ADVANCED TECHNOLOGY PROGRAM

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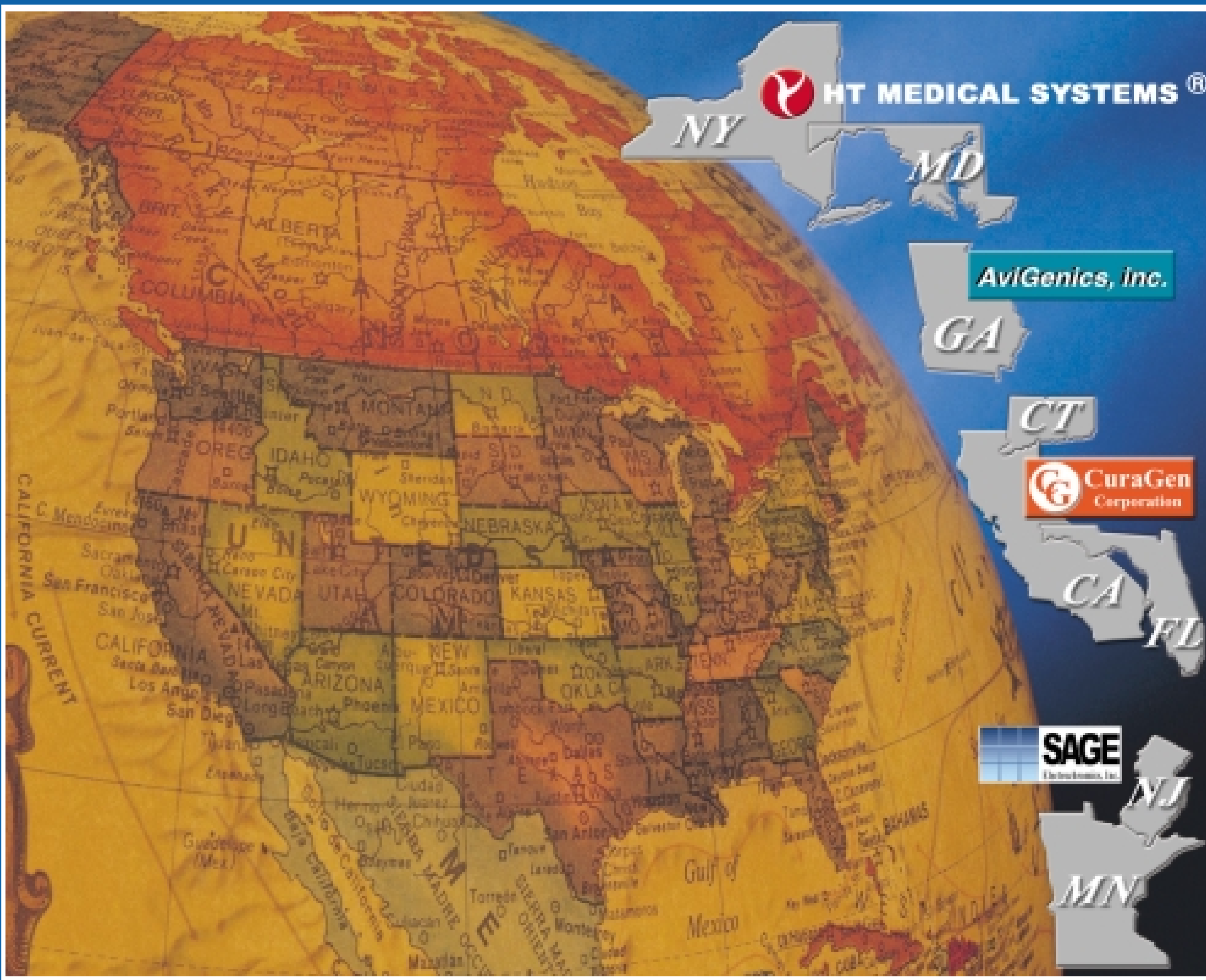
Reinforcing Interactions Between the Advanced Technology Program and State Technology Programs

Volume 2: Case Studies of State and Federal Support to High-Tech Start-up Companies



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REINFORCING INTERACTIONS BETWEEN THE ADVANCED TECHNOLOGY PROGRAM AND THE STATES

VOLUME 2: CASE STUDIES OF TECHNOLOGY PIONEERING START-UP COMPANIES AND THEIR USE OF STATE AND FEDERAL PROGRAMS

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Abstract

This report describes the evolution of four *technology-pioneering* companies, their use of state government programs, and the nature of the state and federal government support received by these companies. Since all four companies were awarded funds from the Advanced Technology Program (ATP) of the U.S. Department of Commerce, we pay particular attention to the relationships between the support provided by state programs and that of the ATP. These cases were selected from states providing a broad array of programs to support the formation and growth of new businesses. We find that that all four of our technology pioneers drew on the resources of public (state) universities. By investing in university research capabilities, encouraging cooperative research activities between faculty and industrial partners, and providing industry access to university laboratories and equipment, state governments have served as a major resource for this type of start-up company in achieving its R&D goals. In addition, for technology-pioneering companies having difficulty in raising funds from private sources, state programs may complement the ATP by assisting these companies in meeting ATP's cost-sharing requirements.

Keywords: Advanced Technology Program, state governments, technology-pioneering start-up companies, public-private R&D partnerships.

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Executive Summary

This report is Volume 2 of a two-part series on the services and programs provided by state agencies to businesses involved in technology creation and commercialization. Volume 1 is a guide that catalogues state programs by the types of challenges — technical, market, and business — that a small company is likely to face at various stages in the creation and development of a business in a new technology area. This companion report describes the evolution of four new companies, illustrating the specific roles of state and federal programs in support of these companies' research and development (R&D) activities. We pay particular attention to the role of the Advanced Technology Program in relation to the resources provided by other federal government programs and the states.

During the 1980s, states embarked on a number of initiatives to support the growth of new enterprises within their borders. In this report, we focus on new enterprises that from their inception were intent on developing and eventually commercializing new technologies. We call this type of start-up company a *technology pioneer* to distinguish it from new enterprises that are not attempting to advance the state of the art in a particular technology area. In addition to the usual problems involved in starting a business, the *technology pioneer* has to invest in research and attract patient investment capital willing to support the development of a technology that may be years away from generating any revenues for the firm. The case histories included in this report illustrate the kinds of state resources and government programs used by technology pioneering companies in the early stages. All four companies discussed in this report were ATP award recipients between 1992 and 1998. Thus, these cases illustrate public-private partnerships involving both federal and state government resources in the development of new ventures.

The following companies are the focus of our case study analysis.

The oldest of these is HT Medical Systems, Inc. founded in Maryland in 1987 under the name High Techsplanation for the purpose of developing and selling customized multi-media educational materials to pharmaceutical and medical instrument producing companies. In the early 1990s, HT Medical began its development of a new interactive "virtual reality" (VR) simulator for medical procedures that was designed to "feel" as if the person using the equipment was actually performing those procedures on a live patient. The company is still headquartered in Maryland and has no satellite operations in other states.

SAGE Electrochromics, Inc., was first established in New Jersey in 1990 to develop electrochromic technology as coatings on glass to control the transmission of light, heat, and near infrared radiation. This technology can be applied to windows, large area information displays, eyewear and photographic and optical filters. In 1998, SAGE migrated to Minnesota in order to be close to its commercializing partners. SAGE is partnering with VIRACON, a producer of high-performance architectural glass for commercial buildings. The company expects to have its energy-saving SAGEGLASS® windows to be available for beta testing and demonstration projects in 2001.

CuraGen, Inc., was founded in Connecticut in 1991 and also had maintained laboratory facilities in Florida from 1997 to 2000. The firm specializes in the development of genomics technology and bio-informatics systems that accelerate the discovery of new therapeutic and agricultural products.

Lastly, AviGenics, Inc., was established in 1996 in Georgia, where it is still located. This new company specializes in developing avian transgenesis technology for altering the embryos of chickens. The goal of the company's R&D program is to use this technology to alter hens in order to produce eggs enriched with pharmaceutically valuable proteins. These proteins can then be used as raw materials for further processing by biopharmaceutical companies.

In their short histories, these four companies have drawn on the resources of a total of eight different states: California, Connecticut, Georgia, Florida, Maryland, Minnesota, New Jersey and New York. CuraGen has benefited from the resources and government programs of California, Connecticut, Florida and New York. To date, SAGE Electrochromics' involvement with state agencies has been limited to New Jersey. Although the company has thus far received no direct assistance from the State of Minnesota, SAGE derives a location advantage in Minnesota from its close proximity to its commercializing and R&D partners (VIRACON, a wholly-owned subsidiary of Apogee Enterprises, and the 3M Company). HT Medical Systems, Inc. has benefited from the assistance provided by New York and Maryland. AviGenics has benefited from a number of programs in the State of Georgia.

These companies appear to have benefited the most from certain specialized resources provided by state governments and by the regional economies within states:

- laboratory and office facilities of universities,
- financial incentives to faculty for research collaborations with industry partners,
- seed capital, and
- regional clusters of firms that specialize in R&D in related technical fields, or that specialize in the manufacture of materials and/or products that potentially stand to benefit from the R&D of our technology pioneers.

University Resources

Through their support of research facilities and personnel at public universities, California, Connecticut, Florida, Georgia, New Jersey and New York provided the infrastructure enabling these technology pioneers to undertake their early stage R&D. Without access to the laboratory facilities and the research capabilities of the Center for Ceramic Research at Rutgers University, SAGE Electrochromics, for one, would not have been able to pursue the type of R&D needed to develop its SAGEGLASS® technology. Although AviGenics is only four years old, this company appears to be following a path similar to SAGE in its exclusive reliance on the laboratory facilities and research capabilities of the University of Georgia. By contrast, CuraGen has drawn on university research capabilities from several states, including California (University of California--Berkeley), Connecticut (University of Connecticut and Yale University), Florida (University of Florida), and New York (Cornell University). For HT Medical, its research collaborations involved state universities in Maryland (University of Maryland) and New York (State University of New York at Plattsburgh).

