Different Timelines for Different Technologies

Jeanne Powell[1]
Francisco Moris[2]

ABSTRACT. Case studies of the first completed Advanced Technology Program (ATP) projects have shown considerable variation in commercialization patterns of ATP-funded technologies. These variations were apparent in the timing of initial revenues, commercialization in more mature and multiple applications, and diffusion of ATP technologies relative to the period of ATP funding of R&D. This study analyzes differences in commercialization patterns for different ATP-funded technologies in a systematic way.

JEL Classification: O380

1. Introduction

The Advanced Technology Program (ATP) is a public–private partnership program aimed at bringing new civilian technologies closer to commercialization. It emphasizes the development of risky but enabling technological capabilities with multi-industry and economy-wide benefits.[1] These benefits include increased productivity and competitiveness of U.S. firms, new and better products, and increased high-wage employment. Project proposals address specific business and economic criteria established by the program. The proposals are submitted to rigorous peer review by scientific, engineering, and business experts.

Awards are made on a cost-share basis for both single applicants and joint ventures. Single-company awards have a maximum allowable length of three years. ATP funding is limited to $2 million for single applicants and may cover up to 100% of direct project costs for small and medium-sized companies. However, all indirect costs are the responsibility of the single applicant. ATP funding may cover up to 40% of total project costs (direct plus indirect costs) for large, single-applicant Fortune 500 companies. Joint venture (JV) projects can last for up to five years and there is no mandated limit on the award amount. JVs must cost share more than 50% of the yearly total project costs.

The ATP's Economic Assessment Office (EAO) performs a variety of evaluation studies, including data collection and analysis, case studies, econometric studies, and modeling. This study will use data collected through ATP's Business Reporting System (BRS) to assess the status and nature of the path to commercialization across the different technology areas funded by the program. The BRS is an internal database of information reported by ATP project participants to ATP on a routine and systematic basis. The database contains technical and business data on project progress, including R&D status, business status, collaboration, and commercialization activities.

Justification, objective, and scope of the study

The study addresses the following research questions:

1. How do expected commercialization patterns differ for ATP projects in different technology areas?
2. What factors appear to account for at least some of the differences?
3. To what extent are actual commercialization patterns mapping to plans?

[1]*Economic Assessment Office*
National Institute of Standards and Technology
100 Bureau Drive, Stop 4710
Gaithersburg, MD 20899-4710
E-mail: jeanne.powell@nist.gov
[2]*Research and Development Statistics*
Division of Science Resources Statistics
National Science Foundation
4201 Wilson Boulevard, Suite 965
Arlington, VA 22230
E-mail: fmoris@nsf.gov

Journal of Technology Transfer, 29, 125–152, 2004

By legislative mandate, a key objective of ATP is acceleration of R&D and commercialization of risky technologies for broad national economic benefit. Does the program meet this mandate? This study provides some direct evidence to answer that question. It has the additional policy value of providing technology-specific data that might inform ATP policy design and proposal evaluation, and aid prospective participants in future ATP competitions. The time frame covered by the data is from 1993 (the beginning of the BRS) to early 2002. This is the first study to use BRS data to track a given group of projects over time.

ATP does not fund commercialization activities or product development. Rather, it funds high-risk, early-stage R&D. Nevertheless, parallel conduct of R&D and planning for commercialization is a cornerstone of the program's strategy for achieving acceleration in technology development and commercialization. Many technology-development projects have early spin-off applications that offer initial commercial potential, even though the major benefits will occur later. This study illuminates the patterns of commercialization associated with different technologies over their life cycle.

The present study differs from studies based on more general R&D expenditure data in at least two ways. Studies based on R&D expenditures tend to underestimate innovative activities related to production done by companies' departments other than corporate labs, such as production engineering departments. This activity may or may not be recognized by formal R&D accounting. Another drawback to such R&D expenditure studies is their limited coverage of small firms and firms in the service sector (Patel and Pavitt, 1995).

ATP's BRS, on the other hand, reflects the high proportion of start-up and other small firms funded by the ATP, while also capturing the participation of leading industrial laboratories across America. ATP activity likely overemphasizes innovation by companies in the highest-risk, earliest-stage technology sectors relative to national data sources. ATP excludes funding product development costs, such as incremental adaptations and imitation of existing technologies, which typically comprise the bulk of industry R&D. In this sense, the BRS is a picture of the innovation process, and its parallel commercialization activity, for the subset of leading-edge R&D. Nevertheless, the data one rich in information about the innovation process—from prototype and design, to product planning and strategies, collaborative activity, and financing—for a broad spectrum of advanced technology development. Analyzing this rich field of data provides an insight into the role of the ATP program in the national innovation process, and also grants a perspective not afforded by more standard measurements of technological activity in the United States.

Related studies

The present study follows a series of case-study status reports of ATP's completed projects by Long (1999) and ATP (2001) and statistical studies by Powell (1999) and Powell and Lellock (2000). The status report volumes were the first ATP studies to examine technical and commercialization performance by technology area. Both found differences in the time-to-market of completed projects across the different technologies for ATP's first 50 completed projects. However, the status reports were based on short case studies, not on more comprehensive BRS data. The present study partially updates the earlier statistical studies by Powell and Lellock (2000) and Powell (1999) and also extends those analyses to examine variation by technology area. Powell and Lellock (2000) is a general report on commercialization progress of ATP projects based on the BRS database through 1997. Powell (1999) focused on small firms in comparison with larger firms.

A number of non-ATP empirical studies in the time-to-market literature attempt to quantify key factors in commercialization progress. For example, Cooper (1994) found that project organization, up-front planning (pre-development activities), and marketing activities were the most significant drivers of timeliness in a study of chemical engineering firms.[2]

ATP's project selection criteria and project management guidelines reflect these findings by emphasizing that early identification of commercialization channels and collaboration partners may contribute significantly to timeliness. Ultimately, the ATP seeks broad diffusion of the technologies it funds. Profitability at some level will be a necessary but not sufficient indication of broad impact.

Organization of the study

Section 2 describes the methodology and ATP project data used in the study. Section 3 draws on the economics of innovation literature to establish a framework for data analysis. Section 4 provides an overview of technology areas and targeted industrial sectors, with a statistical profile of projects, participants, and commercial applications by technology area. Section 5 examines revenue expectations of project participants and compares those expectations with expected windows of market opportunity. Section 6 then discusses several technology-specific features that may lie behind the observed trends. Applying factors cited in the literature to data collected in the BRS, the analysis considers different strategies for commercializing ATP-funded technologies, different types of competitive advantage, and capital availability, as well as embedded characteristics of firm size and R&D project structure. Section 7 summarizes the findings and policy relevance. An appendix provides preliminary data that compares expectations about timing of commercialization with actual performance for a subset of companies using Close-out Reports and Post-project Surveys.

2. Data and methodology

Section 2 provides an overview of the data source drawn upon for this study and outlines the analytical framework used.

Overview of data

The study draws on data collected through ATP's BRS from 1993, when the BRS was established, through September 30, 1999, from firms receiving awards in competitions conducted 1993–1998 and still in their ATP-funding phase. An appendix includes data from post-ATP funding interviews conducted in 2000 through early 2002 for a matched set of companies. Specific variables used and coverage are discussed in each section.

ATP's BRS consists of information collected systematically from the start of ATP funding, in a Baseline Report, annually over the course of ATP funding, in Anniversary Reports, in a project Close-out Report, and subsequently every two years for six years after ATP funding ends, in Post-project Surveys. The system tracks the progress of projects in pursuing their business plans and achieving the anticipated economic benefits outlined in project proposals. The surveys are electronically administered over the course of ATP funding; then telephone interviews are subsequently carried out three times over the six following years. This survey system has been implemented for projects funded since 1993, from their inception.

Methodology of the study

The study follows a set of sequential steps:

- *Step 1:* A synthesis of selected studies in the literature is used to cast an innovation life-cycle framework for studying the variation in commercialization patterns for different types of technologies.
- *Step 2:* ATP-funded projects covered by the study are classified by core technology being developed and mapped to their target applications, by industry, and by type of application (product, process, service).
- *Step 3:* Expectations about timelines for revenues from ATP-funded technologies are examined and compared with expected windows of opportunity for all planned commercial applications, by technology area. These expectations about timing serve as the major indicator of commercialization patterns.
- *Step 4:* Through application of the innovation life-cycle model, differences in firm size, project structure, and other project characteristics, taken together with the underlying technological and economic environment, help explain commercialization patterns identified in Step 3.
- *Step 5:* Completed projects, companies, and commercial applications for which a matched set of data is available are used to compare

expectations about timing of commercialization with actual experience. This step is extended to two to three years after ATP funding with the analysis of Post-project Survey information. This analysis seeks to determine whether actual commercialization patterns will meet expectations and thus whether patterns described in project proposals are credible. The evidence of actual progress the analysis provides may serve as feedback to ATP project management and to the selection processes. Given the preliminary and limited nature of the data available, this analysis is presented in the appendix.

3. Industry and firm differences in innovation: Analytical models in the literature

Section 3 describes the models drawn from the economics literature that serve as the framework for the study.

The innovation life-cycle model

Over the past few decades, several variations of the industrial innovation life-cycle model have evolved in the literature of evolutionary economics and the economics of innovation. In the context of evolutionary economics, innovation is a key force in economic competition.[3] Patterns of innovation are characterized by the degree of technological opportunities and the ability to obtain appropriate returns from R&D, as well as characteristics of the knowledge base. Innovation life-cycle models shed light on differences in the rate of innovation activity and type of commercialization strategies commonly observed for different technologies and sectors and different innovation stages. As will be apparent in this study, these distinctions are useful in assessing commercialization patterns and progress of ATP-funded projects.

