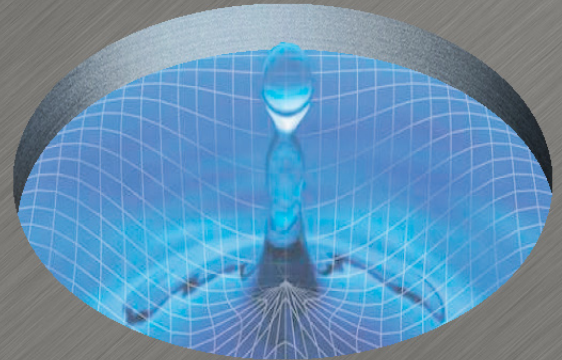



A large, stylized gear graphic in the center of the page. The gear is filled with various images related to manufacturing and technology, including a factory interior, a car on an assembly line, and a computer keyboard.

Enhancing America's Manufacturing Competitiveness:

*A Review of the NIST Advanced Technology Program's
Investment in Manufacturing Technologies*





Enhancing America's Manufacturing Competitiveness: A Review of the NIST Advanced Technology Program's Investments in Manufacturing Technologies

"...the role of our government is to create an environment in which the entrepreneur can flourish, in which minds can expand, in which technologies can reach new frontiers."

President George W. Bush
May 8, 2001

"Manufacturing is an essential part of our economy. Not only are manufactured goods the currency of world trade, but manufacturing is what creates wealth."

Congressional testimony, 2005, Dr. G. Wayne Clough
President, Georgia Institute of Technology

"To live well, a nation must produce well"

Dertouzos et al., 1989
Made In America, The MIT Press

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Enhancing America's Manufacturing Competitive:
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"Manufacturing is an essential part of our economy..."

Acknowledgements

From its inception, the Advanced Technology Program (ATP) has encouraged industry to undertake higher technical risk development efforts than they normally would pursue on their own. The innovative projects funded by ATP have the potential to create broad benefits at the national level. The manufacturing community has been particularly adept at using this public-private partnership to develop advanced, revolutionary processes which they then commercialize to more effectively compete in global markets. ATP has historically reported these manufacturing success stories as a cross-cut of projects in discrete manufacturing. However, this is only part of the story. Just as manufacturing is broader than just discrete parts, ATP's awards in manufacturing come from all industry sectors. This historical report represents this broader prospective for ATP's manufacturing awards.

I would like to thank the ATP experts that prepared this analysis and report: Dr. Richard (Chuck) Bartholomew from the Chemistry and Life Sciences Office, Dr. Amit Bagchi from the Information Technologies and Electronics Office, and Stephen Campbell from the Economic Assessment Office. Their work was based on prior work of the ATP Manufacturing Cross-Cut Team. Helpful comments were provided by many others from ATP, especially Dr. Michael Schen, Acting Director, Information Technology and Electronics Office; Linda Beth Schilling, Director, Chemistry and Life Sciences Office; Dr. Stephanie Shipp, Director, Economic Assessment Office; and Dr. Lorel Wisniewski, Deputy Director, ATP. Jo Ann Brooks from ATP's Information Resources Group provided graphic design for this report.

Marc G. Stanley
Director, Advanced Technology Program
National Institute of Standards and Technology

Enhancing America's Manufacturing Competitive:
A Review of the NIST ATP Investments in Manufacturing Technologies

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What is the Advanced Technology Program?

The Advanced Technology Program (ATP) provides cost-shared funding to industry to accelerate the development and broad dissemination of challenging, high-risk technologies that promise significant commercial payoffs and widespread benefits for the nation. This unique government-industry partnership aids companies in accelerating the development of emerging or enabling technologies that lead to revolutionary new products and industrial processes and services that can compete in rapidly changing world markets. ATP challenges industrial researchers to take on higher technical risk projects with commensurately higher potential payoffs for the nation than they would pursue otherwise. These efforts are typically in a stage of development that is too early and/or too risky to find private sector support.

Congress recognized a need to support such technology development efforts, and thus, in the Omnibus Trade and Competitiveness Act of 1988, directed ATP to support U.S. companies by

"...creating and applying the generic technology and research results necessary to (1) commercialize significant new scientific discoveries and technologies rapidly; and (2) refining manufacturing technologies."

From 1990 to 2004, ATP received nearly 7,000 proposals in 44 competitions from all sectors of industry, representing a wide variety of science and engineering fields. These proposals had over 10,000 participating companies, national laboratories, universities and non-profit associations. A peer-reviewed selection process based on a demanding set of technical and business criteria resulted in 768 awards with more than 1,500 participants. These awards represent \$2.269B in Federal co-funding and \$2.102B in industry cost share for an estimated total awards cost of \$4.371B. The distribution of proposers, awards and participants throughout the nation is shown in Figure 1. Additional information on ATP can be found in the Appendix at the end of this document.

Enhancing America's Manufacturing Competitive:
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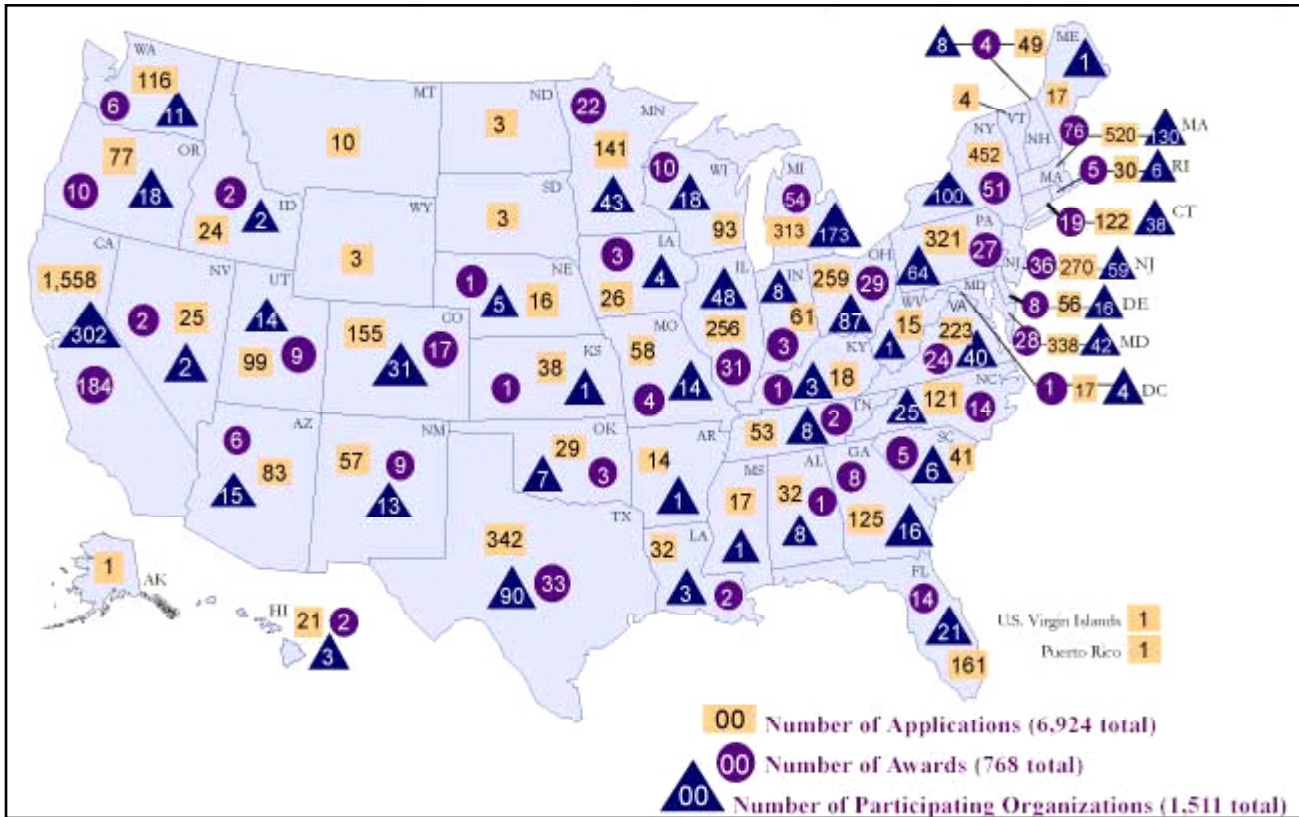


Figure 1: ATP Applications, Awards and Participants by States for 44 Competitions (1990-2004). Note: Total number of applicants includes 7 non-U.S. applicants.