Like twelve other states identified in the appendix of the *Guide* (Volume 1), Connecticut, Georgia, Maryland, and New Jersey have programs designed to encourage faculty at local universities to collaborate on research projects with industry partners. These programs are structured in similar ways. State funds go directly to the collaborating university-based researchers, while the partnering company provides matching funds (or in-kind resources) for the project. The partnerships between industry and universities supported by this type of program include: SAGE with faculty at Rutgers University; CuraGen with Yale University faculty; HT Medical Systems with University of Maryland faculty; and AviGenics with University of Georgia faculty. SAGE, CuraGen and AviGenics provided the cost share for these collaborations from their ATP awards.

Geographic proximity to universities appears to be important to new firms in need of expensive laboratory facilities and experienced research staff, as is evident in the case studies of SAGE and AviGenics. For these companies, the resources provided by the university were so important that the university's role was akin to a technology incubator, since neither company could have carried out its R&D program without the research resources available to the firm through its university partner.

Ties between a technology pioneering company and a university need not always be local. The Foundation of the State University of New York at Plattsburgh supported HT Medical Systems (in Maryland) to develop new educational methods and tools for the university's teaching programs in nursing and other health care professions. SUNY Plattsburgh's teaching laboratory provided a specialized test-bed site for the virtual reality simulation. Similarly, for several years, CuraGen, a Connecticut-based company, maintained collaborative research arrangements with the University of Florida at Gainesville and the University of California at Berkeley.

Even though the parties may be located in different states, research collaborations between companies and universities may still be beneficial to the regions in which both parties are located. University faculty and their students incorporate the knowledge acquired from a particular collaboration in their continuing research activities. Eventually that research may lead to new technological advances, which are taken up by other firms. Moreover, as long as the community of research institutions in the state continues to be creative, that region is likely to remain fertile ground for the formation of new technology-pioneering enterprises.

Public Seed Capital Funds

In Volume 1, the *Guide* identifies thirteen states that provide seed capital funding to new companies through non-profit organizations established by a state government agency. Two of our technology pioneering companies, CuraGen and HT Medical Systems, benefited from such programs. In the case of HT Medical, two funds -- the Maryland Health Care Product Development Corporation and the Enterprise Investment Fund -- established by the state of Maryland are supporting the company's marketing and commercialization of products following the completion of its ATP-funded research projects. Through the risk capital investment program of Connecticut Innovations, Incorporated (CII), the state of Connecticut provided working capital funding to CuraGen when the company was still focused solely on R&D.

Both Maryland and Connecticut anticipate a return on these investments. For Maryland, the return is in the form of royalty payments on products sold by HT Medical. CII received shares of common stock in CuraGen in exchange for its investment. As a consequence of the increase in the valuation of the stock since the company went public in 1998, CII has already received a high rate of return on its initial investment.

Only three states identified in the *Guide* (California, Connecticut and Ohio) have programs that provide matching funds to companies receiving cost-sharing awards from the ATP. Yet, this too may be important to companies when their technologies are at the proof of concept stage, as was the case with CuraGen.

Industry Clusters, Regional Specialization and Infrastructure

Two of the case histories presented in this report – SAGE Electrochromics and AviGenics – illustrate the importance of regional specialization to technology pioneering companies. In the early stages of its R&D, SAGE benefited from the concentration in New Jersey of R&D activities in materials and chemicals, and the specialized industry-university research center and laboratory facilities in ceramics at Rutgers University. In order to exploit the synergy of co-location with its partner during the crucial scale-up phase of production, SAGE moved from New Jersey to Minnesota. In addition to the specialized research resources of the university, AviGenics has also benefited from the investment in the company by a local poultry producer. In this case, both the specialized R&D resources and the downstream production capabilities are located in the same region.

Conclusions

In sum, public resources have played a critical role in the ability of technology pioneering companies to develop their technologies and their businesses. Moreover, the cases illustrate how state and federal government resources complement one another. In each case, the ATP was an important source of funds supporting early stage R&D activities. State programs provided capital and assistance in the business development of these young companies (both at the R&D stage and later, in the commercialization phase). Through their support of university-based research of relevance to industry, state governments provide the technology infrastructure and access to research capabilities that these new firms needed to carry out the R&D projects funded by federal agencies. Hence, this combination of state resources serves as a direct complement to ATP funding of small firms' R&D projects.

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1. *Introduction*

1.1 Types of State Assistance for New Enterprises

In the 1980s, state after state embarked on programs designed for "growing new enterprises." Under this new approach to economic development policy, state governments invested in new research capabilities at public universities for faculty to engage in joint research and development projects with industry partners.[1] States also set up new funding mechanisms (e.g., loans, loan guarantees, or equity investments) to provide capital for new ventures founded within the state. These new policies and programs are focused on creating support systems for nascent businesses within the state's borders.

Volume 1 of this study is a guide to the resources that state governments offer to new and existing businesses. The guide includes programs for start-up technology pioneering companies along with business development and technical assistance programs that are routinely available to all types of enterprises within the state. In 1995, expenditures for this wide range of assistance to business by all state governments exceeded $400 million.[2] Although these are all characterized as "technology programs," a broad array of business development and technical assistance services, as well as economic development programs are included under this umbrella term.

The Guide classifies state programs by the following types of assistance: technical, marketing, and business. Technical assistance includes university-industry research centers, as well as specialized testing or laboratory facilities such as the Colorado Advanced Photonics Technology Center. Marketing assistance includes a variety of services to assist firms in identifying new customers and markets, such as the Massachusetts Export Center, which showcases local businesses for visiting international business delegations. Business assistance includes programs that provide financial assistance, personnel recruitment and workforce development assistance, as well as special incentives to businesses to locate in distressed areas. States may provide early stage equity financing, but rarely directly fund research and

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1 For further details, see Feller (1988).

2 Source: State Science and Technology Institute (1995).

development projects of firms. Instead, the state resources that support firms' R&D activities are closely tied to the capabilities and the cooperative industrial research programs of local colleges and universities.

1.2 The States and the Advanced Technology Program

The highest levels of federal and state governments have begun executing strategies for generating closer state-federal cooperation in the technology policy arena. In 1995, the National Governor's Association and the White House Office of Science and Technology Policy emphasized the potential to

- "achieve new economic growth, high quality jobs, and globally competitive businesses by effectively leveraging U.S. science and technology leadership and resources through partnerships among states, the federal government, industry and universities." (The State-Federal Technology Partnership Task Force, 1995)

At the program level, the Advanced Technology Program (ATP) of the National Institute of Technology (NIST) early recognized the states' mutually reinforcing role, and has consistently sought state cooperation. In 1996, a non-financial memorandum of understanding (MOU) between the ATP and the Science and Technology Council of the States was signed. The MOU foresaw cooperation in outreach, technical and business assistance to applicants, and in facilitating the formation of joint ventures.

The mutual dependency between the ATP and the states is particularly evident in the role that universities play in ATP-funded projects. Universities have been important research partners in 270 of the 468 ATP projects funded between 1990 and 1999. Over the life of the ATP, award-winning companies have partnered with 118 universities from 41 states. These universities are located in every region of the country and in most cases (65%) the universities were involved multiple times in ATP projects.[3] Many state-supported universities have provided critical research expertise and specialized laboratory facilities to companies that have won ATP awards. In turn, the ATP has provided funding through industry that

[3] The top 25 universities involved in ATP projects come from nineteen different states: AL, AZ, CA, FL, GA, IA, IL, MA, MD, MI, MN, NC, NJ, NY, OH, PA, TX, UT, WI.

indirectly augments state funding for university-based research. Thus, the states and the ATP play a mutually reinforcing role in supporting industry's R&D activities.

There are, of course, important differences between the programs operated by states and the Advanced Technology Program. As a program of the federal government, the ATP is concerned with the development of technologies that benefit the nation as a whole. To the ATP, a funded project that leads to the development of a new technology that is successfully commercialized by US-based firms would be considered a success, even though some of the individuals firms participating in the original project may not have directly benefited from that success. Moreover, since many of the firms (72 percent) receiving ATP awards participate in joint venture projects with another company, it is possible for one JV partner to be more successful than another. One JV partner may grow, while another does not. By contrast, to a state program intent on developing new businesses, success is largely viewed in terms of the success of the individual firm and its growth within the region.

1.3 Research Questions and Methodology

In this report, we focus on new enterprises that from their inception were intent on developing and eventually commercializing new technologies. We call this type of start-up company a *technology pioneer* to distinguish it from new enterprises that do not have a strong technology focus. Like other start-ups, technology pioneering companies have some of the same needs for government (and other external sources') assistance in developing the managerial expertise and the necessary capital to grow the enterprise. In addition to the usual problems involved in starting a business, the *technology pioneer* has to invest in research and attract patient investment capital willing to support the development of a technology that may be years away from generating any revenues for the firm. Because of the substantial commitment to R&D necessitated by their technology based business strategy, these pioneers may tap a very different set of state resources than other new firms that are premised on selling a product or service that requires little up-front investment in R&D. Considering the wide variety of programs offered by state governments, our first research question is:

- ***What state-provided assistance and programs do technology pioneers use, especially in the early stages?***

Many of the state and local economic development programs and policies discussed in Volume 1 have as their goal the creation (or retention) of regional clusters of entrepreneurial activity and R&D-intensive firms. There are multiple facets of regional economies that are important to the growth of new businesses and to innovation.[4] For firms intent on developing new technologies, proximity to other innovators and access to the resources of universities (and their graduates) may be especially important. Moreover, a high concentration of scientists and engineers within a region not only serves as a reservoir of specific technical expertise that may be tapped by local industry but also is a potentially important source of new entrepreneurs. Regions that provide proximity to customers or a concentration of potential consumers may also be attractive to firms in commercializing a new technology. Scale-up, prototype development and beta-testing of a new technology are facilitated when a company that is developing a new technology has close contact with potential customers. Some regional economies may have greater concentrations of firms with complementary technical expertise, while other regions provide greater opportunities for interactions with potential customers. Hence, locales that may be rich in resources for a firm to carry out its R&D may not provide opportunities for close contacts with potential customers. Our second research question concerns the attributes of the local or regional economy within the state that are important to technology pioneering enterprises.

[4] For the importance of proximity to other innovators, see Jaffe, Trajtenberg, and Henderson (1993). For a comparison of the regional advantages of the computer industry in Silicon Valley in California and the Route 128-Metro Boston region in Massachusetts, see Saxenian (1994).