Drawing on Abernathy and Utterback (1978) and Utterback (1994), we describe three phases of industrial innovation that correspond to major transformations in characteristics of industrial innovation, market structure, and competition over time. Radically new product lines and emerging industrial sectors accompany the early (fluid) stages of the innovation cycle. In this early, fluid phase, innovation is intense, driven by the rapid entry of new, small, science-based, entrepreneurial entrants who are ready to experiment with highly uncertain new business opportunities. Such firms initially compete by delivering highly customized, essentially service products to a small group of customers. Then in the intermediate stage (the growth phase), output expands, aided by less technical uncertainty and the emergence of standards. The number of firms diminishes. In the third, mature stage, capital intensity and investment requirements increase, becoming significant barriers to the entry of new firms. Competition is now driven mostly by cost reductions, aided by process innovation, technical standards, and economies of scale. In this mature phase, a few companies dominate major markets; innovation aims at new processes; volume and cost are key drivers; and process changes and disruptive new technologies are costly, ultimately causing the pace of change to slow.

Table I summarizes the significant characteristics of innovation and market competition as they evolve over the three phases.

Utterback (1994) notes that the mature phase is not the end of an industry's history. Evolution often continues in the form of waves of innovation and change. Radically new innovations may emerge from within or from outside the industry—or perhaps through collaborative activity across industries. Nevertheless, the base of firms may be smaller in subsequent waves of innovation in a given industry than it is in brand-new industries. In the subsequent waves, markets become better defined, and established firms have distribution channels in place that provide significant barriers to radical innovation or reform of the industry.

Pavitt's taxonomy of industry trajectories complements the life-cycle approach. Pavitt (1984) identifies four types of technology trajectories, shown in Table II.

Pavitt's model suggests that early-stage, science-based industrial sectors, such as biotechnology and software/information systems, are characterized by an emphasis on new products with improved performance, few industry-wide standards, and

Table I
Significant characteristics of three phases of industrial innovation

	Fluid, emerging phase	Transitional, growth phase	Maturity phase
Type of innovation	Radically new products, with frequent major changes; high technical uncertainty but broad R&D focus	Gradual increase in process innovation; at least one stable, high-volume product design emerges	Mostly process innovation, aimed at cost reduction; incremental product innovations
Product life cycle	Short R&D-to-market cycle; diverse, highly customized products and services; frequent product changes; inefficient production processes	Longer development periods and product life; increase in standards and output level; R&D focuses on specific product features	Long R&D-to-market cycle; process change is costly and slow; standard, or commodity-like products
Resource requirements and barriers to entry	Relatively low barriers; small-scale plants located near R&D and general-purpose equipment. Scientist/engineer content	Medium barriers; some automation and specialized equipment; increasing facilities investment required	High barriers; special-purpose equipment, mostly automated processes; less labor content
Number of competitors	Initially few competitors, but rapid entry in response to market opportunities; frequent changes in market share	Declining number of competitors after emergence of dominant design	Few dominant firms; stable market shares
Type of competition	Technical performance	Product differentiation	Price/cost
Organizational control	Informal and entrepreneurial	Growth of hierarchical features (project and task subgroups)	Division structure; rules, and goals; enterprise diversification
Financing	"Family/friends," angel, seed capital; research grants.	Venture capital	Retained earnings, equity, debt

Source: Adapted from Utterback (1994).

Table II
Sectoral technology trajectories

Category of firm		Innovative activity	Industry sectors
Supplier dominated		Mostly process innovation by suppliers of equipment and materials	Non-durable consumer goods, textiles, printing, agriculture, construction
Production intensive—large-scale fabrication, assembly and continuous processes	Specialized suppliers	Mostly product innovations from in-house R&D	Instruments, machine tools
	Scale-intensive producers	Process innovations in house and by suppliers	Consumer durable goods, steel, autos, bulk materials
Science based		R&D intensive firms; mixed product and process innovation	Electronics, chemicals, biotech, information technologies

Source: Adapted from Pavitt (1984).

high entry of small innovative firms. For example, biotechnology companies target emerging or as yet practically non-existent markets. Many biotechnology companies firms operate as adjuncts to universities. Information technology companies face different market constraints, but also have wider opportunities to serve a more diverse set of customers and industries.

Intermediate-stage science-based sectors, such as electronics and chemicals (for instance, pharmaceuticals), have entered their growth phase. Product innovation is still prevalent in the more science-based, large chemicals and electronics firms, with an evolving emphasis towards cost as well as performance.

Supplier-dominated and scale-intensive sectors have passed beyond a science-based innovation to production intensity. Firms in these sectors often have a price-sensitive end user, so the focus of innovation turns to cost cutting. In production-intensive industries such as automobile and aircraft manufacturing and petroleum refining, innovation places more emphasis on process and cost; larger, older firms primarily emphasize incremental innovation. One perceives a reluctance to pursue new markets. Industries based on assembly or fabrication (such as manufacturing) or other continuous processes (such as steel) aim at process technologies. Nevertheless, radical innovations may still emerge from outside the industry or from developers of new process tools. Multi-disciplinary, inter-industry consortia provide a mechanism for introducing new technologies to older companies and sectors.

Extensions of the model

The life-cycle model of industry evolution illuminates broad economic and policy issues facing R&D-performing firms. For example, a better understanding of the technology and market environments at different stages of the innovation cycle has been useful in devising theories that describe different financing, investment, and organizational features at each stage (Auster, 1992). Of particular interest to ATP is the role of collaborative R&D as a key organizational and financing tool.

Cooperative activities offer opportunities to overcome limitations in resources (human resources, financial, fixed capital, managerial, technical and marketing) as needed at any stage of the innovation life cycle (Rothwell and Dogson, 1991). They include subcontracting, licensing, and R&D alliances and joint ventures, all features of ATP projects. (In some studies, the term "joint ventures" refers exclusively to equity-based alliances, rather than to more flexible agreements based on contracts or more informal arrangements. The official ATP definition of a joint venture does not involve any equity structure, but rather a simple contractual agreement for the purposes of accomplishing R&D goals.)[4]

The motives, structure, and performance of these linkages and collaborations are expected to differ over time and over the life-cycle of a given firm or industry, as well as across technology sectors.[5] Vertical partnerships of users and suppliers and horizontal alliances that involve organizations in the same industry, potentially even competitors, tend to have different business objectives for their R&D collaborations.

Vonortas (1997) and Audretsch (2001) both note the strong incentives for small firms, in the fluid phase of the innovation life cycle, to seek R&D partners as a means of dealing with technological risks and with market access to rapidly changing markets. Vonortas (1997) suggests that this might be more common with smaller, vertically structured joint ventures, where individual members can protect their own intellectual property in their component product innovations, rather than with horizontal R&D ventures aimed at process innovations, which are difficult to protect. For relatively mature firms, Vonortas notes, consortia are more suited to cost-reducing process innovations of generic use to a variety of member firms than they are to product innovations—and are especially suited to industries with a slow pace of technological change. Alternatively, strategic partnerships between small/new firms and larger/mature firms bring together the complementary resources needed for mature industries to innovate and diversify.

The innovation life-cycle literature focuses on the traditional assembly-line view of U.S. industry (Vonortas, 1997). Nevertheless, there are linkages to service applications as a strategy for commercializing technologies at an early stage through highly customized products.

Applications to the ATP portfolio

The life-cycle framework serves as a roadmap for empirically examining the actual process of innovation for high-risk, enabling technologies such as ATP funds within their technological, business, and economic environments. Analysis of actual data helps untangle the effects of different markets and technological environments. For example, given the rapid pace of innovation in biotechnology and information technology firms, it is apparent that these are science-based firms addressing emerging industries. However, even these two technology areas differ in the way their target markets operate. Many biotechnology projects target markets that are still nearly non-existent, although many of these potential markets will involve delivery of health care services. These biotech projects also face major regulatory hurdles. Information technologies, on the other hand, target somewhat more established, less treacherous but highly diversified markets. Many IT applications involve delivery of fast-to-market service applications to varied service sectors. In general, we expect commercialization to be slower for a process innovation in a mature manufacturing industry. However, cooperative activity with different technology suppliers, and the right combination of financial and organizational backing from key customers, could speed it up.

The stylized models are presented in terms of firms and industries, not individual plants or company locations. The BRS database, on the other hand, is comprised of data from establishments directly involved in ATP-funded projects. Nevertheless, R&D projects are affected by company-wide strategic and resource considerations. The distinction between establishments and firms is not relevant for the large proportion of small firms and start-ups funded by the ATP.

4. Summary profile

Section 4 provides a detailed profile of the projects and organizations included in the study to establish linkages between the analytical models and technology and business goals and characteristics of ATP-funded companies.

Overview of technology areas and targeted industrial sectors

ATP classifies projects according to the core technology being developed. The five major categories used in recent years are biotechnology, electronics, information technology, advanced materials-chemistry, and manufacturing. The life-cycle model tends to merge technology with firm and industry, consistent with Utterback's evolution of his model from its early focus on innovation and firms to its later focus on industries. In some cases, a technology emerges from one industry to ultimately address another industry, or it provides the nucleus for a new industry. Pavitt and others have elaborated on the relationship between technology-based suppliers and more mature industries.

Many ATP projects involve interdisciplinary technologies. For example, ATP's Microelectronics Manufacturing Infrastructure and Photonics Manufacturing Focused Programs develop both manufacturing and electronics capabilities, while Materials Processing for Heavy Manufacturing advances R&D supporting applications in materials structure and manufacturing processing.

The technology platforms funded by ATP enable commercial activity across multiple industry and market sectors, even though initially they tend to target a particular industry. A cross-section of technologies under development and target industries (by two to three digit SIC) yields the following thumbnail sketches of the projects covered in this study. (For projects funded through 1998, the BRS used the Standard Industrial Classification (SIC) system to classify use sectors for commercial applications of ATP-funded technologies.)

Biotechnology. Biotechnologies potentially form the foundation for new health-care-related markets not yet encompassed by Bureau of the Census classification systems. Many projects with health-care applications will ultimately benefit pharmaceuticals (SIC 283) through new drug discovery and delivery methods. In addition, ATP's biotechnology projects target industry sectors as diverse as medical and laboratory instruments (SIC 382), food products, and aquaculture. ATP has made targeted investments in tissue engineering and tools for DNA Diagnostics through focused programs.

Manufacturing. ATP-funded manufacturing technologies support automobile and aircraft manufacturing, machine tools, intelligent control and manufacturing, and other discrete and flexible manufacturing systems. Most of the applications from this technology area have been classified by the companies as industrial machinery (SIC 35), transportation equipment (SIC 37), fabricated metals (SIC 34), or instruments (SIC 38). ATP has made investments in motor vehicle manufacturing technologies through its focused programs. Many other projects classified by core technology as information technology or advanced materials or electronics will result in manufactured products and involve manufacturing process issues.

