relationship between spillover benefits (knowledge and market) and commercialization, see Jaffe (1997). With reference to spillovers that occur as a new product is sold commercially, he notes: "Market spillovers will not be realized unless the innovation is commercialized successfully. Market spillovers accrue to the customers that use the innovative product; they will not come to pass if a technically successful effort does not lead to successful commercialization" (p. 12). In commenting on spillovers that occur because new knowledge is disseminated to others outside the inventing firm, he observes: "Note that even in the case of knowledge spillovers, the social return is created by the *commercial use* [emphasis in original] of a new process or product, and the profits and consumer benefits thereby created" (p. 15).

14 There were several reasons why answers were not available for the six remaining projects. In one case, the lead company was out of business and the owner deceased. In another instance, the company had changed hands twice, and the current owners were not knowledgeable about the role of the ATP. In other cases, key staff on the project had left the company. Finally, answers in a few cases were too ambiguous to tabulate.

15 Project leaders for three of these 21 projects said their companies would have gone out of business had the ATP award not been made.

16 Another factor potentially influenced by ATP funding — the scope and scale of the project — was not explicitly covered in the interviews for this report.

17 Mansfield, et. al. (1977).

18 When the awardee supplied a range, the midpoint is used for this tabulation. One company, HelpMate Robotics, said the research was completed "much sooner" than it could have been done without the ATP funds. It was counted in the 21 months lag group, which is the median.

19 It is unclear whether the authors used 8 or 15 years in their calculations for this set of innovations. Therefore, both numbers are given here.

20 See Ruegg (1998) and Powell (1997).

21 The ATP's Economic Assessment Office has commissioned detailed economic evaluation case studies for selected projects. See Ruegg (1998).

22 See RTI (1998), pp. 1-22, table 1-3.

23 See Consad Research Corporation (Consad) (1996).

24 See Consad (1996). The Consad study estimated economywide benefits for applications of the technology in the automobile industry only, so its estimates contain no information about potential benefits from application of the new technology in other industries.

25 See RTI (1998), pp. 1-23, table 1-4.

26 See RTI (1998), pp. 1-22, table 1-3.

Chapter 2

1 See Research Triangle Institute (RTI) (1998), p. 3-3.

2 Ibid., pp. 1-22, table 1-3.

3 See RTI (1998), p. 1-22, Table 1-3.

Chapter 4

1 These estimates and others below are from Consad Research Corporation (1997).

Chapter 7

1 EAI Web site, at http://www.eai.com.

2 *Technology Transfer Report* (1994).

3 Gupta (1995).

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About the Advanced Technology Program

The Advanced Technology Program (ATP) is a partnership between government and private industry to conduct high-risk research to develop enabling technologies that promise significant commercial payoffs and widespread benefits for the economy. The ATP provides a mechanism for industry to extend its technological reach and push the envelope beyond what it otherwise would attempt.

Promising future technologies are the domain of the ATP:

- Enabling technologies that are essential to the development of future new and substantially improved projects, processes, and services across diverse application areas;
- Technologies for which there are challenging technical issues standing in the way of success;
- Technologies whose development often involves complex "systems" problems requiring a collaborative effort by multiple organizations;
- Technologies which will go undeveloped and/or proceed too slowly to be competitive in global markets without the ATP.

The ATP funds technical research, but it does not fund product development. That is the domain of the company partners. The ATP is industry driven, and that keeps it grounded in real-world needs. For-profit companies conceive, propose, co-fund, and execute all of the projects cost-shared by the ATP.

Smaller companies working on single-firm projects pay a minimum of all the indirect costs associated with the project. Large, "Fortune-500" companies participating as a single firm pay at least 60 percent of total project costs. Joint ventures pay at least half of total project costs. Single-firm projects can last up to three years; joint ventures can last as long as five years. Companies of all sizes participate in ATP-funded projects. To date, more than half of the ATP awards have gone to individual small businesses or to joint ventures led by a small business.

Each project has specific goals, funding allocations, and completion dates established at the outset. Projects are monitored and can be terminated for cause before completion. All projects are selected in rigorous competitions which use peer-review to identify those that score highest against technical and economic criteria.