We ask:

- ***What kinds of linkages do technology pioneers have to other businesses and universities in the region? Are these linkages related to the resources needed by the company to carry out its own R&D or are they important for bringing the technology to market and use by potential customers?***

We have chosen to address these questions through an exploration of four case histories of technology pioneering companies. All four firms were winners in the national competitions of the ATP. Thus, these cases illustrate public-private partnerships that involve both federal and state government resources in support of private ventures. In each case, we identify the stage of development of the company when it received assistance from a state government, the form of that assistance from state agencies and public universities, and how that assistance dovetailed with the federal government's support of the R&D activities of these companies. In all cases, the technologies are being developed with a combination of public and private resources and are intended primarily for commercial (i.e., non-government) use.

Although many states have programs to support new enterprises, few states have instituted a broad array of technical and business assistance programs that support a new enterprise at every stage of its efforts to pioneer a new technology from the initial conceptualization, through various phases of research and development, and through the commercialization stage. In Volume 1, our review of the types of programs offered by each state indicates that there are ten states – California, Connecticut, Georgia, Illinois, Maryland, Massachusetts, New Jersey, New York, and Pennsylvania – that offer a broad spectrum of programs that address the special challenges facing start-up enterprises that are pioneering new technologies. In order to identify the choices and the combinations of technical and business assistance programs that a technology pioneer may use, we limited our selection of case studies to ATP-funded companies that originated in (or had ties to the resources of) those states with the greatest variety of program options.

Our four case studies illustrate the selective use of this array of state resources by technology pioneering companies. In their short histories, these four companies have drawn on the resources of a total of eight different states: California, Connecticut, Georgia, Florida, Maryland, Minnesota, New Jersey and New York.

To carry out the research, we required the cooperation of each company and the state agencies that had provided the assistance. For each of the companies, managers were willing to provide information concerning the assistance received from state agencies and institutions and to identify the contribution of these resources to their enterprises' growth and development. Our selection of cases was assisted by the recommendations of state technology program officers who cooperated with us in this study and of the staff of the Economic Assessment Office at the ATP. Primary sources of information and data include interviews with company principals, ATP program managers and officials at state development agencies, internal company documents, company prospectuses and other documents in the public domain.

1.4 Organization of the Report

The rest of this report is organized as follows. Beginning with the oldest company (HT Medical Systems) and ending with the youngest (AviGenics), we describe the history of each company, its use of state and of federal R&D programs, and related attributes of the regional economy.[5] Following the four case studies, we provide a synthesis of our findings. We identify common elements in program structures among the states, and in the use of certain state resources by our four technology pioneering companies. Finally, we offer our observations and conclusions concerning the role of state resources in these firm's

[5] Certain commercial firms, trade names, and products are identified in this report in order to specify aspects of the NIST Advanced Technology Program. Such identification is not intended to imply recommendation or endorsement by the National Institute of Standards and Technology, nor is it intended to imply that related products or services are necessarily the best available.

life histories to date, important differences between the roles of the ATP and the states in the evolution of these companies, and region-specific factors affecting the location decisions of these firms.

2. HT Medical Systems, Inc., Improving Medical Practice Through Virtual Reality Simulations

In 1987, HT Medical was founded by a local college graduate, Gregory L. Merril, in Rockville, Maryland. The firm was then known as High Techsplanations and specialized in developing multi-media educational materials for medical equipment producers, government agencies, and schools of medicine and nursing. In 1992, the company began to develop a new, interactive "virtual reality" (VR) simulator for medical procedures that would feel as if the person using the equipment were actually performing those procedures on a live patient. As a teaching tool, this technology would allow medical professionals in training to acquire experience and skills in performing these procedures before having to perform them on a live patient. This early R&D was supported by Merck, a large pharmaceutical company, and by two SBIR grants from the Department of Health and Human Services. Although HT succeeded in developing a research prototype system in 1993, it would take another five years of R&D effort for the company to have a commercial product ready for deployment on an ordinary desktop computer.

Prior to HT Medical's innovation, virtual reality simulations did not involve any interactions of the user with its environment. For example, in a flight simulator, which is used in the training of pilots, the simulation "ends" when the flight ends, either with a successful simulated landing or a crash. HT Medical's technology was the first, real-time interactive simulation that incorporated a realistic "touch and feel" interactive experience. As a result, the first prototype was computationally intensive and required sophisticated programming skills to operate. Moreover, in order to be an effective teaching tool for the medical professions, the simulation had to include a number of different scenarios that reflect known variations in anatomy of individuals and the possibility of complications that a practitioner ordinarily encounters in these procedures. In addition to the large data and computational requirements, HT

Medical had to design a robotic technology that would provide the user the type of feedback sensation that the practitioner would experience in carrying out the procedure on a live patient.

HT Medical has won a number of awards for its VR technology. *VR World*, a trade journal, evaluated the company's simulator as the best virtual reality application of 1995. In 1996, HT Medical was a finalist for the Innovation of the Year Award of *Computer World*, a trade journal published by the Smithsonian Institute. Again, in 1998, the company's first commercial VR system, CathSim®, won a World Medal in the educational media category at the New York Festivals' International Interactive Multi-Media Awards.

CathSim® was introduced in March of 1998. It is a "computer-based system for intravenous therapy simulation."[6] Using the robotic arm, the student is "…able to sense the tactile response of needle and catheter insertion – from the "pop" as the needle enters the skin through entry into the vein lumen." The simulation software provides different patient cases, with varying levels of difficulty and complications.

Two new products were introduced in 1999. The first of these, PreOp® Endovascual Simulator, is designed for training physicians in procedures such as balloon angioplasty, stent placement, and pacemaker leads placement. This system:

- "integrates pharmaceuticals and devices used in the actual procedure – such as thrombolytic agents, contrast media, catheters, sheaths, guide wires, and stents…[The simulator] duplicates the look and feel of the actual procedure [by incorporating] tactile feedback so that clinicians manipulating these devices can 'feel' sensations experienced during procedures, such as encountering an unexpected obstruction in the artery."

The third product, PreOp® Endoscopy Simulator, also introduced in 1999, is designed for medical procedures involving the insertion of a flexible bronchoscope, a device that is inserted by the physician into the nasal passage and through the trachea into the lungs of a patient. Similar to the previous PreOp®

[6] These descriptions of the products and the technology are taken from documents available through HT Medical's web site: http://www.ht.com/products~ .

application, this system consists of the medical tools and instruments actually used in the procedure, the computer hardware and software to run the simulator, and the VR devices necessary to provide tactile feedback during the simulation. In this application, HT's technology:

- "mimic(s) the actual 'feel' of performing a bronchoscopy. [The system] produce(s) real-time computer graphics that realistically simulate the view of the tracheobronchial tree, as seen through a flexible bronchoscope. The anatomical models are developed from actual patient data sets."

For each of its three commercially available VR products, HT Medical provides the desktop computer configured for its system, a software tool kit based on its proprietary TELEOS® operating system, and one or another version of its robotic arm, the AccuTouch® Tactile Feedback Device. The company plans to develop and market additional software modules for other procedures using each of these systems. To date, the company has sold over 250 systems from these three product lines. Currently, the company employs 52 people, with 48 located at the firm's new headquarters in Gaithersburg, Maryland.

2.1 Initiatives in Health Care Technologies: The Role of the Federal Government

In 1994, the ATP launched a focused program called Information Infrastructure Initiative for Health Care (IIIH) aimed at supporting R&D projects that would develop

- "tools and prototype systems to enhance the flow of information between existing legacy systems in the healthcare enterprise while being scalable from a single provider's office to a fully integrated healthcare system." [7]

Under this initiative, HT Medical Systems won two separate awards, the first for $560,000 in 1994 for developing its TELEOS authoring system for use on a wide variety of hardware and in a form that did not

[7] Etzkowitz and Spivack (1999).

required advanced programming skills. The second award, in 1997, the last year of the initiative, was for $2 million and funded the development of the PreOp platform for use in medical diagnosis simulations. With these two awards, the ATP became the largest government source of R&D funding that HT Medical Systems has received to date.

The federal government began funding HT Medical Systems' R&D program in virtual reality technology in 1992 with a small Phase I award ($50,000) from the Small Business Innovation Research Program of the Department of Health and Human Services. Thus far, the company has received $1.5 million from seven SBIR grants, with all but one of these awards coming from the Department of Health and Human Services, through the National Institutes of Health and most recently, the Health Care Financing Administration of HHS.

2.2 R&D Partnerships With Universities

HT Medical has had two collaborations with universities. The first collaboration began at the behest of the university partner (State University of New York at Plattsburgh). HT Medical initiated the second collaboration with a university-based researcher (at the University of Maryland).

In 1994, HT Medical began a fruitful and continuing collaboration with Plattsburgh State University of New York at the behest of Dr. Virginia Barker, then Dean of Professional Studies. She brought the resources of the college in curriculum development and practicum teaching in the health professions and additional funding to support the development of a virtual reality intraveneous training system on the CathSim® platform. Dr. Barker envisioned VR technology as having the potential to revolutionize the teaching of nursing and other health care professionals. In announcing CathSim's commercial debut at a demonstration of the system held in the Damianos Nursing Skills Laboratory on the SUNY-Plattsburgh campus, she asserted:

> "It will change the way we teach invasive procedures for students in the health field…The benefit of using CathSim in comparison to the models that were used in the past is the feeling that the students get of actually inserting a needle into the skin and the vein." (release dated March 5, 1998)

HT's partnership with SUNY- Plattsburgh was funded, in part, by the college's not-for profit foundation, which provided $300,000 to HT Medical between 1994 and 1997. In return for the funding and the cooperative R&D effort undertaken at the school, the Plattsburgh College Foundation will receive 5% royalty fee on commercial sales.

The second collaboration with a university was supported by the State of Maryland. The Maryland Industrial Partnerships (MIPs) program is an example of a program that provides incentives to university faculty to collaborate with industry. This program does not directly provide funding to companies. Instead, funding goes directly to the university faculty who is engaged in the collaboration with a local company. In 1994, MIPs provided $35,000 to support the research of a University of Maryland faculty member who was working with HT Medical to develop a new tactical robotic arm for its VR system.