Advanced materials-chemistry. This technology sector is perhaps the most heterogeneous in ATP's classification system. The materials subcategories include abrasives/coatings/composites (the subcategory with the highest frequency), metals/alloys, and construction materials. The chemicals subsection includes separation technologies, catalysis, food processing, as well as energy and environmental technologies. Materials and chemistry projects typically target the chemicals (SIC 28), industrial machinery (SIC 35), electrical equipment (SIC 36) for energy applications, motor vehicles (SIC 37), and oil and gas drilling (SIC 13) industries, as well as others. These target industries reflect ATP's focused programs in manufacturing composite structures, premium power, catalysis/biocatalysis, and selective membrane platforms.[6]

Electronics computer hardware, and communications. This area includes semiconductors, other computer hardware, microelectronic fabrication technology, communication for data, voice, and video, and optics and photonics. Many of the projects interface with manufacturing processes; for example, components of electronics systems interface with particular applications in photonics and microelectronics manufacturing. These projects most typically have target applications in electrical and electronic equipment (SIC 36) or instruments (SIC 38).

Information technology. Projects in this area typically target applications in business services, health care, or manufacturing. Specialized technologies include pattern recognition, image processing, and security systems based in biometrics capabilities. Information technologies are an acknowledged vehicle for radical process innovation in a number of mature manufacturing industries as well as a platform for a wide range of potential new businesses.

ATP has targeted a number of different industry sectors and types of IT solutions with its IT-related focused programs. Projects funded in ATP's Component-Based Software Focused Program develop technologies needed to enable multi-use software components that can be sold to systems integrators and custom builders to create custom manufacturing applications. Projects funded in ATP's Manufacturing Integration Focused Program support critical efficiency and quality issues in manufacturing and services. The program in Information Infrastructure for Healthcare fosters underlying technologies such as digital libraries, knowledge-based systems, and natural language processing used in information processing and management. Medical software systems are used, for example, in patient monitoring, medical procedures management and analysis, and overall care integration. ATP-supported information technologies have typically targeted service industries such as business services (SIC 73) and health services (SIC 80). Many support telecommunications or broadcasting (SIC 366). A smaller focused program developed information technologies targeted at video information networking.

Profile of participants, projects, and applications

The study draws primarily upon BRS data for ATP project participants and projects funded by the program since 1993 and reporting through September 1999. The complete data set includes 669 project participants in 336 projects. These project participants reported on 1,172 planned commercial applications of their ATP-funded technologies. Not all 669 participants or projects provided information on commercial applications. (Some organizations in joint-venture projects, particularly universities, have a pure research or support role and do not have direct or immediate plans to commercialize the results of their efforts.

Rather, they are building infrastructure and expertise that will support subsequent R&D efforts or other contract research.) Therefore, we reduced our data set to the data records from 558 organizations in 299 projects that reported the plans for the 1,172 commercial applications. The data from the 558 organizations form the basis for the analyses in Steps 2–4. In Step 5, we used reduced sets for which matched Baseline and Close-out Reports were available, and separately for which Post-project Surveys were available. Table III summarizes this spectrum of data by report type.

The data set for the 558 participants in 299 projects reflects 81% of all ATP awards and 63% of all project participants in awards made 1993–1998. Some participants of very large ATP joint ventures are relieved from the ATP business reporting responsibility, and non-profit organizations without R&D responsibility or commercialization plans are likewise exempt from ATP's business reporting requirement. The major reduction in coverage is due to failure to comply with the reporting requirement at all (approximately 15% of participants) or failure to provide information about commercialization plans (approximately 15% of participants, including universities and others in joint ventures with little commercialization intent).

Table IV provides a profile of projects and participants by technology area. Materials-chemistry and IT have the largest number of both participants and projects. Participants/project, a density measure, shows that manufacturing and electronics/photonics have the highest average number of participants per project. Many of these projects are organized as joint ventures, with manufacturing technology-based joint ventures having more participants, on average, than others.

Table V further profiles project participants for each technology area by type of ATP project and size/type of organization. The distributions vary considerably across technology areas. For example, two-thirds of biotechnology participants are single applicants (SAs), by far the largest proportion across any of the technologies, but 62% or more of participants in projects developing the other four technologies are members of a joint venture. Furthermore, biotechnology participants involve the largest proportion (71%) of small companies. For other technology areas, 27–46% of project participants are small firms.

Table III
Summary of projects, participants, and applications, by report type

	Number of projects	Number of project participants	Number of commercial applications
All	299	558	1,172
Matched baseline reports and Close-out reports	147	176	301
Matched Post-project surveys	134*	173*	104

*Includes participants that discontinued plans to commercialize their ATP-funded technologies, as discussed in the appendix.
Source: Data are from the ATP Business Reporting System for projects funded between 1993 and 1998.

Table IV
Distribution of participants and projects, by technology area

Technology	Participants	Percentage	Projects	Percentage	Participants/ project
Biotechnology	83	15	67	22	1.2
Electronics/photonics	97	17	44	15	2.2
IT	140	25	73	24	1.9
Manufacturing	96	17	39	13	2.5
Materials-chemistry	142	26	76	26	1.9
Total	558	100	299	100	1.9

Source: Data are from the ATP Business Reporting System for projects funded between 1993 and 1998.

With the exception of the biotechnology projects, most of the projects in each technology area are joint ventures. ATP-funded biotechnology firms have tended to use subcontracting mechanisms rather than a joint-venture structure to perform collaborative R&D. Many have subcontractor relationships with universities or other small firms. Many are also engaged in joint research and marketing agreements with larger biotech, pharmaceutical, or chemicals firms. The absence of joint ventures and the large number of relationships with universities likely reflect the very early-stage R&D being conducted in biotechnology and the preponderance of small firms.[7]

Table VI shows the distribution of commercial applications by technology area. Averages per participant and project are based on the 558 participants in 299 projects; that is, no assumptions are made about projects for which no applications had yet been reported. Sixty-one percent of applications come from joint venture members and 39% from SAs. The larger number of applications per project for manufacturing technologies likely reflects the larger dollar size of these projects (mainly joint ventures) and the large number of participants in many. Biotechnology projects, on the other hand, had the lowest number of planned applications per project, apparently reflecting the small number of joint ventures and the long time to market for most applications (discussed in later sections of the study). More than half of the applications came from projects developing IT or materials-chemistry technologies.

Most ATP projects involve development of technology platforms that support a number of different commercial applications. Participants in joint ventures often pursue a mix of their own applications and joint applications with others.

Table V
Distribution of project participants in each technology area, by organization type/size and project type

Technology	Number	Firm size (% of participants)			Project type (% of participants)	
		Small	Medium/ large	Other*	SA	JV
Biotechnology	83	71	24	5	66	34
Electronics/photonics	97	38	58	4	18	82
Information technology	140	46	38	16	38	62
Manufacturing	96	38	60	2	23	77
Materials-chemistry	142	27	68	5	31	69
All	558	42	51	7	34	66

Table VI
Distribution of commercial applications, by technology area

	Applications	Percentage of all	Applications per participant	Applications per project
Biotechnology	176	15	2.1	2.6
Electronics/Photonics	181	15	1.9	4.1
IT	307	26	2.2	4.2
Manufacturing	185	16	1.9	4.7
Materials-Chemistry	323	28	2.3	4.3
All	1,172	100	2.1	3.9

Source: Data are from the ATP Business Reporting System for projects funded between 1993 and 1998.

5. Observed variations in timelines for commercialization

In Section 5, expectations about timelines for revenues are examined and compared with expected windows of opportunity, by technology area.

Expectations about the timeline for commercialization

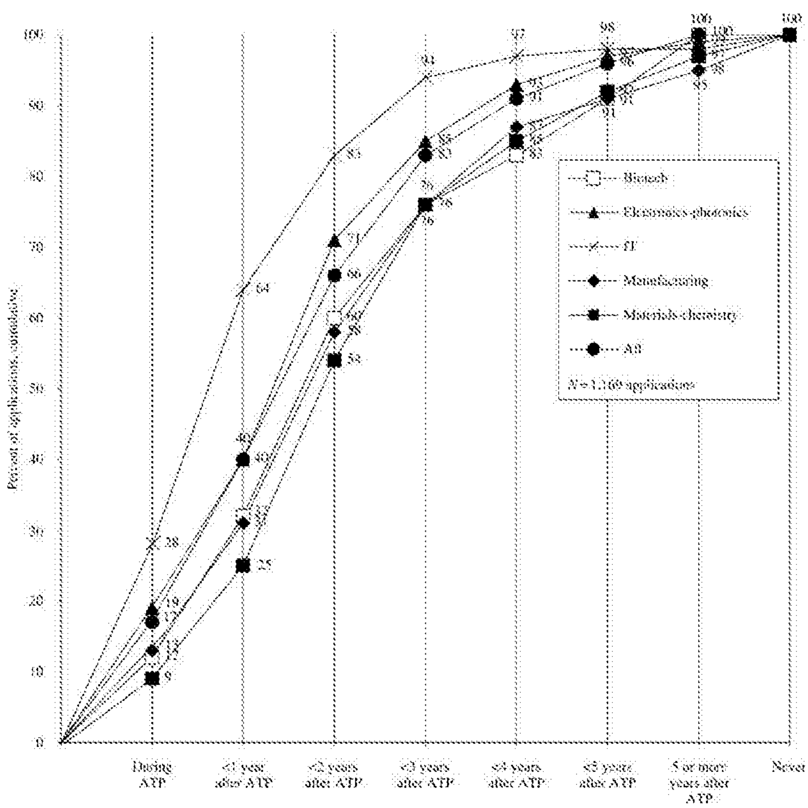
This subsection addresses directly the question, "Are differences in commercialization patterns observed for different technologies?" Using expected timing to initial revenues as a key indicator, we provide graphical timelines for each technology area.

When can we expect to see revenues? Figure 1 shows a year-by-year picture of responses provided by all project participants together and by those from each technology area about their 1,172 planned commercial applications. Participants responded to the following question.