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How Has ATP Supported Manufacturing?

Although ATP supports all areas of technology, industry early-on embraced ATP's statutory obligation to enable development of advanced manufacturing technologies. ATP and industry worked together to define technology-focused competitions with technical scopes that identified challenging manufacturing issues. Technology-focused competitions supporting manufacturing were:

- Manufacturing Composite Structures (1994 and 1995)
- Materials Processing for Heavy Manufacturing (1995)
- Motor Vehicle Manufacturing Technologies (1995 and 1997)
- Catalysis & Biocatalysis Technologies (1995 and 1998)
- Technologies for the Integration of Manufacturing Applications (1995 and 1997)
- Tissue Engineering (1997)
- Microelectronics Manufacturing Infrastructure (1998)
- Photonics Manufacturing (1998)
- Premium Power (1998)
- Selective-Membrane Platforms (1998)

Details on these technology-focused competitions or specific ATP awards can be found on ATP's website.^{1 2}

From these 14 technology-focused competitions and the general/open competitions, ATP has made 293 awards either directly or indirectly related to manufacturing. ATP defines the relationship between direct and indirect contributions to manufacturing as:

- *Direct manufacturing* awards satisfy three criteria: (1) the primary R&D focus is on developments that will be directly commercialized in manufacturing applications; (2) the primary technical innovation is in the field of manufacturing; and (3) the majority of award funds are spent on addressing technical issues enhancing manufacturing.
- *Indirect manufacturing* awards do not satisfy at least one of the direct manufacturing criteria; however, the awards still produce results that can enable or can be adapted to advance manufacturing processes and/or systems.

Manufacturing awards represent 38 percent of ATP's 768 awards with 27 percent related directly to manufacturing and another 11 percent related indirectly. This corresponds to 28 percent of ATP funds going to awards directly related to manufacturing and 13 percent to awards indirectly related, which is 41 percent of ATP's \$2.269B for all awards. A breakdown of these statistics is shown in Tables 1 and 2.

1 The Awards Database can be found at <http://jazz.nist.gov/atpcf/prjbriefs/listmaker.cfm>
2 General information on ATP can be found at <http://www.atp.nist.gov/>

Table 1: ATP Awards in Manufacturing (1990-2004).

Types of Manufacturing Awards	Direct Mfg	Indirect Mfg	Total
Single Company (SA)	135	56	191
Joint Venture (JV)	73	29	102
Total	208	85	293
Percent of All 768 ATP Awards	27%	11%	38%

Table 2: Distribution of Funds for ATP Manufacturing Awards (1990-2004).

Source of Funds	Direct Mfg	Indirect Mfg	Total
ATP Co-Funding	\$629.6M	\$288.7M	\$918.3M
Industry Cost Share	\$581.1M	\$280.6M	\$861.7M
Total	\$1,210.7M	\$569.3M	\$1,780.0M
Percent of ATP Co-Funding (\$2.269B)	28%	13%	41%

Analysis of this data and other information on ATP awards show several interesting characteristics of manufacturing awards compared to all ATP awards:

- The technical scope of manufacturing problems undertaken in ATP's awards often goes beyond the resources and/or capabilities of a single company. This is indicated by joint ventures³ making up 35 percent of all manufacturing awards compared to only 28 percent for all ATP awards.
- Large manufacturing companies selected for funding develop technical solutions that are revolutionary and path-breaking. In manufacturing awards to joint ventures, large companies lead 40 percent of the joint venture awards compared to 33 percent for all ATP awards. Large manufacturing companies are often end-users who typically focus on more incremental solutions addressing near-term customer issues. As leaders of ATP joint ventures, large companies set technical agendas addressing complex integration issues that go beyond an individual company's knowledge-base.

³ An ATP joint venture (JV) consists of at least two separately owned for-profit companies, both involved in the R&D and both contributing to the cost-sharing requirement. Additional details on ATP competitions and awards can be found in the Appendix at the end of this report.

- Manufacturing awards have a greater reliance on university collaboration. Universities participate in 62 percent of direct and 56 percent of indirect manufacturing awards compared to 49 percent of non-manufacturing awards. Greater university participation in manufacturing awards may be the result of factors such as:
 - * Solving system integration problems where universities can offer expertise.
 - * Leveraging specialized analysis, testing and validation expertise in universities.

An added bonus of university collaboration in manufacturing awards is the insight gained by university scientists into future manufacturing challenges and providing better training to the next generation of manufacturing engineers.

These manufacturing awards represent broad participation throughout the nation, as shown in Figure 2.

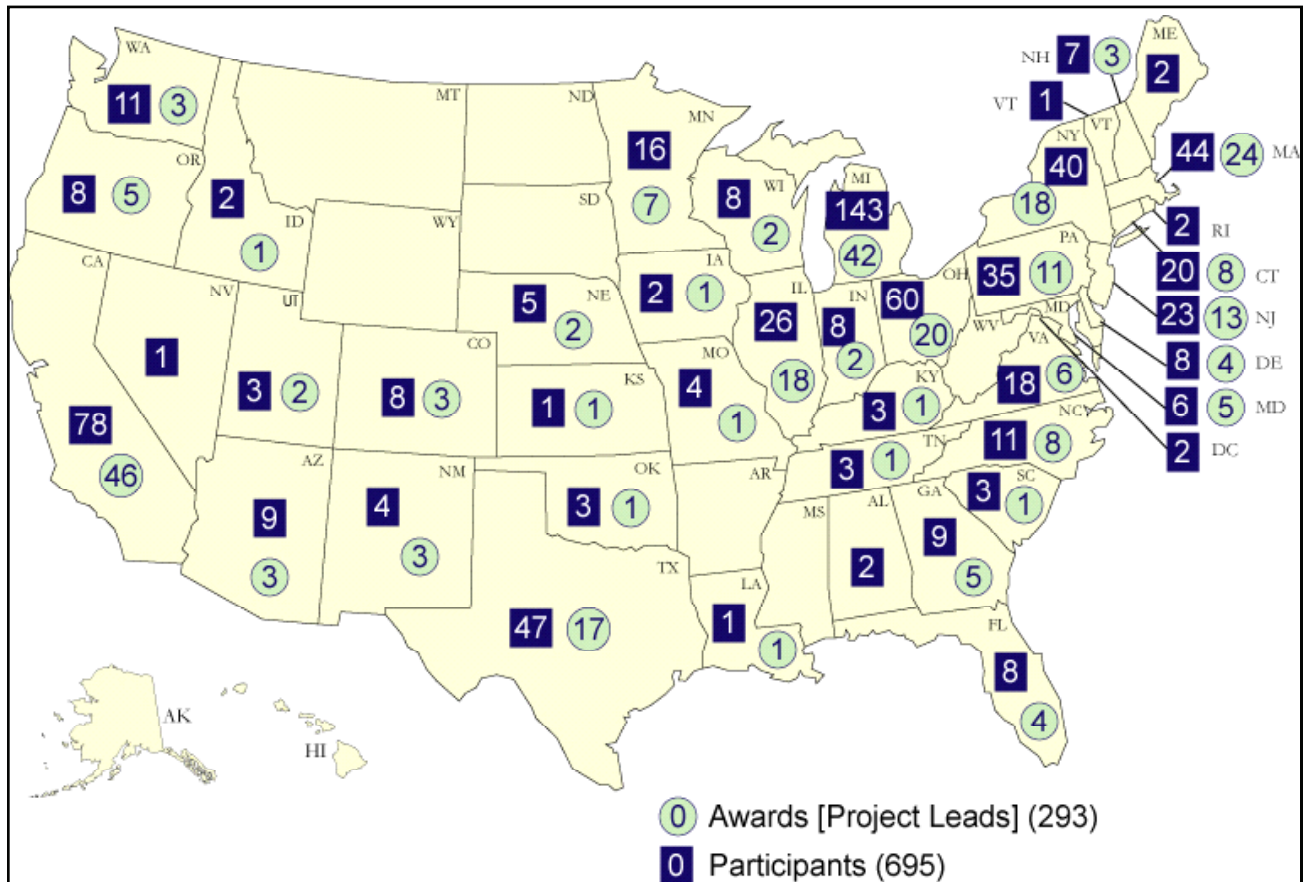


Figure 2: National Distribution of (Direct and Indirect) Manufacturing Awards and Participants (1990-2004).