Contact the ATP for more information:

- On the World Wide Web: http://www.atp.nist.gov;
- By e-mail: atp@nist.gov;
- By phone: 1-800-ATP-Fund (1-800-287-3863);
- By writing: Advanced Technology Program, National Institute of Standards and Technology, 100 Bureau Drive, Stop 4701, Gaithersburg, MD 20899-4701.

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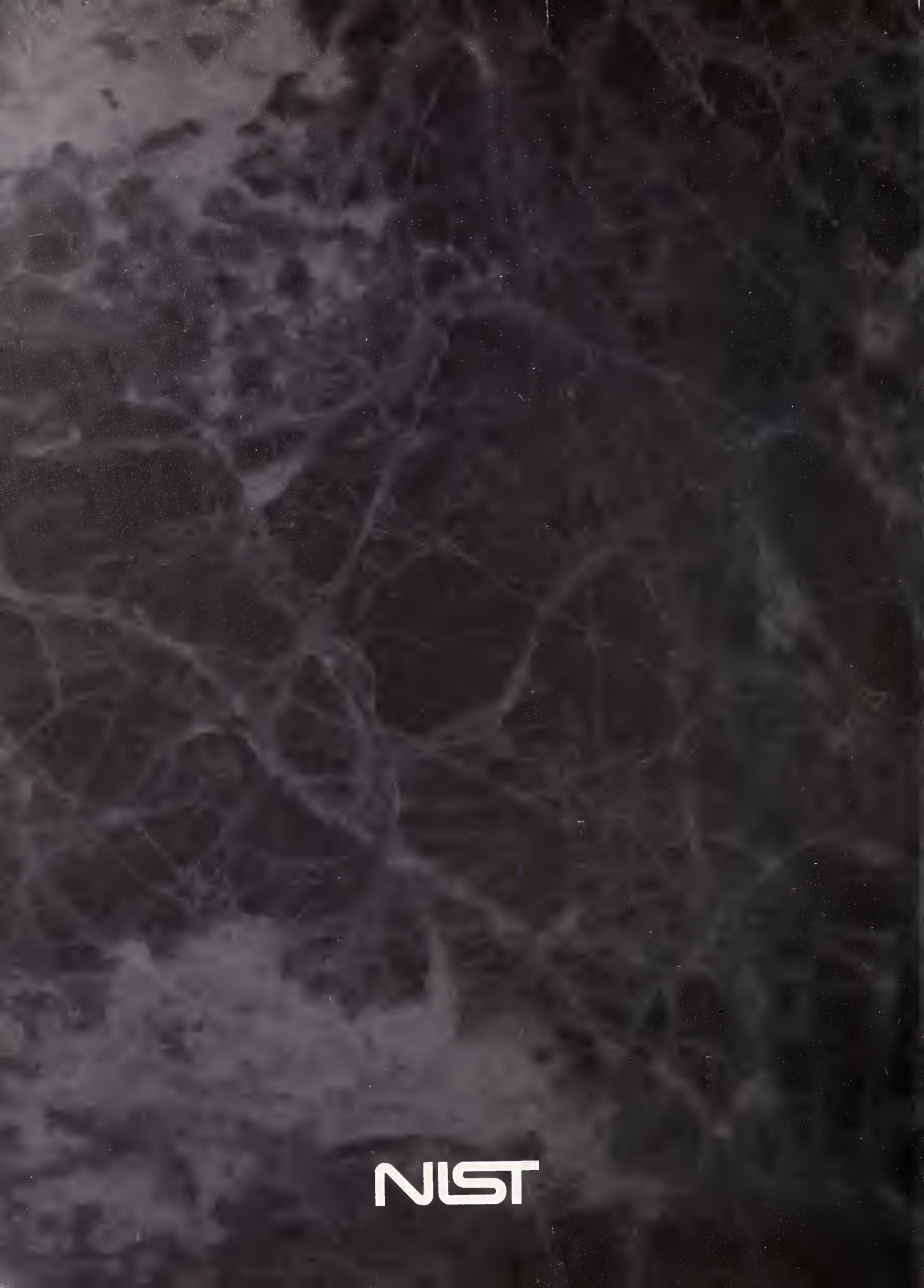
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