When is revenue anticipated?
Response choices:

- During ATP.
- < 1 year after ATP.
- 1–< 2 years after.
- 2–< 3 years after.
- 3–< 4 years after.
- 4–< 5 years after.
- 5 or more years after.
- Never.

Revenues are anticipated for 17% of all commercial applications by the end of ATP funding, for 40% of applications by a year later, and for 66%



Source: Data are from the ATP Business Reporting System for projects funded between 1993 and 1998.

Figure 1. When can we expect to see revenues?

within two years after ATP funding ends (counted cumulatively). The peak number of new applications expecting revenues occurs about two years after ATP funding ends.

But there is considerable variation across the entire time period. For IT applications, revenues are expected for 28% of applications during the period of ATP funding and for 64% of applications by a year after ATP funding ends, the highest proportion for any technology area. Only 25% of materials-chemistry applications and 32% of biotech applications are expected to generate revenues by a year after ATP funding ends.

When we examine the underlying data, we see that while the activity for IT peaks a year after ATP funding ends, the expected peak in new applications reaching the market for other technology areas appears a year later.

Electronics technologies have some early applications, but then they experience a steep rise in activity in the second year after ATP, followed by a fall-off more rapid than in any other technology area except IT.

Materials-chemistry and manufacturing-based applications build up somewhat more slowly and tail off more slowly than electronics and IT.

Biotechnologies have an initial spurt of activity in the second year after ATP funding ends, then another spurt five or more years later.

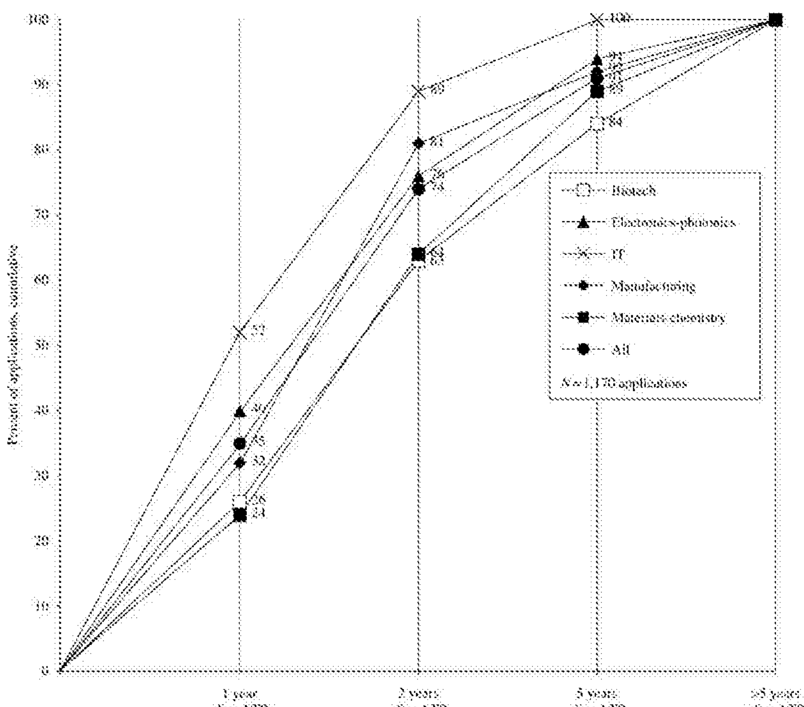
Expected market window of opportunity

If commercialization plans are credible, we expect the window of market opportunity to shadow the expected timing of revenues. This window's timing will pose a constraint on commercial viability of the technologies in their planned applications.

Figure 2 shows responses to the following question:

What is the window of market opportunity?
Response choices:

- A year after ATP.
- 2 years after ATP.



Source: Data are from the ATP Business Reporting System for projects funded between 1993 and 1998.

Figure 2. How long will the window of market opportunity stay open?

- 5 years after ATP.
- More than 5 years after ATP.

The expected windows of opportunity mirror expectations about the timeline to commercialization, with about a one-year lag. For IT, this is especially true. While 35% of applications across all technologies expect a market window of just one year after ATP funding ends, the proportion within IT is 52%, the highest such proportion for any technology area. As seen above, this is consistent with expectations of the timing of revenues for this technology group.

Most electronics applications are under pressure to reach the market within about two years after ATP.

Only a few applications—largely in biotechnology—are expected to see the market opportunity window open longer than five years after ATP.

6. Factors behind observed trends

We use the framework suggested by the industrial innovation life-cycle model in Section 3 to address the second research question: what factors appear to account for commercial timeline differences among technologies? We assess ATP project and company characteristics by technology area against hypotheses derived from the model.

Firm size

The life-cycle model naturally leads us to expect small or younger firms to be associated with the rapidly changing products and short R&D cycles of emerging industries. We also expect to see larger firms associated with more mature industries, and characterized by longer product cycles and less frequent major product changes.

Company size does indeed seem to affect expectations about the speed of commercialization; the effect also seems to be especially associated with certain technologies. Even though BRS data one closer to establishment or plant-level data than to firm-level data, overall firm characteristics should affect the project. For example, the division of a large firm participating in the ATP project may easily draw on the resources of the whole enterprise, depending on the relative priorities of the project vis-a-vis the overall business goals of the firm.

Indeed, across all for-profit firms, small companies report a shorter expected period of time to the first project revenues than do larger participants. Forty-eight percent of small-firm applications are expected to generate some revenues by a year after ATP funding ends, compared to 29% of larger-firm applications. (Data are not shown.)

This relationship holds for each technology area. The differences between small and larger firms expecting revenue by a year after ATP are greatest for materials-chemistry (40% of small-firm applications, compared with 17% of larger-firm applications), IT (72% of small-firm applications compared with 52% of larger-firm applications), and manufacturing (41% of small-firm applications compared with 22% of larger-firm applications).

In general, small companies see market entry as more urgent for cash-flow reasons. They may be under pressure to satisfy outside investors, and therefore may be more eager to launch early products whether or not these embody the full technological potential (Powell, 1999). These firms are also more likely to be in the fluid, early stage of the innovation life cycle, where the pace of change and shifts in market dominance are most rapid.

Following Pavitt, firms developing manufacturing technologies may be specialized suppliers to production-intensive large companies, and therefore may operate somewhat more like science-based firms than like larger firms. Another possibility is that they may be more optimistic and have less experience in what it takes to get to market. Or they may seek to provide the disruptive technology that challenges larger firms. In any event, small-firm suppliers to larger firms will face a barrier in overcoming larger-firm reluctance for costly product or process changes, and the ATP joint-venture structure may provide some assistance.

When we examined the window of market opportunity, the firm-size relationship was less clear. Slightly more small firms have a one-year and two-year market window after ATP than do larger companies. However, this overall result held for IT and materials-chemistry technologies but not the other three technology areas. For materials-chemistry, 82% of applications developed by small firms have a market window of at most two years, compared to 54% of materials-chemistry applications of larger firms. For IT, the difference is smaller—95% for small firms versus 85% for larger firms. In the opposite direction, 75% of larger biotechnology firm applications had a market window of at most two years compared with 59% for small biotechnology firm applications.

For manufacturing, 87% of larger-firm applications had a market window of at most two years after ATP compared with 72% of smaller-firm applications. The greater proportion of larger-firm manufacturing applications with shorter market windows is consistent with their use of collaborative R&D to advance and accelerate innovative R&D even within relatively technologically mature industries. The size effect may reflect the joint-venture structure of these manufacturing projects, rather than firm size per se.

Project structure

As discussed earlier, collaborative R&D and research joint ventures are an organizational, technical, and financing strategy with different objectives along the innovation life-cycle. In the first stage of the life cycle, collaboration can leverage resources and capabilities. At more mature stages, partnerships between new and larger or established firms provide a mechanism for a renewed level of innovative activity and product diversification. ATP-funded joint ventures often include a mix of small and larger firms. Many involve a vertical series of players across a supply chain. Some involve a more horizontal structure or are a hybrid of vertical and horizontal characteristics.

Looking at the differences in commercialization timelines for ATP's single-company with joint-venture projects, 38% of commercial applications developed by joint-venture participants have a market window of just one year after ATP, compared to 31% of those developed by single applicants.

The relative urgency shown by joint ventures holds in each technology area, with a wider margin for some technologies. For example, more IT and electronics applications being developed by joint ventures (57% IT, 44% electronics) report a one-year market window compared with their respective single applicants peers (47% IT, 26% electronics).

R&D collaborations seem to be viewed consistently as a vehicle for acceleration of R&D towards entry to markets with short windows of opportunity. ATP-funded larger firms, in particular, seem to find collaborative R&D the best mechanism for addressing competitive markets. This is particularly important in addressing fast-paced IT and electronics product markets, where technologies change rapidly even into the growth phase of the innovation cycle.

Strategy for commercialization

We refer to commercialization strategy as the selection of a product, process, or service platform for market entry of an ATP-funded technology. Sixty-six percent of all the 1,168 applications reported for this question, across all technologies, involve a specific manufactured product, 24% involve a manufacturing process, and 10% involve delivery of a service. Figure 3 shows the distribution by technology area.

The product life-cycle model suggests service and low-volume product applications will enter the market quickly, but will have a short product life and will most commonly be associated with early-stage technologies and young businesses and industries. At the other end of the spectrum, process technologies with cost-reduction objectives will have the longest life cycles and typically will be more associated with larger, mature firms. Product-focused applications with an emphasis on performance will be associated with firms in earlier stages of the growth phase, in rapidly-changing markets, seeking opportunities to make their product the standard, dominant design. We examined commercialization strategies of ATP-funded technologies against this framework.