Direct Manufacturing Awards

As one might expect, ATP awards directly related to manufacturing have strong representation in traditional manufacturing areas, such as the Industrial Heartland (Midwest through portions of New England), Silicon Valley, and technology rich areas such as Research Triangle in North Carolina, Southern California, and Texas. Joint ventures represent 35 percent of the direct manufacturing awards and 63 percent of ATP's co-funding for manufacturing. The distribution of awards based on type of lead is shown in Figure 3.

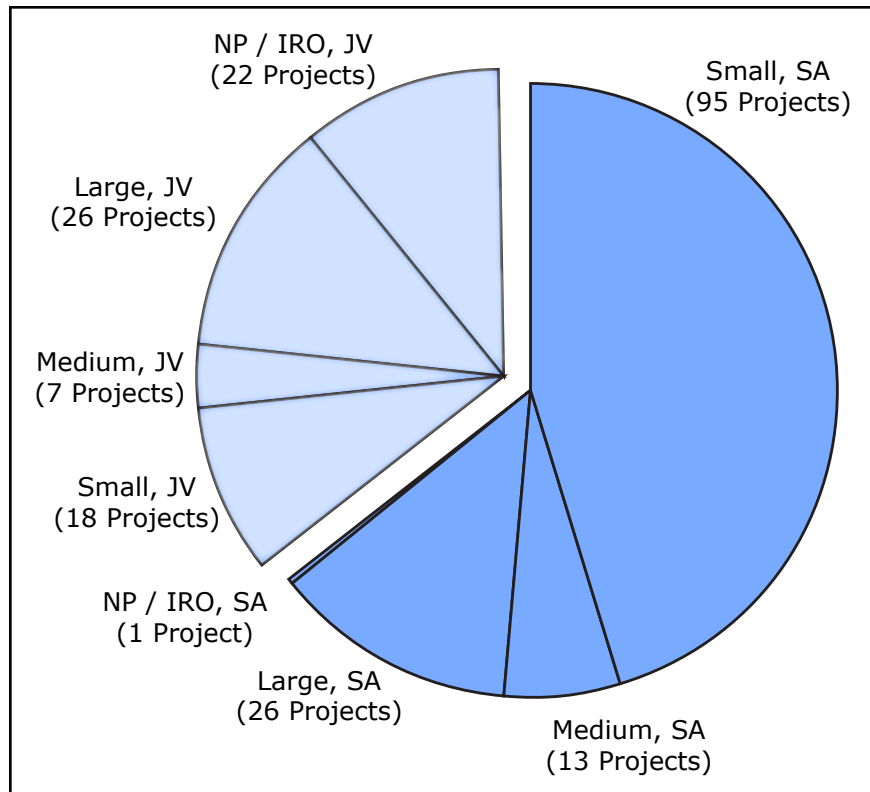


Figure 3: Distribution of the 208 Direct Manufacturing Awards by Type of Award (SA=Single Applicant, JV=Joint Venture) and Size of Lead (NP/IRO=Not-for-Profit/Independent Research Organization, 1990-2004).

Indirect Manufacturing Awards

The distribution of indirect manufacturing awards follows the same general trend of the direct awards. Joint ventures represent 34 percent of the indirect manufacturing awards and 64 percent of ATP's co-funding for manufacturing. The distribution of awards based on type of lead is shown in Figure 4.

Additional data on funding for direct and indirect manufacturing awards can be found in the Appendix at the end of this report.

"Manufacturing is an essential part of our economy..."

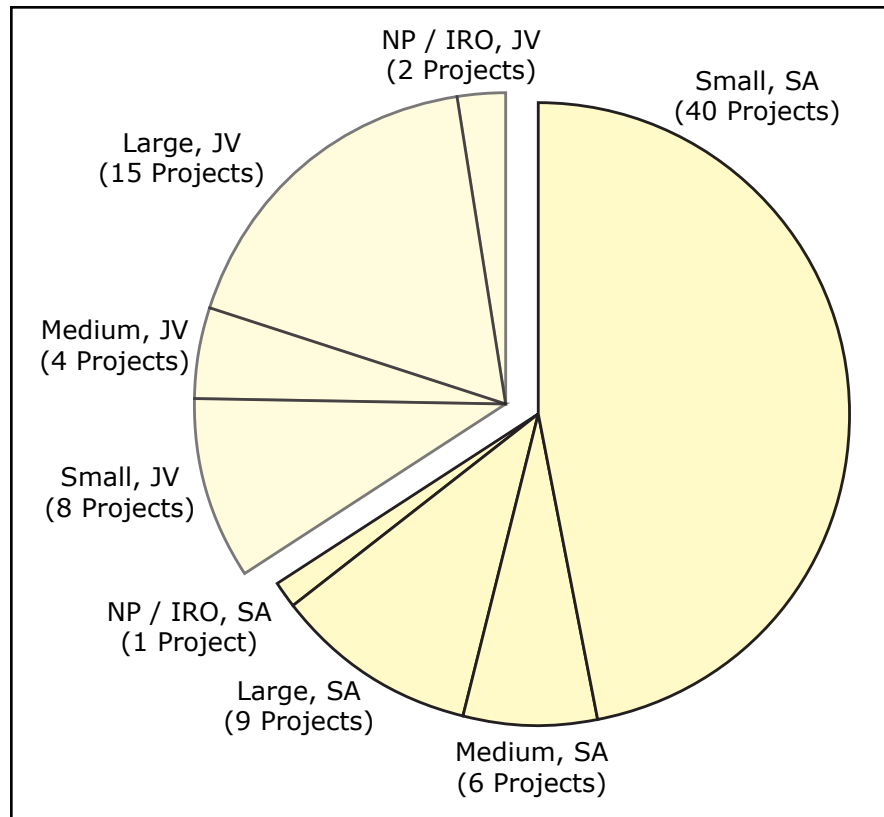


Figure 4: Distribution of the 85 Indirect Manufacturing Awards by Type of Award (SA=Single Applicant, JV=Joint Venture) and Size of Lead (NP/IRO=Not-for Profit/Independent Research Organization, 1990-2004).

Patents and Knowledge Dissemination

Early measures of successful R&D include the creation and dissemination of new technical knowledge. As part of its evaluation efforts, ATP examines various measures of knowledge creation and dissemination. Patenting is one such measure and it is often used as evidence of new scientific knowledge being created. Since 1990, ATP awards have resulted in more than 1,500 issued patents. Direct (334 patents) and indirect (260 patents) manufacturing awards together represent 39 percent of ATP's total patent portfolio. For comparison, direct and indirect manufacturing awards represent 38 percent of the total awards funded by ATP.