Gregory Merril, the founder of HT Medical Systems, Inc., sought assistance in developing the business plan for his growing company from the Michael D. Dingman Center for Entrepreneurship at the University of Maryland, where experienced businesspeople working with students helped him hone the plan's language and mentor the company's development. One outcome of that planning process was the decision to spin off a new company called Sky Fitness, Inc., in 1998. The new company produces a suspended, recumbent bicycle, which provides a lower-body workout for the user, while engaging in a simulated dogfight projected on a monitor mounted in front of the bike. Although this technology was designed to assist the rehabilitation of patients with spinal cord injuries, Sky Fitness plans to market the machine to the larger health/fitness market.

2.3 *Financing Commercialization: Public Investment Leveraging Private Resources*

The most important contribution of the state of Maryland was as a resource in securing investment capital. The state itself invested public funds in the company and provided HT the contacts and leverage needed to attract additional investment from private investment sources. HT Medical Systems first tapped state-funded sources of capital in Maryland during 1996. HT Medical Systems received $400,000 from the Maryland Health Care Product Development Corporation (MHCPDC), a non-profit quasi-public organization funded by Maryland's Department of Business and Economic Development and the U.S. Department of Defense's Technology Reinvestment Program. The purpose of this investment was to support HT Medical's efforts to commercialize its VR technology. Similarly, the Enterprise Investment Fund, also of the Maryland Department of Business and Economic Development, invested $250,000 in HT Medical Systems in 1996.

As a matter of policy, MHCPDC targets companies involved in developing medical technologies of importance to national security and the national economy. Equity investments of MHCPDC range from $300,000 to $500,000, and must be matched by private sources. HT Medical received a matching investment of $400,000 from Cook, Inc., a medical device company located in Bloomington, Indiana. In return for its investment, MHCPDC expects to receive royalty fees, estimated to be 14% per year of the company's net profits. Combined with its equity stake in the company, the MHCPDC expects its investment to eventually yield an annual rate of return of 25%. The Enterprise Investment Fund targets emerging businesses in high-technology fields, providing direct equity investments of up to $500,000. The terms of the Fund's investment in the company were similar to that afforded MHCPDC.

Only in 1996, did the company begin to attract substantial investment from private sources. By the end of 1999, HT Medical reports having received $3.5 million investment from various private investors. Contact with some of these early investors was made through Maryland's Private Investors Network (PIN). This network was established through the efforts of the Baltimore-Washington Venture Group (which is part of the Michael D. Dingman Center for Entrepreneurship, University of Maryland at

College Park) to bring together accredited investors and growing companies in the Mid-Atlantic region. PIN currently services Maryland, Washington, DC, Virginia (as far as Richmond) and Delaware.

2.4 County Government

Montgomery County is also providing assistance to the company. In July of 1999, HT Medical Systems, Inc., moved from Rockville to its new headquarters in Gaithersburg, Maryland. For staying within the county and establishing its headquarters in a new facility, Montgomery County has offered a reduction in local property taxes. The tax abatement is tied to the achievement of specific targets for the number of new employees hired by the company during a particular time frame. In addition, the county has provided a loan in the amount of $35,000 to HT Medical Systems, Inc. Principal and interest on the loan will be forgiven if the company also meets certain hiring goals. According to a company source, HT Medical is well on its way to meeting these requirements.

2.5 Conclusions

From the very start, HT Medical has maintained a viable business in information technology services with contracts with private companies for its customized, multi-media medical education materials. However, in the fast-moving world of information technology, this small company could not hope to generate sufficient profits to launch the type of long-term, large scale R&D effort necessary to develop virtual reality simulations as a teaching tool for the medical professions. External resources were needed to sustain such an effort. Although two states provided support for the company, the development of HT Medical Systems' VR technology was financed largely by agencies of the federal government. From 1992 until the end of 1999, the company received over $5 million from public and quasi-public sources, with federal government agencies (including ATP) contributing the largest share

(88%). The sales of its VR product platforms are growing, and the company is widely acknowledged as the leader in VR simulation systems for medical procedures.

3. SAGE Electrochromics, Inc., Developing Energy-Saving "Smart Windows" Technology

John E. Van Dine, a chemical engineer and thin-film materials technologist, founded Sun Active Glass Electrochromics, Inc., (SAGE) in 1990 to develop electrochromic (EC)[8] technology, specifically, for coatings on glass that control the transmission of light, heat, and near infrared radiation. This technology can be applied to windows, large area information displays, eyewear and photographic and optical filters. SAGE was founded to pursue further development of the technologies necessary to apply EC technology to glass, hence the name "Sun Active Glass."

SAGE conducted all of its early R&D work in New Jersey in collaboration with scientists and engineers at Rutgers University and other researchers working at a number of private laboratory facilities located in the state. The company holds seven US patents on its technology and has an exclusive licensing agreement with the 3M Company – its joint venture partner on its ATP-funded project -- for the use of three patents stemming from joint R&D projects.[9] SAGE has succeeded in developing a prototype of its "Smart Windows" technology – now known as SAGEGLASS® – and has demonstrated the performance characteristics and durability requirements demanded by the architectural glass industry, as evaluated by the National Renewable Energy Laboratory (NREL).

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[8] As is explained in the forthcoming volume of "Status Reports on ATP Completed Projects," the electrochromic window developed by SAGE: "consists of a series of thin conducting layers that change optical properties when an electric voltage is applied. Each layer is thinner than a sheet of paper, and together they support the transport of electrons and ions. One layer of the film, colorless lithium metal oxide, acts as the positive electrode, another, of tungsten oxide, acts as the negative electrode. When voltage is applied, lithium ions begin to traverse from the positive electrode to the negative electrode, which then turns the tungsten oxide to lithium tungstate (a light-absorbing, blue-gray substance), formed by the chemical addition of ions. The longer the voltage is applied, the more ions are transferred and the darker the window becomes."

[9] Two patents assigned to 3M reference the ATP-funded collaborative R&D project with SAGE: # 5,919,571 (awarded July 6, 1999) and # 6,039,850 (awarded March 21, 2000).

As the world's leading certification laboratory for energy-saving technology, the NREL's assessment was influential in bringing the technology to the attention of other companies interested in developing new products with the capabilities offered by SAGE's technology. Compared to competing technologies tested at the same time, the NREL concluded that SAGE's windows demonstrated the best overall performance. This assessment proved to be a critical factor to the company in furthering commercialization of its product technology.

3.1 Partnering for Commercialization: Scale-up of Manufacturing in Minnesota

In 1998, SAGE formed a partnership with VIRACON and a sister company, VIRATEC® Thin Films, Inc., wholly-owned subsidiaries of Apogee Enterprises, which is headquartered in Minneapolis-St. Paul, Minnesota. For SAGE, this partnership provided the opportunity to team up with VIRACON, a producer of high-performance architectural glass for commercial buildings with a world-wide reputation and marketing expertise, and to tap VIRATEC's technical expertise in the manufacturing processes that are critical to the scaling up the production of SAGEGLASS®.[10] In its press release announcing the partnership (June 16, 1998), the advantages to Apogee's Enterprises of the partnership was described thusly:

- "Apogee chose SAGE's electrochromic technology primarily for its product-technology performance, which we rated as the highest overall among the available choices. The SAGE technology also offered the best fit with our current manufacturing and window fabrication operations."

New Jersey has a high concentration of R&D laboratories and talented researchers in the fields of electronics, chemistry, and ceramics, but it is not particularly known for its manufacturing expertise in the mass-production of glass. SAGE Electrochromics migrated from New Jersey to Minnesota in 1998 to be

[10] VIRATEC has considerable manufacturing expertise in applying thin-film coatings to glass to control the reflection and transmission of light.

close to its commercializing partners. The company is now housed in VIRATEC's facilities in Faribault, Minnesota, and has 20 employees. Still a privately-held company, SAGE has begun marketing its technology to consumers through recent exhibits at the EPCOT Center in Florida, in national television home building shows (e.g., Bob Vila) and through information about the technical specifications of its product available on the company's web site (http://www.sage-ec.com).

The next step in the development of SAGE's business involves the scale-up of production and the marketing of the technology to architects and the commercial building and construction industry. SAGE expects to have its product available for beta testing and demonstration projects in 2001. The future success of SAGE is closely tied to market acceptance of its product, and the growth in demand for new commercial and industrial buildings, which fuels the demand for materials used in the construction of these facilities.

3.2 The Early Years In New Jersey

Major research laboratories for some of the most prominent industrial concerns in the U.S., including, for example, AT&T, Lucent Technologies, Allied Signal, General Dynamics, and Dow Chemicals, have been located in New Jersey for decades. From its inception, SAGE drew on its connections with the highly skilled technical community at work on related technologies in these R&D laboratories. Although SAGE Electrochromics was initially headquartered in Valley Cottage, New York, its research was carried out in collaboration with scientists/engineers and organizations located in New Jersey.[11] Moreover, every one of the co-inventors listed on the patents issued to SAGE in the 1990s identify New Jersey as their home and New Jersey-based R&D laboratories or educational institutions as their employers.[12]

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11 Prior to forming SAGE, Van Dine was director of process development at Chronar Corporation, a Princeton-based company, which was acquired by Advanced Photovoltaic Systems in 1991.

12 The seven patents assigned to SAGE from 1994 to 1998 include numbers: 5,321,544; 5,370,715; 5,404,244; 5,659,417; 5,699,192; 5,724,177; 5,757,437.

SAGE had some initial success in securing investment in its enterprise from private individuals in the first year of its operation. Although the details concerning this investment are not a matter of public record, it seems apparent that additional resources from external resources were necessary for the company to launch a large-scale research effort. SAGE looked to NIST's Advanced Technology Program as a potential source. According to interviews conducted by the authors with Mr. Van Dine, this first application to ATP in 1991 was rejected. Even so, the debriefing session, which is available to all non-winners, proved especially helpful to SAGE in re-formulating its strategy. During the debriefing, ATP program managers informed SAGE that although the concept of the technology looked promising, the company lacked the necessary resources and facilities to carry out its R&D plans. The company concluded that it might strengthen its chances of winning an ATP award in the future if it formed an alliance with another company that already had the R&D resources (and facilities) necessary to further the development of EC technology.