Although service applications constitute only 10% of all applications, they represent 25% of IT applications and 14% of biotechnology applications, respectively. One is tempted to associate service applications with small firms. However, given that electronics technologies also involve a large proportion of small firms but almost no

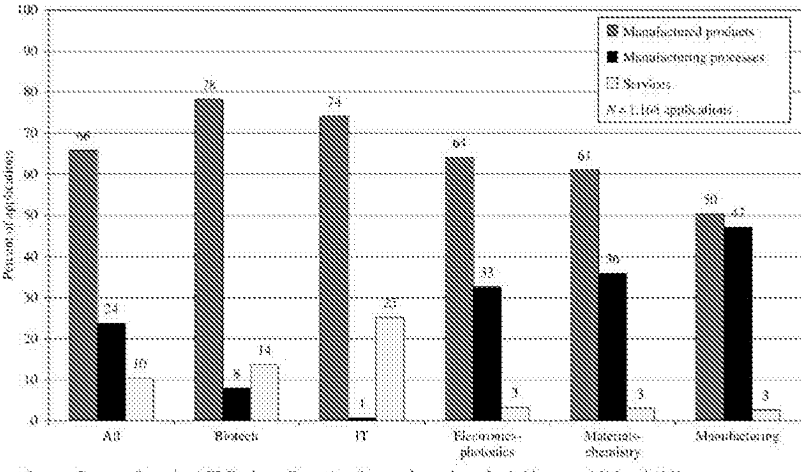


Figure 3. Applications profile: Manufactured products, manufacturing processes, and services.

service applications, size is not the only factor. Biotechnologies and information technologies are clearly addressing earlier-stage, newer markets, many in the service sectors.

Virtually all applications in electronics, materials-chemistry, and manufacturing are either manufacturing products or manufacturing processes. Manufacturing processes comprise nearly half the applications of manufacturing technologies and over one-third of the applications of electronics and materials-chemistry technologies.

Figure 4 compares the timelines for expected revenues for the different types of commercialization strategies reported for 1,165 applications. Results are consistent with expectations.

Service applications show the fastest time to market, with revenue expected during ATP for 33% of them and for a cumulative total of 59% a year after ATP.

Manufacturing processes have the slowest time to commercialization, with only 16% expected to generate revenue or reduced production costs by the end of ATP funding and a cumulative total of 35% by a year after ATP funding. For manufacturing technologies, a similar level of activity was expected for product and process applications during the earliest time period; after ATP funding ended, product applications were expected to commercialize more quickly than process applications.

Figure 5 provides additional evidence supporting the relationship between firm size and commercialization strategy. Small firms pursue service applications more frequently than do larger firms. Among service applications, 49% are being developed by small firms, 30% by larger firms, and the remaining 21% (not illustrated) by universities and not-for-profits. Larger firms are pursuing manufacturing process applications more frequently than small firms. Lastly, among all process applications, 66% are being developed by larger firms compared with 29% by small firms. Manufacturing product applications are somewhat more common for small firms.

At early stages of technology development, customized services and low-volume products provide an early opportunity for relatively low-cost market entry of breakthrough technologies. They generate cash flow and name recognition in the aggressive competition for market share in emerging markets. Further capital investment, completion of the technology goals, and market distribution connections enable higher-volume products and help them reach a broader base of customers. It is important to note that ultimately most ATP technologies are expected to be diffused broadly and to generate their major economic benefits not through customized service relationships but through new products and the implementation of new production processes.

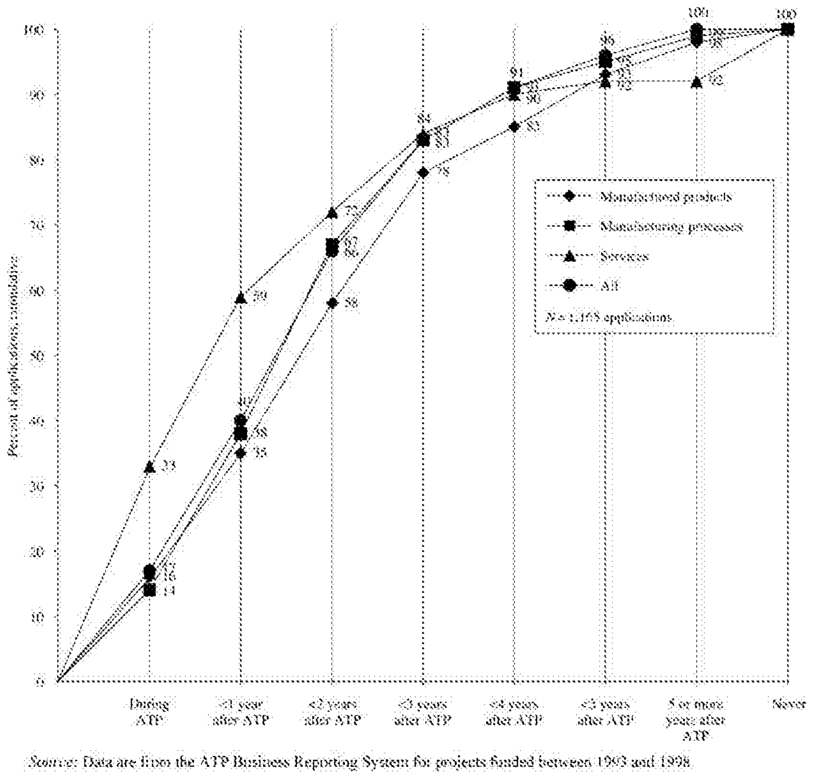


Figure 4. When revenue is expected: By commercialization strategy.

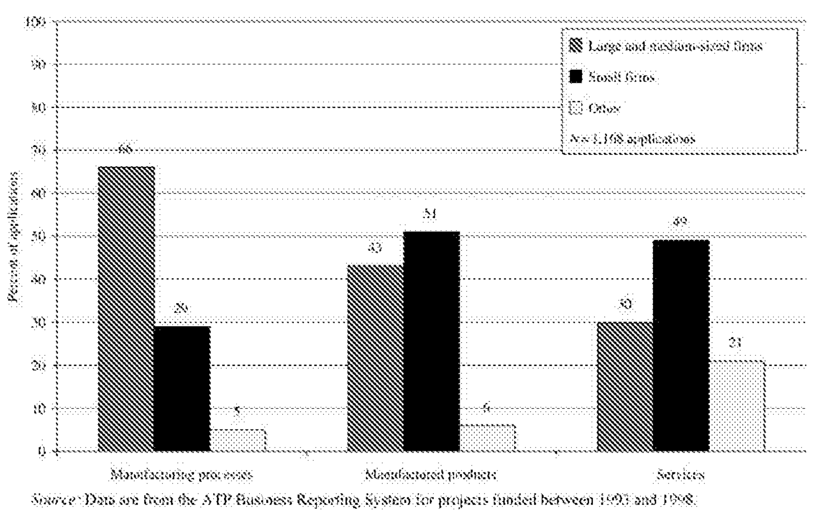


Figure 5. Commercialization strategy: By firm size.

Competitive advantage

This section examines the expected competitive advantage of ATP-funded technologies in terms of improved performance, cost reduction, and other business objectives. The life-cycle model has implications for the nature of the competitive advantage of different ATP-funded technologies. In particular, market competition typically shifts away from introduction of new-to-the-world, radically innovative products, to performance improvements, and then to cost/price considerations over time, as discussed in Section 3. To assess whether business objectives of ATP projects are consistent with this component of the life-cycle model, we examined responses to the following question:

What is your major advantage over the competition or other approaches to meeting the customer need? Response choices:

- Higher performance.
- Lower cost.
- Both higher performance and lower cost.
- New solution.
- Other.

Figure 6 shows the results by technology area.

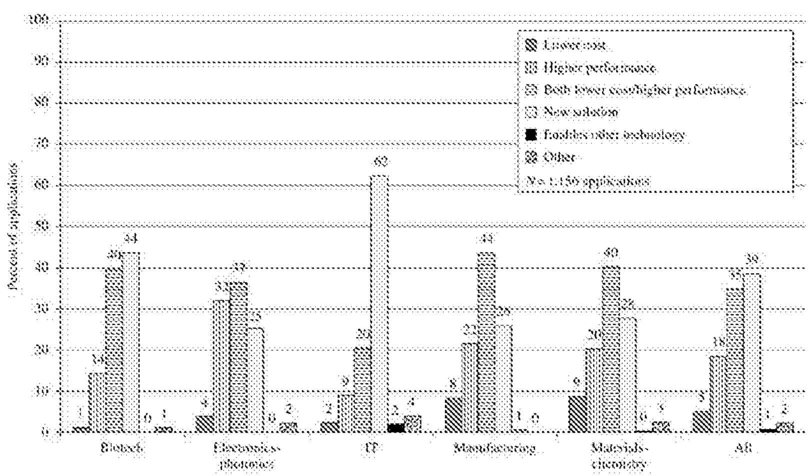
Most revealing for our purposes is that information technologies and biotechnologies have the largest percentage of applications considered to be new solutions to a market problem (62% for IT and 44% for biotechnologies). Other technologies (electronics, manufacturing, and materials-chemistry) most frequently target a combination of both cost and performance objectives, although large numbers of electronics and materials-chemistry applications are clearly focused on performance.

These results provide additional evidence that ATP-funded IT and biotechnologies are often in an early, fluid phase of the innovation life cycle, while electronics and materials-chemistry technologies—and even manufacturing technologies—tend to be in the transitional, growth phase, paying considerable attention to both performance and cost objectives. It should be also noted that a large number of applications offered advantages other than those listed in the response choices.

Availability of capital

ATP funding tends to be relatively small compared with what will be needed subsequently to complete the R&D cycle and bring new products to market. The availability of private capital for ATP-project cost share and for the post-ATP product development phase may affect expectations about the timing of commercialization.

To consider whether capital availability might affect the timing of commercialization by technology area, we examined responses to two different



Source: Data are from the ATP Business Reporting System for projects funded between 1993 and 1998.

Figure 6. Business advantage: By technology area.

questions. First, we asked whether ATP funding itself helped build credibility with investors.[8] Second, we looked at differences in the ability to raise external capital.

To address these issues, we examined responses of the for-profit companies represented in the analyses reported in Sections 5 and 6 above who also responded to questions in the BRS about financing issues. Since these questions are primarily relevant to for-profit companies and to projects that have been underway for some time, we used information provided by for-profit respondents in Anniversary and Close-out Reports. Of the 588 project participants included in the analyses above, 392 provided information about their experience in raising capital and/or their credibility with investors following their ATP award.

To assess the halo effect with outside investors, we examined the 388 responses to the following question:

How has the ATP award affected your credibility with investors?
Response choices:

- Positively.
- Negatively.
- Not at all.
- Not sure.