While issued patents provide a view of new knowledge being created, patent citations reflect the dissemination and significance of that knowledge benefiting others. As of 2006, the 594 manufacturing patents have generated 3,883 citations while the

912 non-manufacturing patents have generated 7,859 citations.⁴ The mean number of citations, 6.5 for manufacturing and 8.1 for non-manufacturing ATP awards are comparable to previous citation analyses reported by the National Bureau of Economic Research.⁵

ATP manufacturing awards also have been relatively successful in disseminating knowledge through the publication of scientific research and results. Between 1990 and 2006, ATP awards have produced over 1,700 publications. Manufacturing awards account for 838 (542 direct and 296 indirect), or nearly half, of those publications.⁶

Acceleration of Technology Development

First to develop and implement new technology has long been recognized as advantageous, but takes on a greater importance in globally competitive markets. Almost all companies participating in ATP awards saw acceleration in developing manufacturing technology (91 percent for direct, 96 percent for indirect manufacturing awards). More than half the companies saw an acceleration of up to 3 years. Almost a third of the companies said they would not have been able to pursue the development effort without ATP (i.e., "No Project Without ATP"). Acceleration of the technology development is a characteristic of ATP awards in general: the difference in the proportion of awards experiencing acceleration for direct, indirect and non-manufacturing awards is small, as seen in Table 3.⁷

Table 3: Company Estimates for Technology Acceleration from ATP Participation.

	Experience R&D Acceleration	Acceleration Estimates			No Project Without ATP
		Less Than 2 Years	2 to 3 Years	More Than 4 Years	
Direct Mfg	91%	37%	24%	5%	37%
Indirect Mfg	96%	38%	27%	5%	30%
Non-Mfg	94%	32%	22%	5%	42%

4 Analysis of ATP patents and citations by PricewaterhouseCoopers, LLP

5 Adam B. Jaffe and Manuel Trajtenberg, Patents, Citations, and Innovations: A Window on the Knowledge Economy, The MIT Press, 2002

6 Based on data from <http://www.atp.nist.gov/factsheets>

7 Based on data from <http://www.atp.nist.gov/factsheets>

What Are ATP's Manufacturing Application Areas?

The 208 direct and 85 indirect ATP manufacturing awards fall into six application areas:

- Biomanufacturing,
- Bulk materials manufacturing,
- Chemical processing,
- Electronics and photonics manufacturing,
- Manufacturing systems and controls, and
- Manufacturing for power generation and storage.

A breakdown of ATP's co-funding for these application areas is shown in Figure 5. It is not surprising to see strong representation in traditional manufacturing application areas such as manufacturing systems and controls, bulk materials manufacturing and electronics and photonics manufacturing. What is interesting is ATP's early involvement with manufacturing technologies for both traditional and emerging areas such as chemical processing, biomanufacturing, and power generation and storage manufacturing. A brief overview of the different application areas and the innovations ATP has seen, along with examples of awards, follows.

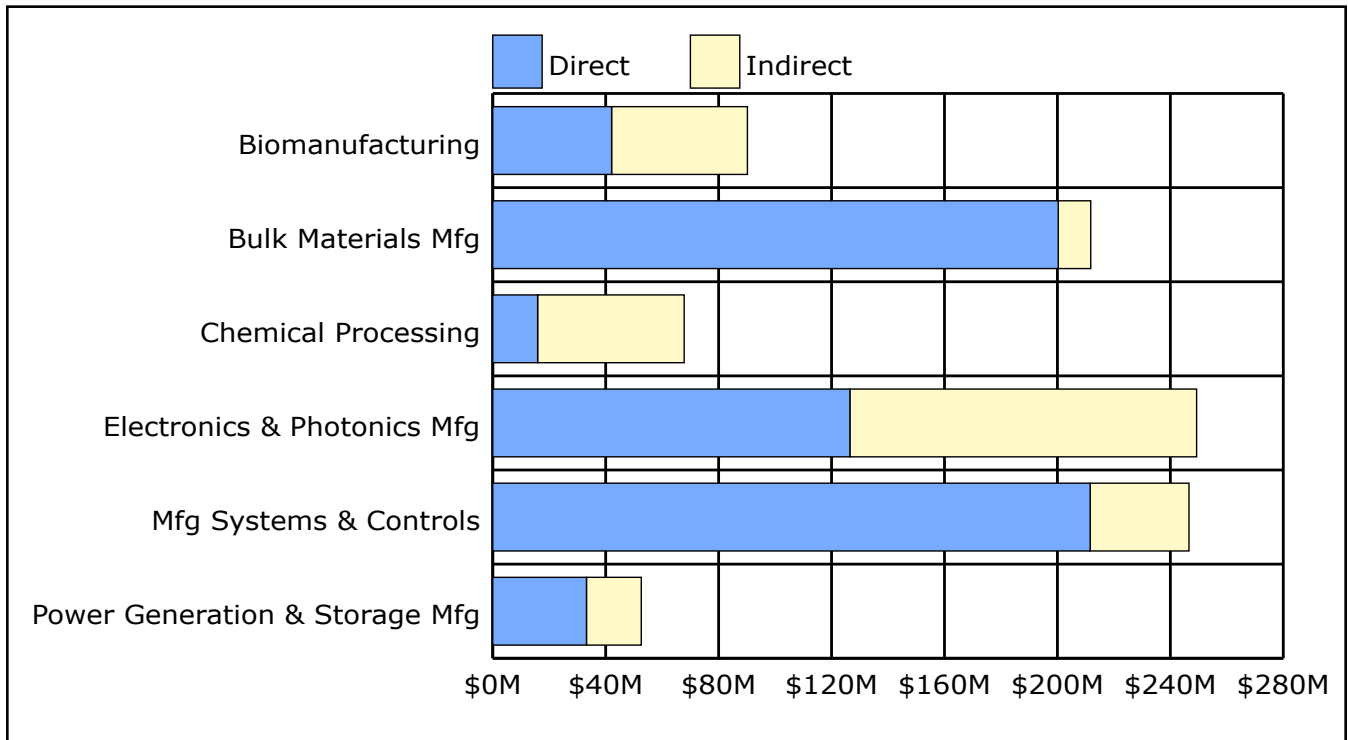


Figure 5: Distribution of ATP Co-Funding for Six Manufacturing Application Areas (1900-2004).

Biomanufacturing

Biomanufacturing uses biotechnology and the control of biological systems and processes to produce products (such as chemicals, proteins, therapeutics, biological substances and devices). Note that this area is much broader than just biomanufacturing for healthcare and can include many other areas that use biomanufacturing such as agriculture, food processing and industrial chemicals.

Application areas include laboratories-on-a-chip; bioreactors; and the processing of bio-compatible materials, engineered tissues and organs.

Manufacturing innovations include microfabrication techniques, process advancements based on metabolic engineering and genetic manipulation, and new automation technology.

- **GlycoFi, Inc.**⁸ (Lebanon, NH) was awarded \$2M over 3 years in November 2002 to address a critical problem in the pharmaceutical industry: a potential shortage of high volume production capacity for new therapeutic proteins.

Proteins are complex biological molecules that cannot be made by simple chemical synthesis like traditional drugs; they are manufactured by living cells or organisms that have been genetically engineered to produce a particular protein product. The problem is complicated by the fact that higher mammals naturally attach certain specific sugars to their proteins in a particular way through a process known as glycosylation. The sugars on genetically engineered glycoproteins made by certain micro-organisms are different and are attached in a different way, so these proteins are recognized by human systems as “foreign.” Unless the organisms also provide human-like glycosylation, the usefulness of the proteins is severely limited.

GlycoFi produced an engineered strain of yeast that can be modified to produce a wide range of human glycoproteins with human-like glycosylation. Tailoring a yeast strain to produce a specific protein is a widely recognized technique in biotechnology, but changing the yeast’s natural glycosylation system represented a major new challenge. Because glycosylation is a complex process over and above the initial production of a given protein, the task required major changes to the yeast’s metabolic system, and targeted replacement of many genes that play a role in the process.