SAGE independently negotiated a joint venture with 3M Corporation in 1992. With the added strength from partnering with another company and a commitment from Rutgers University to provide laboratory facilities, SAGE was successful in winning an award from ATP in the 1992 competition. SAGE received no government assistance, state or otherwise, in locating and securing the matching funds for this ATP award.[13]

Rutgers, the State University of New Jersey, was a subcontractor to SAGE on this ATP project. However, through the Malcolm G. McClaren Center for Ceramic Research (CCR), the university became a critical partner in SAGE's R&D program. CCR provided the company its own dedicated lab space and equipment at that facility for the ATP project and its first real home as a fledgling R&D enterprise. Thus began a fruitful five-year collaboration with the CCR and with Rutgers faculty. By the end of 1994, SAGE

[13] SAGE raised its ATP matching funds from a group of independent, private investors, each of whom received an equity stake in the company.

established its headquarters in Piscataway, New Jersey. The chosen location was no accident, since the CCR is housed at the Busch Campus of Rutgers, which is also located in Piscataway.

3.3 Public R&D Resources Provided by the State of New Jersey

The lead agency responsible for directing the state's resources in specific technical areas, New Jersey Commission on Science and Technology (NJCST), was first established in 1985. The most important assistance to SAGE by the NJCST came through the Commission's support of research facilities and programs of Rutgers, the State University of New Jersey. In particular, as discussed above, the Malcolm G. McLaren Center for Ceramics Research (CCR) – one of 12 advanced technology centers funded by the NJCST to conduct cutting-edge R&D with industry partners – played a critical role early in the life of the company. According to Dr. Dale Niesz, CCR's Director, there is some doubt that SAGE's second proposal to the ATP would have been perceived as credible without the research facilities and technical expertise of the graduate students and faculty affiliated with the center.

CCR was first established in 1982 as an NSF-funded industry-university cooperative research center with the goal of

- "developing the fundamental understanding required to realize the potential of advanced ceramic and composite materials in emerging applications."

CCR is housed in a new facility built in 1985, financed largely by the state of New Jersey through the NJCST. Moreover, since the establishment of CCR, the Commission has provided an additional $8 million towards the purchase of state-of-the-art research equipment. Other sources (including private industry and federal government agencies) have also contributed funds to the center.

The resources of the center are available to New Jersey companies, i.e., those with a facility in the state, regardless of the size of the firm. Companies may gain access to the Center through the cooperative research program or the visiting scientists/engineers program.

Membership in the Center's cooperative research program is largely an option exploited by large, established companies with their own internally funded R&D programs. Some out-of-state companies also affiliate with the center because of its growing reputation in advanced materials and ceramics research.[14] Member companies provide unrestricted support for the research of at least one graduate student. In addition, as a condition of their participation in the cooperative research program, member companies are obligated to contribute a minimum of $35,000 per year towards the research activities of the CCR. In exchange, member companies may choose to allocate their funds to projects of special relevance to them. Moreover, as members of the industry advisory board, industry members can recommend R&D projects for inclusion in the program. Member companies receive semi-annual reports (oral and written) on the research projects funded through the program, have the option to a non-exclusive, royalty free right to patents from the cooperative research program, and also, may place a visiting scientist/engineer at the center.

With respect to small companies, the CCR provides technical services and conducts research on a contract-by-contract basis. For a select number of small firms, the state also subsidizes visiting scientists/engineers at the Center (both on a part-time and full-time basis). In allowing a small firm like SAGE to have access to its equipment and the technical expertise of the staff, faculty, and graduate students, the CCR is, in effect, acting as an "incubator" for the technical capacity of a small firm needing these resources. In this capacity, CCR provided critically needed resources to SAGE at a very early stage in the company's development.[15]

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14 State-funded centers at public universities may develop national and international reputations for performing cutting-edge research. As a consequence, financial support from member companies located outside the state may come to exceed that provided by local enterprises, as Kelley and Arora (1996) observed in the case of one of Ohio's Edison Technology Centers.

15 In interviews conducted by the authors, both Mr. Van Dine and the director of the CCR, Dr. Dale Niesz, acknowledged the criticality of the Center's research to the development of SAGE's technology. Neither could estimate the value of that contribution in financial terms. However, Rutgers has been issued common stock in the company in recognition for the university's contribution.

From 1993 through 1997, visiting SAGE engineers worked with staff and faculty at CCR on research projects funded by the federal government. In addition to NIST's ATP project, SAGE also conducted other research projects funded through the SBIR programs of several different federal agencies, including the Department of Energy and the Department of Defense. The resources available at CCR in material "characterization" – the measurement and definition of a material's composition – were particularly helpful to SAGE in testing and calibrating its technology.

Beyond contributing the laboratory resources and technical expertise, the state directly assisted SAGE with its research by providing $125,000 in grants to Rutgers faculty members through the NJ Innovation Partnership (IP) program in 1994 and 1995. Operating under the auspices of the NJCST, the IP program is a peer-reviewed, competitive grant program providing support to faculty members at New Jersey's four-year colleges and universities (including private as well as public educational institutions). The grants are made to faculty for industrial research collaborations with short to-mid-term commercial promise. Although companies are not eligible grant recipients, the program is designed to provide an avenue for technology transfer and research support in areas of interest to New Jersey businesses. In return, the industrial partners of successful proposals are expected to provide 1:1 matching support to the university investigators funded by the IP grant. In-kind contributions of services and equipment may be accepted in lieu of cash matching, especially in cases where smaller firms are involved as partners.

Professors Lisa C. Klein and Steven H. Garofalini from Rutgers Department of Ceramics and Materials Engineering were the recipients of IP grants. SAGE had close working connections with these scientists from 1993 through 1997. Klein conducted research on sol-gel materials, while Garofalini worked on molecular dynamic models to simulate the characteristics of electrochromic materials. Professor Klein, in particular, made important contributions to the development of SAGE's technology, as evidenced by the three patents assigned to SAGE (#5,404,244 in 1995; and #5659,417 and #5,699,192 in 1997) that identify her as a co-inventor. Not only did SAGE fund faculty research but the company also had employed Dr. Vijay Parkhe, a recent graduate from the Rutgers program, whose research for

SAGE made important contributions to the development of EC technology, as acknowledged in all seven of the patents awarded to SAGE during this period.

3.4 Assessing the Contributions of the State and Federal Governments

Between 1992 and 1998, federal government agencies awarded SAGE more than $4 million in grants and cost-sharing contracts to pursue its research and development program. With its $2 million award to SAGE in 1992, the Advanced Technology Program was the first and the largest single source of federal funding to the company during this period. As discussed previously, the ATP's de-briefing process provided SAGE with much-appreciated advice on a potential strategy for success through partnering with other firms and university research centers.[16] Moreover, the joint venture with 3M provided SAGE complementary R&D expertise and experience. Even though the specific project did not yield the desired results for 3M, the R&D partnership that was formed for this project has continued as evidenced by the recent patent awards to 3M, in which John van Dine (of SAGE) is identified as a co-inventor.[17]

The contribution of the state of New Jersey to SAGE's development is difficult to estimate in financial terms. In addition to its own efforts, SAGE benefited from the accumulation of decades of private and public investments in the R&D facilities located in the state and the expertise of the scientists and engineers employed in both private and public institutions. SAGE was particularly adept at learning about and exploiting related technological developments taking place in the R&D laboratories of major firms located in the region. With its mix of public and privately sponsored R&D activities, CCR and the

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[16] In addition, the Department of Energy provided a platform for SAGE to demonstrate its product through exhibits and to provide an independent evaluation of the durability and performance of the technology in comparison to that of its competitors.

[17] This patent (#6,055,089) was awarded to 3M on April 25, 2000.

state of New Jersey provided a rich laboratory environment for SAGE to learn and to further develop its technology.

3.5 Conclusions

Place-specific investments by industry and government over an extended period of time lead to advantages that may be captured by new firms. In a region with such a history (like New Jersey), a new firm (like SAGE) is able to build on the discoveries and the technical expertise of nearby firms more quickly and with less investment of its own resources than would be possible in another region without such a legacy. However, as is so apparent in this case, a region that spawns innovative activity is not necessarily the principal recipient of the resulting long-term economic benefits in return.

To the extent that SAGE is successful in marketing and commercializing SAGEGLASS®, the ATP expects the nation to benefit from the energy-saving properties of this "smart windows" technology. However, the growth in employment and income generated by this product will largely occur outside New Jersey. Minnesota and California where VIRATEC has manufacturing facilities are more likely to be the locations to reap the short-run direct economic benefits from SAGE's future commercial success.

We conclude our assessment of this case by observing that transfers of knowledge between R&D collaborators are rarely uni-directional. Even though SAGE has left the state of New Jersey, the knowledge developed in its research collaborations has not. University faculty and their students incorporate that knowledge in their continuing research activities, and eventually that research may lead to new technological advances, which spread to other firms. As long as the community of research institutions in the region continue to be creative, it is also likely to be fertile ground for the formation of new *technology-pioneering* enterprises. Some new firms will remain and grow within the state's borders. Others will migrate to other regions to take advantage of place-specific economies related to production or marketing.

4. CuraGen, Inc., Advancing Genomics Research and Bio-Informatics Tools

CuraGen, a new firm specializing in the development of genomics technology and bio-informatics systems that accelerate the discovery of new therapeutic and agricultural products, was incorporated in November 1991. At the company's inception, the founders were two young scientists affiliated with major research universities. Dr. Jonathan Rothberg was affiliated with the Yale University School of Medicine, while Dr. Gregory Went was engaged in post-doctoral research at Cornell University and continuing his research collaborations with scientists at the University of California at Berkeley. They established the company in Connecticut, and it is still headquartered in New Haven, the home of Yale University. However, as a result of its rapid growth during the 1990s, the company added a new facility in Branford, Connecticut. The company has enjoyed considerable success in gaining prestigious research awards from the National Institutes of Health's (NIH) Human Genome Project and from NIST's ATP during its early years. It also raised considerable private capital for its endeavors in later years. Less than 8 years after its birth, CuraGen became a publicly-traded company in 1998 with an initial market capitalization of more than $40 million.