Most notably, 82% of biotechnology companies reported a positive effect in their relationship with investors, compared with only 34% of manufacturing-technology companies and 36% of materials-chemistry companies. A large percentage of the companies in earlier stages of evolution, particularly biotechnology companies, said they felt they were making progress in building relationships to acquire financial resources.

We assessed the level of activity in raising capital by examining responses of the group of 387 for-profit project participants to the question:

Have you received new external funding for the ATP-funded technology or its commercialization since the ATP award was announced?
Response choices:

- Yes.
- No.
- Uncertain.

The group was also asked a follow-up question to determine the sources of that new external funding. Participants could choose from this list:

- Owner/angel investors.
- Stock issue: venture capital.
- Stock issue: public offering.
- Long-term debt financing.
- Federal program: SBIR.
- Federal program: Other.
- State or local government.
- Other.

We expected to see that companies with technologies in relatively early stages of the innovation life cycle would be more active in the capital markets if

Table VII
External funding activity

	All	Biotech	Manufacturing	IT	Materials-chemistry	Electronics/photonics
Percent receiving external funding	26	46	9	33	16	37
Percent receiving each type of external funding						
Public stock issue	3	8	0	1	2	5
Other federal sources	11	32	3	6	7	16
State/local governments	4	10	0	4	5	5
Venture capital	7	12	0	14	4	9
Owner/angle investors	10	19	1	13	6	16
Other (mostly corporate)	10	14	5	10	11	9

$N = 387$ companies responding to the question about external funding.
Source: Data are from the ATP Business Reporting System for projects funded between 1993 and 1998.

they were to achieve their aggressive commercialization timelines for early applications. Results are shown in Table VII.

Among 387 companies responding to the first question, 26% reported receiving some form of external funding since receiving their ATP award. The range was substantial: from 46% for biotechnology participants to only 9% of participants developing manufacturing technologies. A higher percentage of biotechnology participants than any other technology's participants received every type of funding, except venture capital.

For example, 8% of biotech participants receiving external funding through a public stock issue, compared with 0% of manufacturing and 1% of IT participants. (Note that the cutoff date for the data was September 1999, before the turmoil in the stock markets in 2000–2002.)

Over 30% of biotech participants received funding from non-ATP federal sources, compared with 16% of electronics/photonics participants, and 7% of materials-chemistry participants.

Funding from owner/angel sources was somewhat frequent for electronics and IT participants as well as biotech participants (16%, 13%, and 19%, respectively), and lowest for manufacturing (1%).

Participants from all technologies received funding from other sources than those listed. Most of these "other" sources involved strategic alliances and joint development agreements with other companies.

Biotechnology companies appear to be particularly successful in raising the capital from a variety of sources needed to achieve their goals for commercialization in some early applications. This ability to raise capital strengthens their reports of "increased credibility with investors". Together, the evidence supports the conclusion that ATP funding is a positive factor in providing firms the name recognition and credibility for building partnerships to help fund applications that require long regulatory periods of clinical testing.

Biotechnology participants were slightly less successful than information technology participants in raising funds from venture capital, which typically insists on short investment recovery periods. Funding from venture capital was most frequent in IT: 14% of IT companies, compared to 12% of biotechnology companies, 9% of electronics companies, and none of the manufacturing companies.

Manufacturing participants were more likely to receive funds from corporate partners than other sources, although external financing was rare for this group. Small companies involved in manufacturing projects likely considered financial relationships with potential customers more useful than financing alone, and many were involved in ATP joint ventures that included potential customers.

Together with the analysis of other factors, the information on financing provides additional evidence supporting the life-cycle framework and enhances the credibility of the expected patterns of commercialization.

7. Summary of findings by technology area, conclusion, and future work

A summary of findings presents the results of the factor analysis presented in Section 6 in the context of the life-cycle framework. We conclude with policy implications and plans for future work.

Summary of findings by technology area, conclusion, and future work

Some of the key findings, by technology area, are as follows:

Biotechnologies and information technologies. These technologies support a host of new-to-the-world applications in a number of industries. They support formation of new industries.

Information technologies enter the market quickly, with a significant percentage of applications expecting commercialization during the period of ATP funding, and with nearly two-thirds expecting commercialization by a year later. For half of IT applications, the window of market opportunity is expected to close within a year after ATP funding ends. This timeline is consistent with the rapid pace of the early phase of the innovation life cycle for small firms competing to open and capture new markets. Service applications can be important commercialization strategies as an initial point of market entry to end users in many industries, as a more primary mechanism for technology advancement in mature manufacturing industries, and as a strategy for addressing growth industries like health care and telecommunications services.

Biotechnology projects have a number of early opportunities for service applications (for example, research and testing services) that are useful for market conditioning and validation. That is the case even if biotech applications do not generate large cash flows or economic impact in therapeutic markets until much later. Regulatory requirements prohibit fast market entry for many health care applications. The market is expected to remain open for major applications for more than five years after ATP funding ends.

- The innovation focus is on achieving basic functionality and performance of new-to-the-world products.
- The flow of investment capital suggests investors envision the broad future potential of the markets expected to emerge.
- The precise nature of the larger markets and distribution mechanisms is still blurred.
- Technology-based competition is keen, and dominance changes rapidly in new and emerging markets.

Manufacturing and materials-chemistry projects. These projects more typically are developing new process technologies for existing classes of products in mature, commodity-oriented industries. Manufacturing technologies and materials-chemistry technologies commercialize slowly; however, opportunities are expected to accelerate about two years after ATP funding ends and then to decline relatively slowly compared with other technologies.

- The focus is on manufacturability and cost to gain advantage in "cents per pound," high-volume markets, as well as on higher performance products.
- Capital investment and validation requirements are costly and lengthy. Financing typically comes from retained earnings.
- Product life cycles and market windows are longer than for IT or electronics projects. Technological change occurs more slowly than in new product areas, particularly for commodity types of products.
- Joint ventures are an important vehicle for sharing risks and technological uncertainties, particularly in addressing interdisciplinary issues where different technologies converge, such as information technology for manufacturing or healthcare applications or many electronics/photonics projects that involve a mix of materials, electronics, and manufacturing issues.

Electronics. Electronics (and related materials) projects tend to involve a mix of new and established firms in transitional, rapid-growth stages of innovation, company, and industry development.

- Product applications are more common than process applications.
- Cost and manufacturability are critical objectives.
- Electronics product markets are extremely competitive; product life cycles are short; and capital requirements for high-volume production remain steep barriers to market entry.
- Nearly three-fourths of applications are expected to earn revenues within two years after ATP funding ends. Windows of market opportunity are expected to diminish quickly after two years.

Conclusion and policy implications

The innovation life-cycle model provides a useful framework for illuminating differences in commercialization patterns across ATP-funded technology areas. Our analysis shows that characteristics such as speed to market, size of firm, project structure, commercialization strategy, and technology area map to most features and stages of the innovation life cycle summarized in Table I. This innovation life-cycle framework provides a general trajectory of what to expect when and under what circumstances for future use in project selection and assessment of project performance. For example, credible and appropriate commercialization plans and expectations about revenue must be expected to vary by technology area, consistent with the analysis presented in this study. Project proposals that indicate pathways to markets with major deviations from this analytical framework need to be examined before funding is committed.

Future work

The data on timing of commercialization and windows of market opportunity used in the body of the study reflect expectations at the time of the last report on file from each ATP project participant, rather than actual commercialization history. This study initiated a further effort to compare actual commercialization histories of ATP-funded technologies against expectations. These analyses are presented in the appendix.

Data presented in the appendix from Close-out Reports for a large portion of the project participants covered in the body of the study suggest that ATP projects are meeting or exceeding expectations for their earliest commercial applications. Data from Post-project Surveys conducted two to three years after the end of ATP funding suggest that the commercialization pace may have slowed down relative to expectations by that time.

Given the small number of Close-out and Post-project reports available from each technology area, their analysis must be judged to be preliminary. Additional data and analysis by type of commercial application, by technology area, and by type of ATP project and role within the project are needed to document the longer-term history and to identify characteristics of success and failure to meet expectations.

This study is the first of many anticipated studies that characterize the differences in commercialization patterns of different ATP-funded technologies. The growing number of Post-project Surveys provide substantial data documenting the actual performance of projects against plans over longer portions of the technology life cycle. Future studies will analyze ATP-funded innovation by specific industry-use sectors and areas of technology impact as well as core technology area.

Acknowledgments

This report was made possible through the cooperation of hundreds of ATP-funded organizations that are providing information through ATP's BRS in support of program evaluation and project monitoring efforts. Many individuals in ATP and NIST contributed to the report. Stephanie Shipp provided insightful comments. John Nail performed analysis of actual commercialization experience using Post-project Survey data. Many ATP staff participated in the review process. Richard (Chuck) Bartholomew and Linda Beth Schilling provided helpful comments in the ATP review process, and Hayden Brown, Building and Fire Research Laboratory, provided additional assistance during the WERB process.

Francisco Moris, currently an economist with the National Science Foundation, performed the major part of his work on this study while serving in ATP's Economic Assessment Office. The views expressed in this document do not necessarily reflect the views of the National Science Foundation.

Notes

1. See Ruegg (1996) for more discussion of enabling technologies and ATP program objectives. For a related concept from the macroeconomic perspective see Helpman (1998).
2. See also McDonough (2000).
3. For example, see Breschi *et al.* (2000).
4. For an introduction to the literature on research partnerships, see Hagerdoon *et al.* (2000).
5. For example, see Hagerdoon (1993).
6. For a historical, business, and R&D overview of industrial chemicals, see Arora and Gambarella (1999).
7. Audretsch (2001) and others have noted the important role of university scientists in biotechnology companies and the strong ties to universities.
8. See Powell (1999) and Feldman and Kelley (2001) for earlier evidence and a discussion of the halo effect of ATP funding.

References

Abernathy, W.J. and J.M. Utterback, 1978, 'Patterns of Industrial Innovation,' *Technology Review* **80** (June/July), 41–47.

Advanced Technology Program, 2001, *Performance of 50 Completed ATP Projects: Status Report Number 2*, NIST SP 950-2, December.