At the completion of the project in 2005, performance was estimated to be improved by a factor of 20 and would need only a quarter of the time compared to current cell culture technologies. The company projected this could save up to \$675M in drug development costs over the next 7 years which should encourage pharmaceutical companies to undertake higher risk drug development projects. Recognizing the potential of this technology, Merck & Co in 2006 purchased GlycoFi for approximately \$400M.

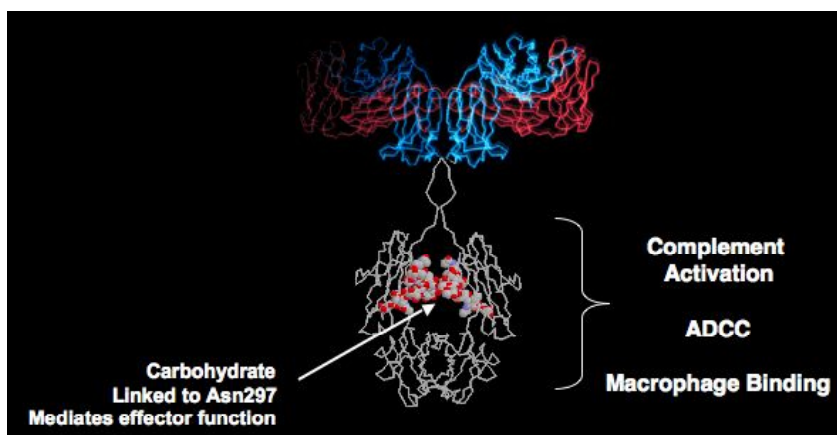


Figure 6: Diagram showing the binding of a sugar to a protein.
(Image: Courtesy of GlycoFi, Inc.)

8 <http://jazz.nist.gov/atpcf/prjbrieffs/prjbrieff.cfm?ProjectNumber=00-00-5035>

Bulk Materials Manufacturing

Bulk materials manufacturing transforms starting materials into finished products by mechanical and physical processes that focus on the micro- or nano-structural properties of materials for high-volume production.

Application areas include structured materials for transportation, power generation, petroleum exploration and production, sorting recyclable materials, composite structures and computer hard disks.

Manufacturing innovations include laser forming; ultrasonic welding; use of neural networks and intelligent control for casting, molding and grinding; engineered surfaces and coatings; near net-shape forging and casting; composite materials processing; use of powder materials; controlling mechanical properties at the nanoscale; and lubrication layers.

- **ATI Allvac**⁹ (Monroe, NC) and **GE Global Research Center** (formerly GE Corporate Research & Development, Niskayuna, NY) were awarded \$2.6M over 4 years in November 2001 to develop an innovative casting process enabling larger, more efficient turbines for the production of electricity. These turbines, operating at temperatures of 1350°C (2500°F) are made from special nickel-based “superalloys” having complex chemistries which make them difficult and expensive to produce. Current casting technology for superalloys based on a triple melt process already had been pushed to its limits and thus could not be scaled-up further.

The project team developed a commercially viable clean metal nucleated casting (CMNC) process based on casting in the semi-solid state. This enables the production of large ingots of fine-grained, homogeneous superalloy at rates 6 to 10 times faster than the state of the art and cutting the number of melting steps by a third. The fine-grained structure obtained directly from CMNC also makes it possible to sharply reduce or eliminate thermo-mechanical processing steps used to convert ingots into forgeable billets. Reducing processing steps at this point in the manufacture of turbines can help ensure that a million dollar ingot is not likely to become a million dollar piece of scrap.

Commercialization of this technology is projected to contribute more than a \$1B annually to the economy through the construction and sale of the new, larger and more efficient turbines, reduced fuel costs, and reduced emissions. Additionally, the technology is enabling the production of entirely new superalloy materials.



Figure 7: Turbine rotor showing the turbine blade disk and blades.
(Image: Courtesy of GE Global Research Center)

9 <http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=00-00-4454>

- **Edison Materials Technology Center**¹⁰ (EMTEC, Dayton, OH), along with **Delphi** (formerly Delphi Automotive Systems, Kettering, OH), **Timken** (formerly Torrington Company, Canton, OH), **Kennametal** (Latrobe, PA), **Third Wave Systems** (formerly Third Wave, Minneapolis, MN), **Hardinge** (Elmira, NY), **Metaldyne** **Hatebur Operations** (formerly Masco Tech, Royal Oak, MI), **Georgia Institute of Technology** (Atlanta, GA), and **The Ohio State University** (Columbus, OH) were awarded \$5.9M over 5 years in November 2000 to develop significantly improved processes for making hardened steel parts.

These parts carry critical loads in everything from automotive drive trains and jet engines to industrial bearings and metal-forming machinery. Prior to this project, parts were made using a multi-step process: parts were first machined from a relatively soft metal, heat treated, and then finished using multiple precision grinding and polishing processes to make the surfaces ultra-smooth to reduce friction and wear.

As the result of this project, far more efficient and less costly processes could be used to precisely forge hot metal into nearly perfect parts, harden the parts and then finish the parts using a single machining operation known as "hard turning." By machining the parts after they have already been hardened, several steps are eliminated, waste is reduced and the need for polluting coolant essential for traditional cutting and grinding is eliminated.

The project team estimates that because there are now fewer steps and less expensive processes, manufacturing costs for this class of components could be reduced by up to 30 percent and U.S. industry could see annual gains of up to \$1B.

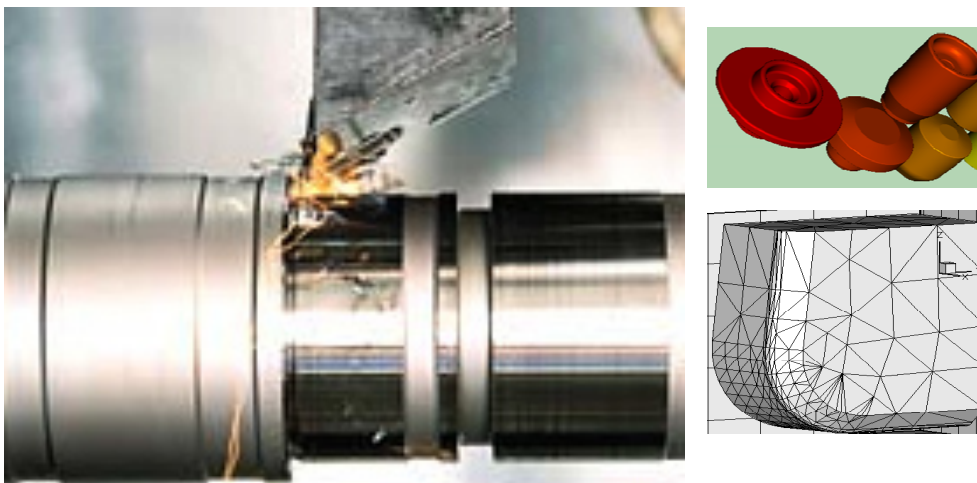


Figure 8: Clockwise, from top, hard turning of a part on a lathe, modeling of the precision-forged parts, and modeling of the cutting tool used in hard turning operations.

(Images: Courtesy of Hardinge, Metaldyne, and Third Wave Systems)

10 <http://jazz.nist.gov/atpcf/prjbrieffs/prjbrieff.cfm?ProjectNumber=00-00-4143>

- **Ford Motor Company**¹¹ (Dearborn, MI), **IdraPrince** (formerly Prince Machine Corporation, Holland, MI), **Intermet Corporation** (Troy, MI), the **North American Die Casting Association** (NADCA, Wheeling, IL), and **Synventive Molding Solutions** (formerly Dynisco Hot Runner System, Peabody, MA) were awarded \$3.4M over 5 years in November 2000 to develop casting technology for large magnesium parts.