According to its first annual report for the fiscal year ending December 31, 1998, CuraGen has developed a portfolio of "fully-integrated genomics technologies, processes and information systems [that] are designed to rapidly generate comprehensive information about gene sequences, gene expression, biological pathways and the potential drugs that affect these pathways." The company's drug discovery platform consists of three primary systems:

- Gene Discovery
- SeqCalling™
- Generation of sequence databases and full-length clones of virtually all expressed genes in any species, including low-abundance genes and cSNPs (cloned Single Nucleotide Polymorphisms). Produces fully annotated databases integrated with GeneCalling™ and PathCalling™.
- GeneCalling™
- Rapid and comprehensive expression analysis of virtually all genes associated with disease and drug response based on proprietary gene tagging, quantification, and database look-up processes.
- Pathway and Target Discovery
- PathCalling™
- Efficient elucidation of interactions between proteins, accelerating the identification and validation of biological pathways and targets.

Each of these technologies consists of proprietary tools to support a high throughput, automated process to generate information and a database containing the information. The technologies are integrated through CuraGen's GeneScape® bio-informatics operating system, which also provides an easy-to-use web-based interface, allowing researchers interactive, remote access to the company's genomic databases and technologies.

CuraGen now employs more than 300 people, 25% of whom hold doctorate degrees in fields such as molecular biology, chemistry, and medicine. Its stock is now valued in excess of $1 billion. The $15 million in revenues that the company earned in the fiscal year ending December 1999 came largely from contracts with other companies (rather than public sources) for joint research projects and services. As a further indication of its success, CuraGen was awarded its first patent in 1999 and, as of May 2000, the company had secured a total of ten US patents on its technologies.[18]

CuraGen markets the application of its technology to pharmaceutical, biotechnology, agricultural, and other life science companies, and forms research and discovery collaboration partnerships with many

[18] The following six patent numbers refer to patents assigned to CuraGen by the U.S. Patent Office in 1999: 5,871,697; 5,938,904; 5,972,693; 5,977,311; 5,986,055; 5,993,634. As of April 1, 2000, four additional patents were assigned to CuraGen: numbers 6,013,630; 6,017,434; 6,027,941 and 6,057,101.

of them. These joint ventures are typically under multi-year contracts and involve the application of CuraGen's technology and genomics expertise to advance the research conducted by its partner. The partner's research is usually aimed at product development. For example, in 1996 CuraGen entered into a collaboration with an agricultural concern, Pioneer Hi-Bred International, whose goal was to discover genes that would enhance crop production. As a result of this collaboration, Pioneer Hi-Bred currently has several new products under development. By the end of 1999, CuraGen had established research and development collaborations involving the use of its technologies with Abgenix, Biogen, COR Therapeutics, DuPont, Genentech, Glaxo-Wellcome, Hoffman-La Roche, Pioneer Hi-Bred, and Roche Vitamins. Beside these collaborations, CuraGen is also pursuing its own internal product discovery and development program covering such disease areas as obesity and diabetes, cancer, autoimmune diseases, and central nervous system disorders.

4.1 Public Funding in the Early Years

Two federal government agencies were the main sources of funding for the company's research and technology development activities, providing a total of more than $11 million to CuraGen. The company received eight research grants from NIH (five under the SBIR program), with the bulk of the funding coming under the auspices of the Human Genome Project. During this period, ATP/NIST provided three cost-sharing awards to CuraGen. The accumulated funds CuraGen received from each agency were approximately equal, with $5.9 million coming from ATP/NIST and $5.8 million from NIH.

With limited external sources of funding, the company's principal scientists spent the first two years, 1991 and 1992, performing research in support of the company's proprietary technologies, preparing research grant proposals, and making decisions about the firm's organizational and management structure. In 1993, CuraGen received its first funding – a small amount – from an external source. The NIH, under the Small Business Innovation Research (SBIR) Program, provided $50,000. This Phase I, proof-of -concept research project was a harbinger of the flow of public resources to the company in the ensuing years. From 1993 through 1996, nearly all (99%) of CuraGen's technical and business development activities were supported by a combination of federal and state government funding sources.

CuraGen received its first funding of a large-scale, multi-year R&D project from the ATP in 1994. That year, the ATP gave multi-year awards for two separate research projects involving CuraGen. The company's total share of ATP funding was nearly $4 million to be expended over a three-year period. Unlike the SBIR, each of the ATP awards supported an R&D project that was unrelated to the other.[19] Both projects were structured as joint ventures with other companies and were subject to the ATP requirement for the partnering companies to contribute at least 50% of the overall costs of these projects. Connecticut Innovations, Inc., an independent, state-sponsored agency, provided CuraGen's cost-sharing match and critically needed seed capital. The overall contribution of the state to CuraGen in 1994 totaled $1.4 million. In 1994, NIH awarded the company over $230,000 in three separate SBIR grants.[20]

CuraGen continued to attract substantial funding from federal funding sources in 1995 and in 1996. NIH substantially increased its funding to CuraGen, with 4 grants totaling $5.5 million. In 1996, CuraGen received a third ATP award amounting to $2 million for an entirely new research project.[21] Connecticut also continued its support, providing $167,000 to the company in the form of grants and loans.

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[19] One project was selected in the general competition where there is no specific technical focus, and the other was awarded under the focused program on Tools for DNA Diagnostics. For the latter project, CuraGen proposed developing an "integrated, automated DNA analysis instrument." Three patents assigned to CuraGen in 1999 acknowledge the contribution of this ATP project (patent nos.: 5,871,697; 5,938,904; 5,972,693). On the ATP project selected through the general competition in 1994, CuraGen's focus was to develop a "generic molecular technology… to identify short protein segments called peptides that interfere, block, or otherwise inactivate the problematic protein-protein interactions" related to certain diseases. This project was important in generating a stream of substantially different technologies protected by its own set of patents (nos. 5,977,311; 6,027,941; and 6,057,101).

[20] Looking on the patents recently awarded to CuraGen, it is apparent that NIH support was directed at a different set of technologies from those generated through ATP. The following patents are associated with NIH-funded research projects: #5,993,634 and #6,017,434.

[21] For this ATP project (completed in 1998), CuraGen proposed to develop a "practical nanoscale pump not only capable of transporting molecules from one point to the next, but also of actually separating them by mass." The benefit of such a device is that it would allow for "fast and convenient separate of DNA molecules for rapid genotyping."

The period 1997-98 marks the transition for CuraGen in the financing of its R& D activities, a shift from public-sector sources to private sector sources in the form of private and public issues of stock. Revenues from contract research services and agreements with other companies also increased. Although the largest new sources of investment capital were private companies and individuals, the state of Florida also made an investment in CuraGen valued at $1,000,000 in 1997 through the University of Florida's Research Foundation. In total, from a combination of federal and state government sources CuraGen received over $14 million in public funds between 1993 to 1997.

4.2 *Collaborative Linkages with Universities*

Public universities have been important resources to CuraGen. Research teams at the University of California at Berkeley, the University of Connecticut, and at the University of Florida have collaborated with CuraGen scientists. The collaborations with researchers at the University of California and the University of Connecticut were funded through the company's ATP projects. Dr. Carl Mueller, a member of the University of Connecticut faculty in 1994,[22] brought his research expertise on nuclear magnetic resonance imaging to CuraGen as a subcontractor on the company's first ATP project. In addition, research conducted at two private universities, Cornell and Yale, contributed to projects undertaken with ATP support.

The Yankee Ingenuity Initiative (YII) program of Connecticut Innovations, Incorporated (CII), [23] provided funding to university-based researchers collaborating with CuraGen on its ATP projects. The

[22] Dr. Meuller subsequently moved to Yale University and continued his collaboration with CuraGen.

[23] CII was established in 1989, replacing the Connecticut Product Development Corporation, the country's first state-sponsored agency charged with the responsibility for supporting new ventures' product development activities with various financing mechanisms, such as equity investments. Unlike its predecessor, CII concentrates exclusively on companies in seven technology areas based on the recommendations of the Connecticut Academy of Science, on economic need, and on Connecticut's research strengths. These seven areas are advanced marine applications, advanced materials, aerospace, applied optics and microelectronics, bioscience, energy and environmental systems, and information technology.

program was developed by the state of Connecticut to expand the research capacity of university resources, enhance small companies' profitability, share resources and expertise from institutes of higher education, and help to establish long-term relationships between faculty members and Connecticut businesses. It is very similar to the programs operated by the states of New Jersey and Maryland discussed in the previous two cases.

YII funds can be awarded to any higher educational institution (public or private) in Connecticut offering programs in high-tech research fields. At least one co-sponsoring business must be an established, independently owned Connecticut-based enterprise. Co-sponsoring businesses must match state funds with cash or in-kind contributions. YII funds go directly to the educational institution. The state makes $1,000,000 available to this program per year.

For ATP projects in 1994 and 1996, CII supported CuraGen's research with YII grants totaling $235,399. On both occasions, the grants subsidized the research of Yale University scientists whose work focused on discovering the genetic basis of particular diseases. Yale University was the recipient of the YII grants and CuraGen contributed matching funds (per the requirement of the program). The Yale scientists provided the tissue samples for the ATP-funded study, while CuraGen applied its technology and genomics expertise to analyze these samples. Hence, the YII support was another state supplement to the ATP projects.

CuraGen also benefited directly from the State of California's investment in the laboratory facilities and research capabilities of the University of California at Berkeley. Like the University of Connecticut and Yale, UC-Berkeley was a subcontractor on the ATP project responsible for specific research tasks important to the completion of the project. At the University of California at Berkeley's micro-fabrication laboratory, CuraGen scientists conducted research on miniaturization in collaboration with university researchers. This work was supported by CuraGen's third ATP grant in 1997. The collaboration with UC-Berkeley was instrumental in CuraGen's development of a complex "mini-lab" built into a micro-chip.

4.3 Connecticut: Providing Seed Capital and Complementary Funding for ATP projects

In total, CII invested $1.5 million in CuraGen between 1994 and 1996. As a quasi-public corporation, CII serves as the lead agency in the state of Connecticut on technology policy and is charged with the development of technology businesses. Its programs address a broad spectrum of the needs of technology businesses, starting with research funding and culminating with equity financing to bring products (or services) to market. The risk capital investment program is at the core of CII's activities. Through this program CII makes investments in emerging high technology companies located in the state. Companies may use these funds for product development, product marketing, or working capital. The form of the investment is typically equity or near-equity (debt convertible to equity or debt with warrants). CII expects an annual compounded rate of return of at least 25-40% and typically commits between $8-10 million per year to high-tech start-up companies through this program. Currently, the CII portfolio is achieving an internal rate of return above 40%.