Audretsch, D., 2001, 'Strategic Research Linkages and Small Firms,' *Strategic Research Partnerships: Proceedings from an NSF Workshop*, July.
Auster, E.R., 1992, 'The Relationship of Industry Evolution to Patterns of Technological Linkages, Joint Ventures, and Direct Investment Between U.S. and Japan,' *Management Science* **38** (6), 778–792.
Arora, A. and A. Gambarella, 1999, 'Chemicals,' in *U.S. Industry in 2000*, Washington, D.C.: National Research Council, National Academy Press.
Breschi, S., F. Malerba, and L. Orsenigo, 2000, 'Technological Regimes and Schumpeterian Patterns of Innovation,' *The Economic Journal* **110**, 388–410.
Cooper, R.G. and E.J. Kleinschmidt, 1994, 'Determinants of Timeliness in Product Development,' *Journal of Product Innovation Management* **11**, 381–396.
Feldman, M.P. and M.R. Kelley, 2001, Winning an award from the Advanced Technology Program: Pursuing R&D strategies in the public interest and providing a halo effect. National Institute of Standards and Technology, NISTIR 6577, January.
Hagerdoon, J., 1993, 'Understanding the Rationale of Strategic Technology Partnering: Inter-Organizational Modes of Cooperation and Sectoral Differences,' *Strategic Management Journal* **14**, 371–385.
Hagerdoon, J., A. Link, and N. Vonortas, 2000, 'Research Partnerships,' *Research Policy* **29**, 567–586.
Helpman, E. (ed.), 1998, *General Purpose Technologies and Economic Growth*, Cambridge, MA: MIT Press.
Long, W., 1999, *Performance of Completed Projects—Status Report Number 1*, NIST Special Publication 950-1, Advanced Technology Program, Gaithersburg, MD: National Institute of Standards and Technology, March.
McDonough, E.F.III., 2000, 'Investigation of Factors Contributing to the Success of Cross-Functional Teams,' *Journal of Product Innovation Management* **17** (3), 221–235.
Patel, P. and K. Pavitt, 1995, 'Patterns of Technological Activity: Their Measurement and Interpretation,' in P. Stoneman (ed.), *Handbook of Economics of Innovation and Technological Change*, Oxford: Blackwell Handbooks in Economics.
Pavitt, K., 1984, 'Sectoral Patterns of Technical Change: Toward a Taxonomy and Theory,' *Research Policy* **13**, 343–373.
Powell, J.W., 1999, *Business Planning and Progress of Small Firms Engaged in Technology Development through the Advanced Technology Program*, NISTIR 6375, Gaithersburg, MD: National Institute of Standards and Technology, October.
Powell, J.W. and K. Lellock, 2000, *Development, Commercialization, and Diffusion of Enabling Technologies: Progress Report*, NISTIR 6491, Advanced Technology Program, National Institute of Standards and Technology, April.
Rothwell, R. and M. Dogson, 1991, 'External Linkages and Innovation in Small and Medium-Sized Enterprises,' *R&D Management* **21** (2), 125–137.
Ruegg, R., 1996, *Guidelines for Economic Evaluation of the ATP*, NISTIR-5896, Advanced Technology Program, National Institute of Standards and Technology, November.
Utterback, J.M., 1994, *Mastering the Dynamics of Innovation: How Companies Can Seize Opportunities in the Face of Technological Change*, Harvard Business School.
Vonortas, N.S., 1997, *Cooperation in Research and Development*, Boston: Kluwer Academic Publishers.

Appendix: Actual versus expected commercialization timelines: Preliminary results

Expectations alone are an incomplete indicator of the timeline for commercialization—particularly given the risky R&D projects ATP funds. Early on there are considerable uncertainties about achieving the technical goals. Technical hurdles, and additional capital requirements, may delay the projects beyond the window of opportunity. ATP does not seek to fund projects with high business risks, but some risks are unavoidable.

ATP's objective is to fund breakthrough, enabling technologies, some of which will serve as platforms for emerging industries. Many projects target markets that are just emerging or are almost non-existent. Business risk is an inherent characteristic of such projects. Moreover, technologies may be already ahead of the market or ahead of critical complementary technologies and products. Unexpected competition may arise.

Enough ATP projects have now been completed to begin comparing actual commercialization activity with expectations. Here, we take a small step forward. This appendix provides a preliminary assessment of the question: To what extent is actual commercialization mapping to plans? Data are still very limited. This is the first study to use BRS data to track a given group of projects over time, from the beginning of the ATP funding into the post-ATP funding period. Some initial observations are possible. Given its preliminary nature, this analysis seems most suited to an appendix. More in-depth analysis will follow as more data become available.

We identified Close-out Reports to match Baseline Reports for approximately one-third of all the applications analyzed in the body of the study. (See discussion of these reports in Section 2 A.) We used these paired reports to compare actual commercialization experience (as of the end of ATP funding) with expectations at the start of the projects.

Similarly, we had Post-project Surveys to match approximately one-third of the project participants whose reports are analyzed in the body of the study. The Post-project Surveys were conducted two to three years after the end of ATP funding. They enabled comparison of actual commercialization experience as of two to three years after the end of ATP funding with expectations in the ATP-funding period.

Very early commercialization—during ATP

Our reduced data set of matched Close-out and Baseline Report data covered 301 commercial applications reported by 176 organizations in 147 projects. We compared the characteristics of the matched Close-out and Baseline Reports and compared actual business progress reported in the Close-out Reports with expectations about the timing of commercialization reported in the Baseline Reports.

Profile of matched commercial applications. The distributions by size of firm, technology, project structure, and type of application are shown in Table A.1.

The distributions for this reduced, matched set of Baseline and Close-out reports can be summarized and compared with the full set, as follows:

- These 301 applications are about equally divided between small and medium-large-sized firms. Just over half the applications were reported by small companies, approximately the same percentage as for the full group analyzed in Section 4.
- Nearly one-third are applications of materials-chemistry technologies, while a quarter of the applications involve information technologies. Proportions of biotech and materials-chemistry applications were somewhat higher, and proportions of electronics/photonics and manufacturing were somewhat lower than for the larger group of applications analyzed in Section 4.

Table A.1
Profile of commercial applications in matched close-out and baseline reports

1. By organization type/size and project type

		Firm size (% of applications)			Project type (% of applications)	
	Number of applications	Small	Medium/ large	Other*	SA	JV
All	1,172	46	47	7	39	61
Matched Baseline and Close-out applications	301	51	49	0	68	32

2. By technology area

Technology	Applications All/Close-out	Percentage All/Close-out
Biotechnology	176/56	15/19
Electronics/photonics	181/30	15/10
IT	307/76	26/25
Manufacturing	185/41	16/14
Materials-chemistry	323/98	28/32
Total	1,172/301	100/100

* Includes universities, nonprofits, and government.
Source: Data are from the ATP Business Reporting System for projects funded between 1993 and 1998.

- Over two-thirds (68%) of these applications come from single-company projects. Applications from participants in joint-venture projects are poorly represented given that applications from single-company projects represent only 39% of the 1,172 applications analyzed in Section 4, but 68% of the smaller, matched group of Close-out and Baseline reports.

Baseline expectations versus Close-out performance. For evidence of commercialization as of the end of the ATP project, we used responses to the following questions in the Close-out Reports:

- Have you earned revenues from products/services to date? (Y/N?)
- Have you to date begun production (of a new product or in a new process)? (Y/N?)

The results are shown in Table A.2 and Figure A.1. These results show that at the beginning of ATP funding, revenues were expected for only 14% of the 301 matched applications during the ATP-funding period, ranging from a high of 29% for IT technologies to a low of 5% for biotechnology applications. By the project Close-outs, 22% of the matched set of applications had generated some revenue from their initial, first-generation applications.

All technology areas except manufacturing had earned revenue for more applications than expected at this early stage. IT and electronics-based applications showed the most commercial activity, with 33% of IT-based applications and 31% of electronics-photonics-based applications reporting some revenue.

A few caveats are in order. It is evident from the information provided in Close-out Reports about actual amounts of revenue to date that much of the activity was at a low level. The applications for which revenue was reported represented the earliest opportunities to commercialize early stages of the technology. Almost no company reported more than one application with revenues (data not shown). On the other hand, the results may undercount actual commercial activity because the revenue question is not directly applicable to (or posed for) process applications that may have been implemented.

Early revenues sometimes derive from sales of samples or relatively early prototypes, rather than actual commercial production. To compensate for limitations in the earned revenue variable, we examined responses to the question "Has production begun?" This question applies to process as well as product applications, but not to service applications. In general, the production results shown in Table A.2 are consistent with the revenue earned results, but show somewhat lower levels of activity.

Across all applications, actual production appeared to be occurring ahead of baseline expectations of revenue. Production activity was reported for 17% of applications, compared with baseline expectations of 14%.

Biotechnologies showed much more early production activity than any other technology area. This early biotech activity was likely associated with the fluid stages of innovation, highly custo-

Table A.2
Expectations versus actual commercialization results from matched baseline and Close-out reports, by technology area

	Percent of applications*		
Application	Revenue is expected during ATP (Baseline)	Yes, have earned revenue (Close-out)	Yes, production has begun (Close-out)
Biotechnology	5	14	18
Electronics/photonics	10	31	17
IT	29	33	24
Manufacturing	10	10	7
Materials-chemistry	11	20	16
All	14	22	17

*$N = 301$ applications.
Source: Data are from the ATP Business Reporting System for projects funded between 1993 and 1998.