At the initiation of this project, conventional processes utilized by the magnesium die casting industry resulted up to 50 percent offal, resulting in substantial material costs. The industry needed a “game changing” development of new processes to alleviate this issue, however, did not have the R&D capabilities or resources to undertake a research effort of this scale.

The vertically-integrated team, consisting of the end-user, equipment developers and suppliers and a trade association developed and integrated new designs for the furnace to melt the magnesium, hot runners to deliver the magnesium to the die, injection nozzles, multipoint injection capabilities and the three dimensional modeling capabilities needed to design and optimize die casting operations. A key advantage of the process was that by using multiple points to inject the metal into the die, lower injection pressures could be used to make large parts on die casting machines typically used for smaller components. This makes the new process attractive as a retrofit to existing facilities.

The project was able to reduce the rate of scrap from 50 percent for traditional casting processes to 5 percent by reducing the amount of metal that was used in casting but not associated with the part itself (i.e., biscuits, runners, flash).



Figure 9: Left: Two components cast conventionally illustrating offal (biscuits, runners, flash); Right: Single component “as cast” via the new technology.
(Images: Courtesy of Ford Motor Company)

11 <http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=00-00-4334>

Enhancing America's Manufacturing Competitive:
A Review of the NIST ATP Investments in Manufacturing Technologies

- **wTe Corporation**¹² (Bedford, MA) was awarded \$2M over 3 years in November 2000 to address a major recycling opportunity. The U.S. metals industry today is seriously threatened by inexpensive metals and alloys supplied by overseas sources. To compete, the U.S. must create alternative low cost indigenous sources of metal "feedstock." Greater scrap usage presents just such an opportunity. As one of the world's largest consumers, the U.S. generates a large supply of non-ferrous (aluminum, copper, zinc, etc.) metals in the form of scrap — more than 30 billion pounds annually.

Using large quantities of scrap to produce new high-grade alloys currently is limited in large measure by widely varying composition. If scrap metals could be accurately sorted to close compositional tolerances (perhaps even by alloy type), the amount of scrap used in making new metal could be increased. This would provide many benefits including: reduced cost, less reliance on foreign virgin feedstock, energy savings, and emission of fewer pollutants.

The U.S. scrap industry historically has done little to take advantage of computer technology. Most metal scrap separation is done using hand-and-eye sorting techniques. Such labor intensive methods leave the U.S. at a competitive disadvantage from production cost and worker safety perspectives.

wTe Corporation, working in partnership with several small companies and universities, has developed and patented an entirely new platform of opto-electronic technologies capable of reliably and cost effectively sorting mixed nonferrous metals on a large scale. The new Spectramet® technology can "fingerprint" objects (scrap metal) in fewer than 10 milliseconds and then automatically sort them at rates approaching 100 objects per second. This new technique represents a quantum leap in sorting methodology.

By converting current mixtures of scrap metal into high grade specification alloys, more scrap can be recycled and thus re-used in the melting process saving time and money and diminishing environmental impacts — thereby making our US metals industries more competitive and at the same time reducing U.S. reliance on scarce strategic materials that today must be purchased from abroad.



Figure 10: Left: The Spectramet® alloy sorter consisting of a sorting chamber and material ejectors; Right: Non-ferrous metals tend to be ejected farther than non-metals (plastics, rubber) and thus can be separated by a splitter plate prior to being sorted by the Spectramet® alloy sorter.

(Images: Courtesy of wTe Corporation)

¹² <http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=00-00-4043>

"Manufacturing is an essential part of our economy..."

- **Wyman-Gordon Company**^{13 14} (North Grafton, MA) was awarded \$1M over 3 years in September 1995 to address an important forging problem. Forged parts such as superalloy disks used in land-based gas turbines for the power generation industry have grown to such a large size that existing U.S. forging presses cannot produce the current and next generation parts as cost-effectively as the larger capacity presses that exist outside the U.S. The larger capacity of the foreign presses allows production of the parts with lower input weight. Further, utilization of the foreign presses adds significant cycle time to the production cycle due to the need to ship parts overseas. It is unlikely that new larger capacity presses will be built in the U.S. due to prohibitive capital equipment costs for larger press capacities.

Wyman-Gordon's solution is based on a partial forging process. Here the forging is done in segments, allowing larger pieces to be forged in existing presses. The solution required integrating analyses for the part, press and tooling with the forging process to correctly make the part. The result is the capability to forge larger, more complex parts, with less input weight, using existing forging presses and saving capital expenditures.

The project resulted in domestic presses, such as the Wyman-Gordon or the Alcoa 50,000-ton press being able to use partial forging to process parts that require closed-die presses with at least a 100,000-ton capacity press costing about \$100M. Wyman-Gordon estimates the partial forging process can reduce its forging costs and input materials by 20 percent.

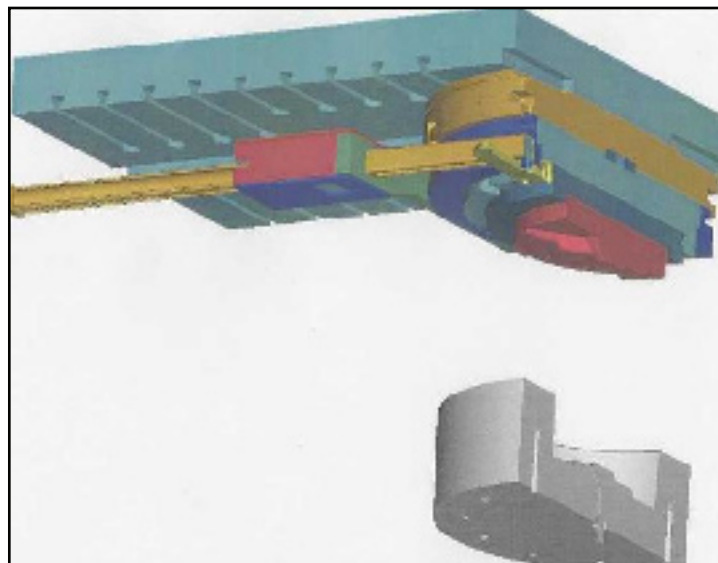


Figure 11: CAD drawing of the components used in the new partial forging process.

(Image: Courtesy of Wyman-Gordon Company)

13 <http://jazz.nist.gov/atpcf/prjbrieffs/prjbrieff.cfm?ProjectNumber=95-07-0026>
14 <http://statusreports.atp.nist.gov/reports/95-07-0026.htm>

Chemical Processing

Chemical processing utilizes specific chemical characteristics of starting materials to produce intermediate and final products using separation processes, catalytic conversion of materials, and environmentally friendly processes.

Application areas include separation, processing chemicals and plastics, and petroleum refining.

Manufacturing innovations include catalyst development, advanced reactor technologies, membrane technology, and "green" manufacturing processes that reduce waste streams, or utilize new biocatalysts to make polymers and plastics.

- **Cabot Superior MicroPowders¹⁵** (formerly Superior MicroPowders, SMP, Albuquerque, NM), a small start-up company, was awarded \$2M over 3 years in November 1998 to develop a patented spray-based catalyst manufacturing process.

It has long been recognized that electro-chemical devices such as batteries and fuel cells could have their performance improved and costs reduced if the processing of electrocatalytic materials could be precisely controlled.

SMP developed a process that takes a liquid with the desired chemical precursors and creates liquid droplets that are passed through a controlled heating process to evaporate the solvent to generate particles with the desired properties. The particles, on the order of microns (millionths of a meter) have their size distribution, shape, composition, and other particle characteristics precisely controlled.

Results have been impressive to date: fuel cells using SMP's materials exhibit improved performance while using 50 percent less platinum, an important precious metal.

In 2003 SMP was purchased by Cabot Corporation for \$16M. This opportunity has continued to grow and recently was launched as Cabot Fuel Cells to provide leading performance electrocatalyst materials to the fuel cell market.