In 1994, CuraGen obtained $600,000 in working capital from CII's risk capital investment program. The terms of this investment included the option of converting the debt to common stock in the company. In 1997, CII received nearly 400,000 shares of common stock, in consideration of nearly $1.48 million, which represents the full payment of the note including over $800,000 in accrued interest. At the close of the IPO, in 1998, these shares were valued at $4,400,000, a return in excess of 200%, which far exceeds the average rate of return that CII ordinarily expects from its investments.[24]

CII provided assistance to CuraGen in a second way, by providing funding to the company to meet its' cost-sharing match requirements on its ATP awards. CuraGen received two grants totaling

[24] We do not know if CII has retained its CuraGen stock, or sold it. If CII had held these shares until March 2000, the stock from that initial $600,000 investment would be valued in excess of $30 million.

$687,500 from Connecticut's Federal Technology Partnership Program (FTP) in 1995. The FTP was the precursor to the Connecticut Technology Partnership (CTP) program, which presently offers cost-sharing loans as matching funds to companies awarded research and development grants under federal programs, such as the ATP. The terms of these grants to CuraGen differ in important ways from the current CTP program. CuraGen's grants from the FTP have ten-year terms and do not require re-payment, except under certain extreme circumstances. If during this ten year term, the company commits a serious breach of contract, or is required to re-pay the federal grant to which the cost-share applies, it would be required to re-pay up to 100% of the amount of these grants. Moreover, if CuraGen ceases to have a "Connecticut presence" during the terms of the grants, then CII may require the company to repay 200% of the initial amounts.

CII also provides Phase III financing of up to $50,000 for SBIR grant recipients. These funds may be used for the development of a marketing plan, beta site testing, promotional literature, and other marketing expenses. Phase II SBIR applications are evaluated for the likelihood that the product under development will reach the marketplace in the commercialization stage (i.e., phase III). CII commits to provide Phase III support to Connecticut companies' commercialization efforts in the hope of making the project more competitive in the national competition for Phase II SBIR funds. In 1995, the FTP provided CuraGen $50,000 for the commercialization of its Phase II SBIR-supported technology.

4.4 The State of Florida: Transferring University-Based Science and Technology

The state of Florida's involvement with CuraGen comes relatively late in the history of this young company. In 1997, the University of Florida Research Foundation (UFRF) made an investment valued at $1 million in exchange for stock in CuraGen. Although specific inventions and technologies in question are confidential, UFRF's equity position in the company suggests that there has been a transfer of technology to CuraGen that was developed by one or more of the company's collaborators from the University of Florida. That collaboration is clearly evident in the stream of recent research publications from CuraGen authors and collaborators. For example, CuraGen's Jonathan Rothberg has co-authored papers (*Genome Research*, 1999) with academic researchers, some of whom have been conducting studies at the College of Medicine of the University of Florida since 1992. In addition, from 1997 to 2000, CuraGen maintained a satellite research facility in Aluchua, Florida, 18 miles away from the Gainesville campus of the University of Florida.

The UFRF is a not-for-profit organization established in 1986 by the University of Florida for the purpose of supporting university-based research with potential commercial value. The foundation provides a means for the discoveries, inventions, processes, and work products of university faculty and staff to be transferred from the laboratory to the public domain. Recognizing that university-based research often requires further development in order for it to be exploited in the public domain, the foundation has the option to assign university researchers' inventions and copyrights to industry through licensing agreements and through equity positions it holds in specific companies. The latter is the type of arrangement that UFRF established with CuraGen in 1997.

In 2000, CuraGen expanded its Branford, CT facility and consolidated its Florida operations into that location. Nearly 25 of the 30 Florida employees were successfully transferred to Connecticut. According to Rebecca Horton of CuraGen, since the company does science in a "high-throughput" and highly efficient manner, it made sense to consolidate its internal drug development programs under one roof. Although scientists at the Alchua and Branford sites were well-connected via the Internet, there was a significant amount of "duplication of efforts" that the company was able to overcome through this consolidation.

4.5 Conclusions

In the life of a biotech firm, CuraGen is still quite "young." Only two years have passed since its initial public offering of stock. The company has yet to earn a profit and is still engaged mainly in high-risk research on its own and in collaboration with other firms and universities. However, as indicated earlier, the company has been awarded ten patents on its proprietary technologies, and the use of these technologies by other firms is an important source of revenue. The technologies that CuraGen has developed with support from the ATP, the NIH, and the resources of universities supported by the states of California, Connecticut, and Florida are enabling this company and its partners to develop new treatments for disease and improved agriculture products. To the extent that these new treatments are safe and effective, the nation as a whole benefits.

From the beginning of the company's federally-funded research programs until the start of the commercialization phase for specific technologies, CuraGen's home state of Connecticut has provided financial assistance to the company. The state has already benefited materially from its investments, receiving a return on its initial capital investment that has far exceeded expectations. Moreover, the company has expanded its operations within the state, becoming the largest bio-tech firm in Connecticut. In recognition of its success and commitment to the state, CII presented CuraGen with a Job Growth Award in 1998.

Although Florida's gain in employment growth from CuraGen was short-lived, other benefits from the connections between the company and the university are expected to have longer-term benefits. Similar to the case of Rutgers University and SAGE, we expect that the research collaboration between CuraGen and University of Florida's scientists will yield benefits to the faculty and students who may be expected to incorporate that knowledge in their own research. In addition, UFRF has received a substantial return on its investment in CuraGen stock, thus providing additional resources for the University of Florida's research programs.

CuraGen has tapped a far-flung network of R&D collaborators – its university-based R&D partnerships have involved five different universities in three different regions of the nation (Northeast, West, and Southeast).[25] The company's success in these collaborations illustrates how adept a technology pioneer can be in handling long-distance R&D collaborations. Moreover, when the research expertise needed to carry out R&D does not require a firm like CuraGen to be close to, or to invest in, specialized laboratory or production facilities, the new company's location decision may have more to do with the preferences of key scientific personnel than with proximity to the specialized expertise of organizations with such facilities.

[25] In addition to far-flung university connections, CuraGen's ATP-funded projects also involved R&D partnerships of firms from three different states: Connecticut, California and Massachusetts.

5. *AviGenics, Inc., Developing Transgenesis Technology for the Poultry Industry*

AviGenics is the youngest high-tech start-up company in the set of four cases we selected to illustrate the role of the states in the development of such enterprises. The company was established in 1996 by Dr. Robert Ivarie, Professor of Genetics at the University of Georgia, and an entrepreneur, Mr. George Murphy, who had experience in developing several new companies in heath care and biotechnology. The new company specializes in developing avian transgenesis, a technology that can be used to genetically alter chickens. The goal of the company's R&D program is to use this technology to alter hens in order to produce eggs enriched with pharmaceutically valuable proteins. These proteins can then be used as raw materials for further processing by biopharmaceutical companies. For example, according to one report (*Atlantic Business Chronicle*, 1999), one application would be to alter the eggs so that they contain large quantities of human serum albumin (HSA), a protein that is used in saline intravenous solutions in hospitals. If the technology is successful, egg-laying hens could produce HSA at a fraction of the current cost of extracting this protein from human blood plasma.

Although there are now several companies racing to produce commercially useful quantities of protein in the eggs of transgenic chickens, AviGenics was the first to enter this field. Moreover, in 1999, Dr. Ivarie received his first patent for the methodology he developed to inject genetic material into a chicken egg. Compared to other techniques for manipulating chicken embryos, the advantage of the Ivarie method, as described in the patent award (#5,897,998), is that it achieves a much higher survival rate for the developing embryos. Dr. Ivarie is the inventor identified on the patent, and, because the research leading to the innovation was conducted at the University of Georgia, the University of Georgia Research Foundation is the organization assigned the patent. However, the foundation has made the technology available to AviGenics through a licensing agreement. AviGenics' access to the technology may provide the company a competitive advantage in achieving economies of scale in the production of transgenic chickens.

The fledgling company is currently located in two facilities on the campus of the University of Georgia, has 21 employees, and provides approximately $250,000 annually in sponsored research at the university, supporting 2 post-doctorate research, one technician, and one graduate student. AviGenics derives its own financial support from a combination of private investment capital, ATP's award, and support from the state of Georgia. Upon incorporation, the co-founders raised more than $1.2 million from private investors, including Crystal Farms, a Georgia-based poultry company. In 1998, AviGenics received $1.5 million from the ATP in support of the company's efforts to develop genetic techniques necessary to introduce specific genes into chickens for subsequent expression in the hen oviduct during egg development. As detailed in the following section, the state of Georgia has provided assistance to the company in a number of ways.

5.1 The Role of the State of Georgia in AviGenics, Inc.

AviGenics is a new company developed with considerable support from the state of Georgia. Several different programs in operation at the University of Georgia have made and are continuing to make contributions to this start-up company. In particular, AviGenics is the beneficiary of the University of Georgia Research Foundation, the Georgia Research Alliance, Inc., a non-profit organization funded by the state and by contributions from business, and by the Advanced Technology Development Center.

The company first received assistance from the Advanced Technology Development Center (ATDC).[26] With funding from the state and additional support from the Georgia Tech Research Corporation, the ATDC was established in 1986 as an incubator for new high-tech business ventures. The ATDC provides companies' access to facilities, personnel and students throughout the University of

[26] According to Combes and Todd (1996), this center was originally conceived to be an NSF-sponsored industry-university center; however, the center was not awarded any federal funding.

Georgia system. The center is situated on the campus of the Georgia Institute of Technology as part of the Economic Development Institute and manages the institute's new enterprise development activities. At the ATDC facility, its Warner Robins location and at the ATDC/GCATT facility, early-stage companies enjoy a strong entrepreneurial working environment and have access to professional business consulting, contact with university research faculty, and modern office and laboratory facilities with central staff support. In 1992, the ATDC established the Faculty Research Commercialization Program. Dr. Robert Ivarie was one of three faculty in the UGA system to receive a business development grant under this program for AviGenics, Inc. in 1997.