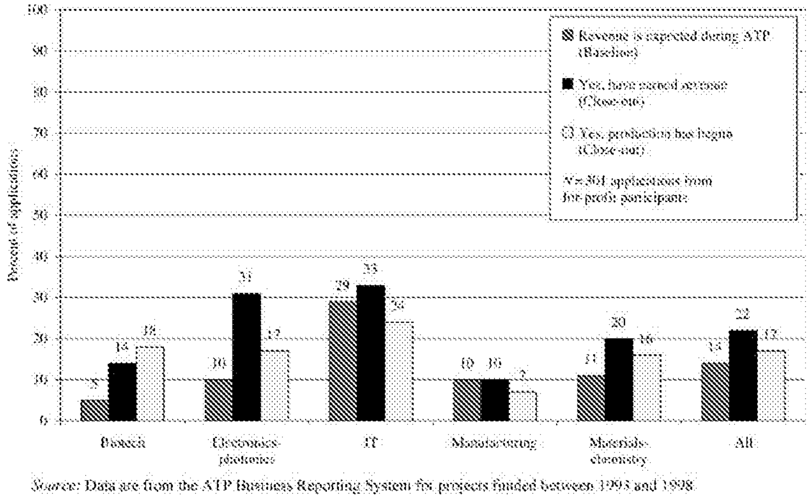


Figure A.1. Comparison of actual revenue activity at project Close-out with expectations at baseline.

mized products, and new markets being served. Perhaps the vigorous venture capital activity in the late 1990s facilitated this early activity.

Production results for manufacturing technologies and information technologies showed somewhat fewer applications in actual production than baseline expectations suggested.

The omission of service applications in this variable may account for the IT result. The manufacturing applications that had earned revenues as of the end of ATP funding were likely only in pilot production.

Biotechnology companies were in production for some applications that had not yet actually generated revenues. One would expect this of process applications, but not of the product applications that are more typical of biotech firms. More investigation is needed, but the early production using biotechnologies may simply reflect different definitions biotech and manufacturing-based companies apply to "production" in the early stages of their product cycles.

The key result is that when these matched applications are considered as a whole, at least as many applications as was expected resulted in actual commercial activity at ATP-project closeout—for each technology area. The many small companies were seeking to raise market awareness for very early generations of their products and to increase cash flow. There is considerable competitive pressure to be first to market in new or emerging markets. Larger-volume, higher-value applications would come later.

Longer-term commercialization activity—two to three years after ATP

Post-project Surveys generate considerable detail about commercial activity after ATP funding ends. Among the 558 ATP-project participants covered in the body of the study, we identified 173 companies (from 135 projects) that were covered in the Post-project Surveys completed as of early 2002. These surveys covered participants in ATP projects that were completed by the end of 1998 and thus were eligible for their first Post-project Survey by 2001. Survey results were available from approximately 95% of single and joint-venture project participants in the eligible group. We used the Post-project Survey data to perform a longer-term comparison of actual commercialization with plans.

Profile of matched project participants. Table A.3 compares the distribution of participants in these Post-project Survey data with the 558 participants whose commercialization plans are analyzed in the body of the study.

The similarities and differences in portfolio characteristics in the total set of 558 participants and the reduced set of 173 post-project participants can be summarized as follows:

Table A.3
Distribution of participants and projects

1. By organization type/size and project type

	Number of project participants	Firm size (% of participants)			Project type (% of participants)	
		Small	Medium/ large	Other*	SA	JV
All	558	42	51	7	34	66
Post-project survey	173	48	50	2	66	34

2. By technology area

Technology	Number of project participants All/PPS	Percentage All/PPS	Number of projects All/PPS	Percentage All/PPS	Participants per project All/PPS
Biotechnology	83/32	15/18	67/29	22/21	1.2/1.1
Electronics/photonics	97/22	17/13	44/17	15/13	2.2/1.3
IT	140/46	25/27	73/37	24/27	1.9/1.2
Manufacturing	96/18	17/10	39/16	13/12	2.5/1.1
Materials-chemistry	142/55	26/32	76/36	26/27	1.9/1.5
Total	558/173	100/100	299/135	100/100	1.9/1.3

* Includes universities, nonprofits, and government.
Source: Data are from the ATP Business Reporting System for projects funded between 1993 and 1998.

- The entire group of 558 and the post-project group were both about equally divided between small and medium-sized firms. A very small number of non-profit organizations were included in each.
- Two-thirds of the post-project group were single-company awardees, but only one third of the larger group were single-company awardees. The Post-project Surveys reflected a much larger percentage of single-company projects because those projects and participants were a larger fraction of the first completed ATP projects and thus the first to become eligible for Post-project Surveys. The average number of participants per project was considerably smaller for the post-project group because there were relatively few joint ventures.
- Percentage distributions by technology area were quite similar for the larger group and the post-project group. The major differences were that there was a smaller percentage of manufacturing participants in the post-project group and a larger percentage of materials-chemistry participants. This difference disappeared in looking at the project distribution by technology area. It likely had little impact on the comparability of the post-project and earlier data.

Post-project performance

For evidence of commercialization in the post-ATP period, we used responses to these questions in the Post-project Survey:

- Has your organization earned any revenue (or experienced reduced costs of production of goods for sale) to date as a result of its ATP project? (Y/N)

For those who said No:

- In the next two years, does your organization anticipate earning revenue from its ATP-funded technology? (Yes, No, Don't Know)

For those who said No:

- In the next two to ten years, does your organization plan to introduce product/license, or introduce a process in house that incorporates ATP-funded technology? (Yes, No, Don't Know)

The following is a summary of the responses from the 173 organizations:

- 46% reported they had received revenues (or cost reductions from new processes) from 104 applications in their first Post-project Survey.
- 14% expected to launch products in the next two years, and 12% planned to introduce a product in the subsequent two to ten years.
- 28% no longer anticipated revenues from their ATP-funded technology or were very uncertain about it.
- 78% of the applications that have earned revenues to date involve new products or services; the rest are about evenly split between manufacturing processes and patent licensing.

Table A.4 provides a detailed breakdown by technology area. Given the small number of participants in each area, the results must be considered preliminary. Nevertheless, it appears that the major portion of the companies reporting who will commercialize their ATP-funded technologies have done so, at least for their first applications.

This preliminary analysis strongly suggests that a large portion of the commercialization activity in all technology areas occurs, or at least begins, by two to three years after ATP funding ends. Nearly nine out of ten Information Technology participants who still expected to commercialize their ATP-funded technology had already done it. Two out of three electronics/photonics participants who still expected to commercialize had done it. In both areas, no further new commercialization was expected after the next two years. Biotechnology and materials-chemistry participants, on the other hand, expected considerable new activity in the next two to ten years. Over one in three electronics/photonics and manufacturing participants no longer expected any revenues at all or were very uncertain as to their timing.

In general, the pattern is consistent with the results presented in the body of the study. Information technologies and electronics/photonics technologies either commercialized quickly or not at all. Biotechnologies had considerable early commercialization activity for at least some types of applications, but many companies saw a long window of opportunity and commercialization timeline. The number of data points was small for manufacturing participants; however, it appears that there were a large number who had cancelled plans to commercialize. Additional investigation is needed to determine the reasons, but it may be that the cost targets were not met or had shifted so that the technologies developed with ATP funding were not deemed commercially viable.

Note that this analysis was conducted by summarizing activity by project participant rather than by individual commercial applications, as was done in the Baseline-Close-out comparisons. By two to three years after ATP funding ends, markets have changed substantially since Baseline

Table A.4
Actual and expected commercialization activity as of two to three years after ATP, by technology area

Technology area	Have earned revenues (%)	Expect revenues within two years (%)	Expect revenues in two to ten years (%)	Do not expect revenues or are uncertain (%)	Total (%)
Biotechnology	44	12	22	22	100
Electronics/photonics	41	23	0	36	100
Information technology	61	9	0	30	100
Manufacturing	44	22	6	38	100
Materials-chemistry	36	13	24	27	100
All	46	14	12	28	100

Note: Revenue activity includes use of new manufacturing processes for reducing production costs.
Source: Data are from the ATP Business Reporting System for projects funded between 1993 and 1998.

reports were submitted. Therefore, the Post-project Surveys do not specifically relate applications reported in the Post-project Survey with those reported at the start of the ATP project. Nevertheless, the distribution of applications by type (product, service, or process) was similar for the Post-project, Close-out, and larger body of data. Considerable application-level information is available in the Post-project Surveys and should become part of future analyzes.

Finally, we considered whether the ATP project participants were satisfied with their progress towards commercialization—that is, to what extent they felt progress had met their expectations at that point in time. We examined responses to the following question:

- Overall, to what degree have your organization's business goals for the ATP project at this point in time been achieved? Would you say you have:

Response choices:

- Achieved beyond your goals?
- Achieved your goals?
- Achieved less than your goals?
- Don't know.

Results can be summarized as follows:

- 11% had exceeded their business goals.
- 24% had achieved their business goals.
- 65% had failed to achieve their goals.

Reasons for failure to achieve goals were quite evenly spread across a variety of business and technical factors.

Although the Close-out Reports had indicated that the timing of initial revenue activity had exceeded expectations, the pace seemed to slow down after ATP funding ended. Cumulative commercial activity for most project participants was somewhat less than expected by two to three years after ATP funding ended. Looking at the data from the ATP-funding period (Section 4) together with the Post-project data, 66% of companies expected revenues from at least one application within two years after ATP; however, only about 54% of the companies in the Post-project group had achieved commercialization by two to three years after ATP. Of the remainder, half still expected to earn revenue (most in the next two years); the other half apparently had largely given up hope. Sixty-five percent reported they had failed to achieve their goals for this point in time.

Are expectations about commercialization patterns of ATP projects being met? Significantly more data are needed, both aggregate and by technology area, to answer this question. For example, the Post-project data available reflected a much larger percentage of smaller, single-company projects than the data set used in the body of the study. Furthermore, the data presented in this study do not address the magnitude of commercialization efforts or actual benefits to the ATP-funded organizations or the nation.

Given the risky nature of ATP projects, and the relatively long timelines to commercialization, not all projects will be successful in accomplishing the technical goals needed to achieve maximum economic impact. For many, substantial technical barriers remain after ATP funding ends. Those that do meet their technical goals will face business hazards during the long planning and development period—hazards that may force them to miss the market window of opportunity.

The early data suggests that a large proportion of the projects that will ultimately achieve commercialization will do so, for their initial applications, within two to three years after ATP funding ends. The momentum of some project participants will continue along longer time paths. Two to three years after ATP funding ends, a significant number will have dropped plans for their ATP-funded technologies or are highly uncertain about them.

Overall, the emerging patterns of actual commercialization are consistent with expectations about timing of commercialization presented in the body of the study. Further studies will examine whether the different trajectories for different technologies, and associated commercialization strategies and objectives, remain consistent with the innovation life-cycle model over the longer term.