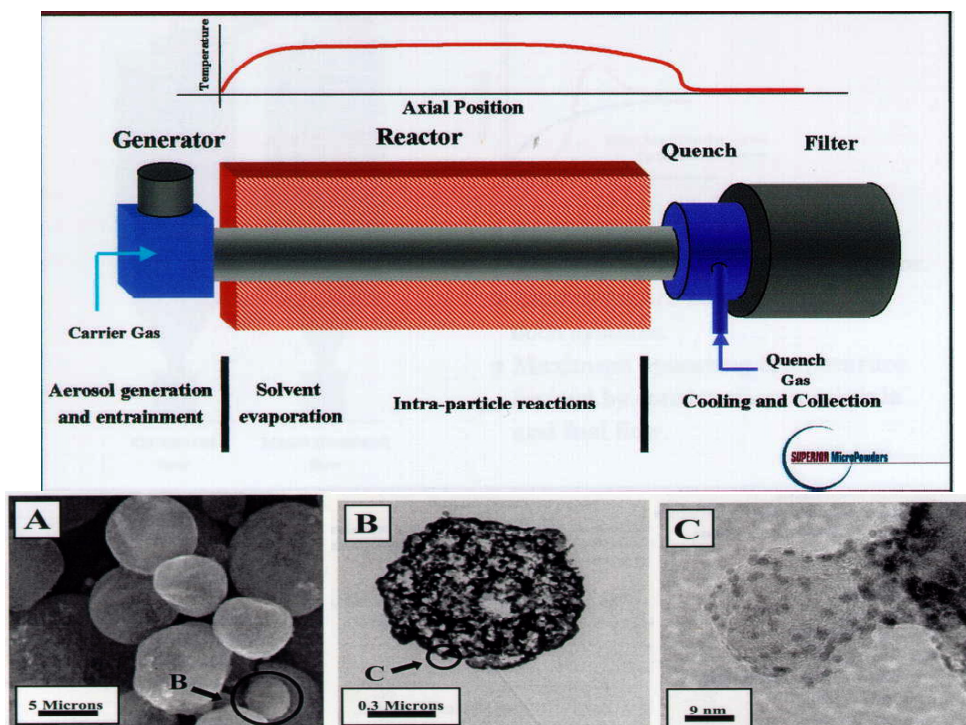


Figure 12: Top: process components; Bottom: (A) cluster of particles, (B) view of single particle, (C) platinum deposits on larger particles.
(Images: Courtesy of Cabot Superior Micropowder)

- **UOP, LLC** (Des Plaines, IL)¹⁶ was awarded \$2M over 3 years in October 2004 to develop a selective liquid-phase oxidation process to convert methane to methanol.

Methane, an abundant and inexpensive natural resource, is typically only used as a fuel for power generation. The reason for this under utilization is that there are few commercially viable processes for converting methane to other higher value products. One of the traditional approaches converts methane to methanol (one of the top 25 chemicals produced in the world) through an indirect conversion process at high-temperature and high-pressure that dates back to the 1920s. It is expensive, energy intensive, and impractical for use in remote locations where many methane reserves are found. An efficient, cost effective, direct route from methane to methanol could make a major impact on the chemical and fuel industries.

UOP's process is based upon a novel liquid-phase oxidation process that takes place at relatively low temperatures and pressures, which simplifies plant design, increases safety, requires a less expensive plant, uses less energy and produces fewer pollutants than the current technology.

The project will develop additional U.S. energy sources from stranded natural gas reserves in remote locations such as Alaska. UOP estimates their process will reduce the amount of energy used to produce methanol from methane by 60 percent and thus help to reduce the price of methanol.

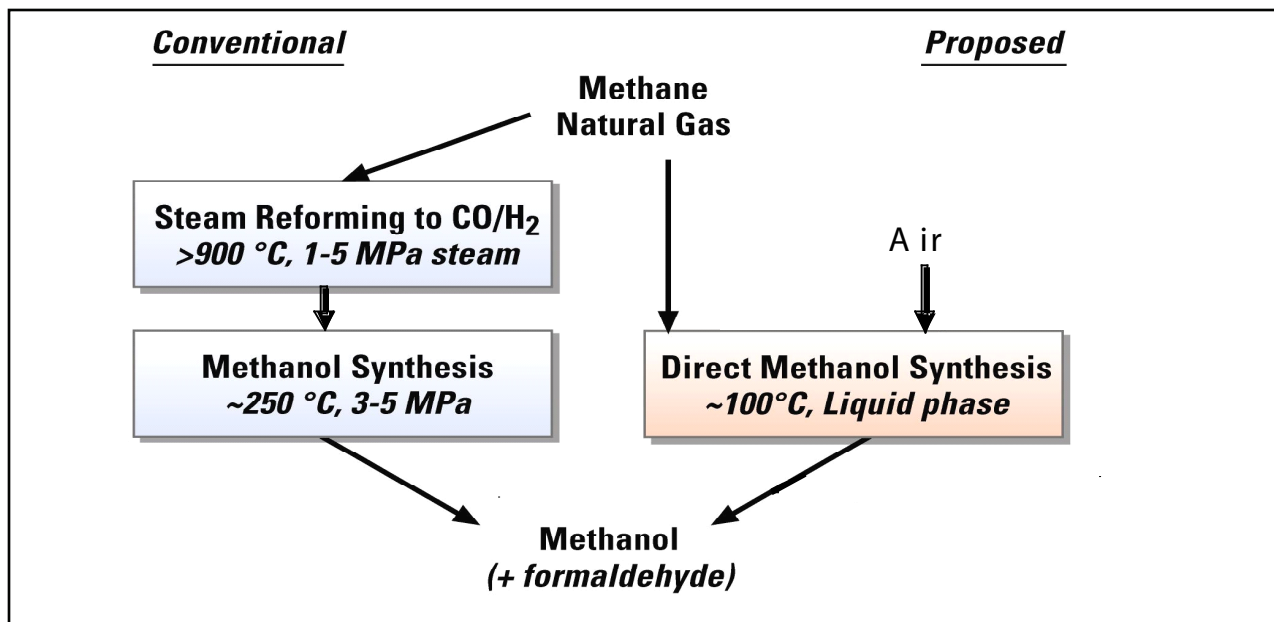


Figure 13: Comparison of conventional and proposed processes for converting methane to methanol.
(Image: Courtesy of UOP, LLC)

16 <http://jazz.nist.gov/atpcf/prjbrieffs/prjbrieff.cfm?ProjectNumber=00-00-7040>

Electronics and Photonics Manufacturing

Electronics and photonics manufacturing develops technologies that utilize physical and chemical processes to transform starting materials or assemblies into highly structured devices and components that exhibit unique electrical, optical, magnetic or electro-mechanical functions.

Application areas include electrical, semiconductor, micro/nano-electronic and photonic devices, components and systems; Micro-Electro-Mechanical Systems (MEMS), Micro-Opto-Electro-Mechanical Systems (MOEMS) and Nano-Electro-Mechanical Systems (NEMS); visualization technologies; lasers, optical elements and fibers; and electric motors, transformers and inductors.

Manufacturing innovations include improvements in electronic materials, semiconductor, wafer and photonics processing; materials processing; thin film, deposition and etching/removal processes; optoelectronics and optical assembly; lithography; improved assembly, joining, and interconnection; and new inspection and metrology methods.

- **RAPT Industries**¹⁷ (Livermore, CA) was awarded \$2M over 3 years in May 2003 to develop a prototype system for etching and polishing semiconductor and optical materials. RAPT Industries uses a combination of non-contact, sub-aperture, atmospheric plasma figuring and as required a conformal buffing process to produce damage-free, high aspect-ratio surfaces. Traditional abrasive based or contact processing methods lead to considerable sub-surface damage with associated yield and reliability problems.