The Georgia Research Alliance (GRA) has been instrumental in developing the research infrastructure of the university and linkages to local industry. The GRA is also a non-profit organization, which was established in 1990. Although the alliance was originally founded by a group of Atlanta businessmen, the bulk of its funding now comes from state appropriations.[27] The GRA has funded the upgrading or modernization of research facilities at the various campuses of the UGA system and the Technology Development Partnership (TDP) Program, which was developed to help capitalize on GRA's extensive investments in university research infrastructure. The goals of this program are to encourage research collaborations between Georgia industry and academia, and to assist with the development of technology with commercial promise. The program invests in university-based research projects that have attracted matching support from an industrial firm and have successfully passed the program's review process. Moreover, TDP attempts to keep research conducted in Georgia from going elsewhere as the technology develops.

AviGenics leases space in two GRA-funded buildings on the University of Georgia campus. Most notably, the AviGenics laboratory facilities are part of the new state-of-art Animal Science Complex that was recently completed with funding from the GRA. In FY1998, the GRA also provided $60,000, to

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[27] Through fiscal year 1998, the state of Georgia has invested $200 million through the alliance in research and development programs at its six member universities, while another $50 million came from private sources.

the university for research with AviGenics. Another round of funding of the same type was provided by the GRA in FY1999, for $50,000. Similar to the programs operating in Connecticut, Maryland, and New Jersey, the company did not receive any direct funding. Instead, the TDP funds go to the University to spend on AviGenics-related research projects. In both instances, AviGenics provided its own matching funds. The state's money was used for research on the modification of the chicken genome via transgenesis procedures taking place in Dr. Ivarie's laboratory at the University of Georgia.

5.2 Licensing University-based Technologies for Commercial Applications

The University of Georgia Research Foundation, Inc., (UGARF) oversees the acquisition of gifts, contributions, and grants for sponsored research from individuals, industries, private organizations, and government agencies, and assists with transferring technology developed through UGA research programs to benefit the university and the public. It was established in 1978 as a non-profit corporation. In 1979, the University System of Georgia assigned to the foundation all the intellectual property developed in the research programs of the university. Moreover, the UGARF administers the process of securing patents and copyrights on the inventions originating from UGA research, and arranges agreements with industry on licensing fees and royalties for the use of UGARF intellectual property.

The first patent issued to Dr. Robert Ivarie in 1999 identifies the UGARF as the assignee organization. The UGARF has agreed to license the patented technology to AviGenics, and presumably expects to realize a return from that agreement, in terms of either licensing fees or future royalty payments. Without such an agreement, AviGenics would not be able to exploit the technology that Ivarie developed in his research as a UGA faculty member.

5.3 Conclusions

AviGenics provides a good illustration of the role of state government programs in fostering the type of research at universities that is of potential importance to local industry. As the leading poultry producer in the nation, the state of Georgia has a lot to gain from technical advances that affect the industry's growth. AviGenics' technology has the potential to revolutionize that industry. If successful, the technology provides the opportunity for the poultry industry to become a supplier of medical products that may be used in hospitals throughout the country. Although the company is an offspring of the university (formed by a faculty member), it derives support from local industry as well. Since its founding, AviGenics has raised more than $1.2 million from private investors, including Crystal Farms, a Georgia-based poultry company.

6. *Concluding Observations: How States Augment the Capabilities of Technology Pioneers*

6.1 Access to University-Based Research and Resources

The technologies being developed by the four companies we selected are very different. Yet, in each case, we see a similar combination of state and federal government resources deployed early in the company's evolution as a technology pioneer. In all cases, the federal government played the largest direct role in funding the R&D activities of the company. In all four cases, state governments indirectly supported the firm's R&D activities through university-based programs. Connecticut, Georgia, New Jersey, and Maryland operate similar programs that provide grants to university-based researchers who collaborate with an industry partner. In each of our four cases, the programs were similarly structured: state funding went to the university researchers (not to the company) and the partnering company was obliged to provide matching funds (or in-kind resources) for the project. The partnerships between industry and universities supported by such programs include: SAGE Electrochromics, Inc., with faculty at Rutgers University, CuraGen with Yale University faculty, HT Medical Systems, Inc., with University of Maryland faculty, and AviGenics with University of Georgia faculty. With the exception of HT Medical Systems, the other partnerships occurred at the earliest stages of the company's R&D activities and were critical elements in the ATP-funded project. In the case of HT Medical, New York's Plattsburgh State College Foundation directly funded the company's R&D activities.

Public universities have also provided unique support as technology incubators for two new companies. In the case of SAGE Electrochromics, for one, without the access to the laboratory facilities and the research capabilities of the Center for Ceramic Research at Rutgers, this small company would not have been able to pursue the type of R&D needed to develop its SAGEGLASS® technology. AviGenics is actually a spin-off company started by a faculty member from the University of Georgia. Although the company is only four years old, AviGenics appears to be following a similar path as SAGE, in relying heavily on the laboratory facilities and research capabilities at the University of Georgia.

In addition, we find that two companies (CuraGen and AviGenics) depended on university-based research to develop their technology, securing rights to the university's intellectual property from a non-profit organization established by a state government (Florida and Georgia, respectively) for the purpose of transferring university-based inventions to industry. In turn, the companies agreed to do one or more of the following: pay licensing fees, royalties, or provide a quantity of company stock in exchange for the use of this intellectual property. This type of partnership is evident in CuraGen's arrangement with the University of Florida Research Foundation, and in that of AviGenics with the University of Georgia Research Foundation.

6.2 Public and Private Sources of Capital

Connecticut and Maryland provided seed capital funding to new companies, but the timing of these public investments in the life of the enterprise was quite different. Connecticut provided public venture capital funding at the same time as CuraGen received its first major federal funding from the ATP. By contrast, Maryland's investment was preceded by four years of federal funding of the company's R&D program. The state's investment followed public recognition of HT Medical's technology by a trade journal as having the "best virtual reality application."

With respect to private sources of capital investment, AviGenics, HT Medical, and SAGE Electrochromics had alliances with private companies that provided some early stage funding for their R&D activities. Only CuraGen was wholly dependent on public funding sources in the early years. However, because three of the companies are privately-held, information on the amounts and the terms of private investment capital received by these companies is limited. Substantial flows of private investment capital appear to follow public recognition of the value of the company's technology. In the case of CuraGen, a series of large awards from NIH's Human Genome Project and NIST's Advanced Technology Program preceded any substantial investment by private sources. Similarly, the results of the independent performance tests performed by the National Renewable Energy Laboratory on SAGE's smart windows technology were sufficiently compelling to attract a large company with the manufacturing and marketing resources to commercialize the technology. Apogee Enterprises cited these test results as important in its management's choice of SAGE over competing technologies. For HT Medical Systems, Inc., recognition through industry awards for the innovativeness of its VR technology attracted private *and* public sources of capital.

6.3 Regional Specialization and Infrastructure

Over an extended period of time, a regional economy may become highly specialized in terms of the types of industry or the activities of firms that are located there. When firms with similar technical requirements cluster together in the same location, the economy of the region may accumulate expertise and an infrastructure that is difficult to replicate elsewhere. New firms benefit from locating in such regions because of the connections to other firms and access to place-specific resources. Two of the case histories presented in this report – SAGE Electrochromics and AviGenics – illustrate the importance of regional specialization to technology pioneering companies.

SAGE, for one, has benefited from two locations each with its own unique cluster of resources. In the early stages of its R&D, SAGE benefited from the concentration in New Jersey of R&D activities in materials and chemicals, and the specialized industry-university research center and laboratory facilities in ceramics at Rutgers University. Having completed the research and developed a technology with certain performance characteristics, SAGE began a search for a partner with both the manufacturing and marketing capability needed to commercialize SAGEGLASS®. SAGE found that partner in the state of Minnesota, within a region centered on the metropolitan area of the twin cities, Minneapolis-St. Paul, which is noteworthy for its concentration of manufacturing capabilities in glass and thin-film materials. SAGE moved from New Jersey to Minnesota in order to exploit the synergy of co-location with its partner during the crucial scale-up phase of production.

AviGenics has benefited from two related features of the *same* regional economy. Georgia is the leading producer of poultry in the United States, and the state of Georgia has invested considerable resources in the University of Georgia for research that is of potential interest and value to local industry. AviGenics is a product of that investment. In addition to the specialized research resources of the university, AviGenics has also benefited from the investment in the company by a local poultry producer. In this case, both the specialized R&D resources and the downstream production capabilities are located in the same region. AviGenics technology has the potential of revolutionizing the poultry industry and the state of Georgia has a unique capacity to capture much of the direct benefit from the success of AviGenics and the subsequent use of the technology by local industry.

Location within a region with a cluster of resources from universities and other firms may be important at certain phases in the development of both a technology and a firm. A company may begin its operations in one state, only to expand elsewhere in order to be closer to those external resources deemed important to the firm in furthering its technological development. As a result, a state that provides the initial support for a high-tech start-up is not likely to capture *all* of the benefits from the subsequent growth of the company.

Lastly, we observe that early state support of start-up companies is not always local. In the case of HT Medical Systems, early state support came from New York to this Maryland-based company. In support of its educational mission, the State University of New York at Plattsburgh provided early support for the research undertaken by the company to develop the CATHSIM technology. This technology was supported as part of SUNY-Plattsburgh's commitment to develop new educational methods and tools for its teaching programs in nursing and other health care professions.

Although the goal of state support of new enterprises is to grow the local economy, the exchanges between industry and university partners can itself be beneficial even if the enterprise is not a local employer. Instead, exchanges between university and industry-based researchers should be viewed as providing benefits to both parties, whether or not the industry partner is local. University faculty and students incorporate knowledge gained from these collaborations in their continuing research activities, and eventually that research may lead to new technological advances, which spread to other firms. As long as the community of research institutions in the region continues to be creative, the region is likely to be fertile ground for new enterprises wanting to leverage these resources in developing new products and services. Some new firms will remain and grow within the state's borders. Others will migrate to other regions to take advantage of place-specific economies related to production or marketing.

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