RAPT is currently using its novel manufacturing technique to fabricate advanced mirrors from ceramic materials used for space and missile defense applications. Thanks to the nature of the process, the speed of finishing is unparalleled in optics manufacturing and passes tangible benefits in lead times to the customer in what has traditionally been a critical path item in precision manufacturing (optics). This technology further finds use in applications that benefit from damage-free surface processing.

One such application is the edge-cleaning of semiconductor wafers during integrated circuit manufacturing. Cleaning silicon wafers with this novel non-contact process eliminates damage to the edge and greatly increases yields from a single wafer. This technology has been licensed to Accretech USA for this particular application.



Figure 14: Plasma beam cleaning and polishing the surface of a wafer.
(Image: Courtesy of RAPT Industries)

17 <http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=00-00-4992>

- **Motorola, Inc.**¹⁸ (Schaumburg, IL), **Dow Chemical Company** (Midland, MI) and **PARC, Inc.** (Palo Alto, CA) were awarded \$7.7M over 5 years in November 2000 to develop solution processable organic semiconductor materials (functional inks) and the associated design and manufacturing technologies to fabricate inexpensive large-area printed electronics such as flexible displays.

Electronic devices are typically made in batches using expensive lithographic-based techniques with manufacturing occurring in a wafer fabrication facility that costs approximately \$4B to build. Motorola proposed to manufacture electronic devices utilizing a continuous, roll-to-roll process that leveraged existing, relatively inexpensive printing technologies commonly used to print graphic arts posters and shampoo bottle labels.

The team successfully produced the world's first all-printed semiconductor integrated circuit (IC) using high-volume graphic arts technologies and nanotechnology-enabled electrically functional inks in 2003. By the end of the NIST ATP program, more than 50 kilometers of high-yield, functional integrated circuits had been fabricated.¹⁹ The technology developed builds the technical foundation for wholly new and pervasive all-printed electronic products, such as emissive dynamic signage for use as a promotional marketing tool, printed radio frequency identification (RFID) tags,²⁰ electric paper, smart cards and automotive electronics, and displays. This disruptive technology platform will enable financial growth for both the domestic microelectronics and graphic arts printing industries as printed and organic electronics enabled products are commercialized to establish robust new markets.

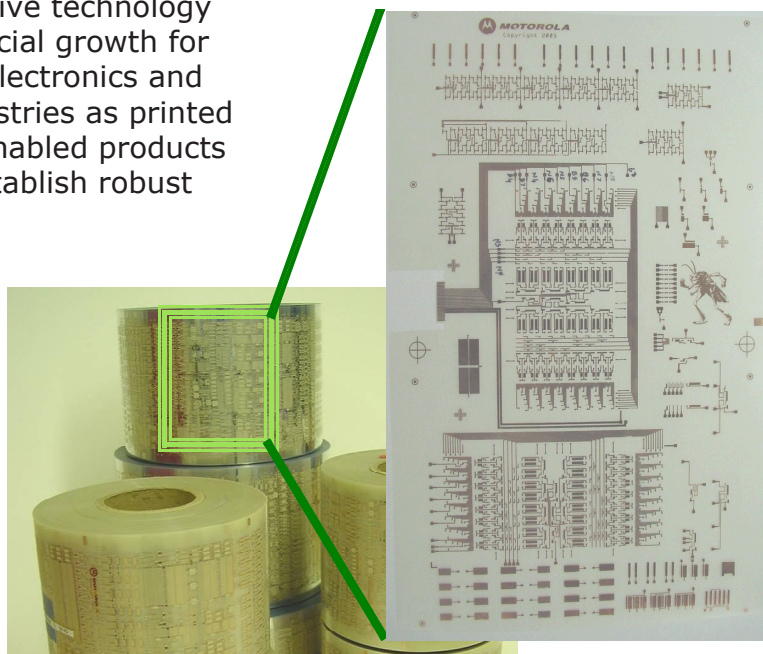


Figure 15: Functional blocks of an RF integrated circuit made using continuous roll-to-roll printing – each roll is more than 750 meters long.
(Images: Courtesy of Motorola, Inc.)

18 <http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=00-00-4209>

19 IEEE Spectrum, September 2005, p. 54, www.spectrum.ieee.org

20 Embedded.com, August 25, 2006, <http://www.embedded.com/showArticle.jhtml?articleID=192300283>

Manufacturing Systems and Controls

Manufacturing systems and controls develops technologies that integrate disparate systems that currently do not communicate with each other; simulate specific manufacturing processes; and/or develop automated metrology and inspection systems for production and process lines.

Application areas include automotive assembly, discrete and electronics manufacturing.

Manufacturing innovations include new approaches to control; inspection, metrology, sensor and actuator improvements; laser cutting and welding; and machining, machine design and tools.

- **OG Technologies, Inc.**²¹ (Ann Arbor, MI) was awarded \$2M over 3 years in November 2000 to develop a real time inspection technology for steel rolling mills.

Surface defects are the primary cause of scrap in the steel rod and bar industry. Because the steel is processed at high temperatures and in a hostile environment, it was impossible to accurately inspect the surface of the steel in-line. The practice of cooling the steel in order to physically inspect the surface is expensive, time consuming, unreliable, and unable to correct the source of the surface defect. The steel industry needed a method to inspect for surface defects in real time.

OG Technologies solution integrated a high temperature vision system with decision-making capabilities to analyze defects and report them in real time. Named HotEye™, the system identifies surface defects as small as 0.001 inch in hot steel bars and rods moving through a rolling mill at speeds of up to 225 mph at 2000°F to 2600°F. The system generates reports giving the location, size, kind, severity, and image of each surface defect.

This technology has the potential to help the U.S. steel industry produce superior quality bars and raw materials for automotive and other manufacturing industries. OG Technologies estimates waste could be reduced by 90 percent, thereby saving the U.S. steel industry \$4B in inspection costs and 3 billion kilowatt-hours of electricity annually.²² This energy savings is roughly equivalent to the annual electricity consumption for 282,000 homes.²³ OG Technologies has applied the HotEye™ technology to surface inspection and measurement of critical dimension of billets in-line.

In 2006, OG Technologies received R&D Magazine's 100 best technologies award.²⁴



Figure 16: Left: Steel being coiled; Right: A 900 mm by 3 mm "seam" detected by the HotEye™ system.

(Image: Courtesy of OG Technologies, Inc.)

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- 21 <http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=00-00-3945>
 22 <http://www.ogtechnology.com/press.html>
 23 Based on data from http://www.eia.doe.gov/emeu/reps/enduse/er01_us.html#Electricity
 24 http://www.atp.nist.gov/gems/og_00-00-3945.htm

- **Ingersoll Machine Tools, Inc.**²⁵ (Rockford, IL) was awarded \$2M for 3 years in August 2004 to develop an ultra precise miniaturized machine for micro- and meso-scale commercial applications.

Small parts are currently made using processes such as milling, chemical etching, laser cutting and electron beam machining on large machines that were designed to make macro-sized or large parts, but are using very small tools. This approach has been shown to have a number of limitations. Using a machine specifically designed for these small scales would enable the manufacture of mechanical components with features measuring hundreds of microns or less and yet maintain the 'relative accuracy' of the components. Relative accuracy means the smaller the part size the tighter the tolerance for same functionality.

Ingersoll's solution is based on developing new machine tool technologies such as non-contact linear and rotary air-bearing and super high speed spindles and integrating other sensing and control technologies to satisfy rigorous machining error constraints. The 3, 4 & 5 axis machine's work zone size is projected to be a cube whose side is between 25 mm and 50 mm and cost \$25,000 to \$50,000, a fraction of the cost of currently available machines.

The capabilities of this machine are needed in optics, electronics, avionics, medicine, biotechnology, communications, and other fields to make microscale fuel cells, micropumps and valves, microfluidic controls, microholes for fiber optics, medical implants, micronozzles for high temperature jets and micromolds for microforming of components.

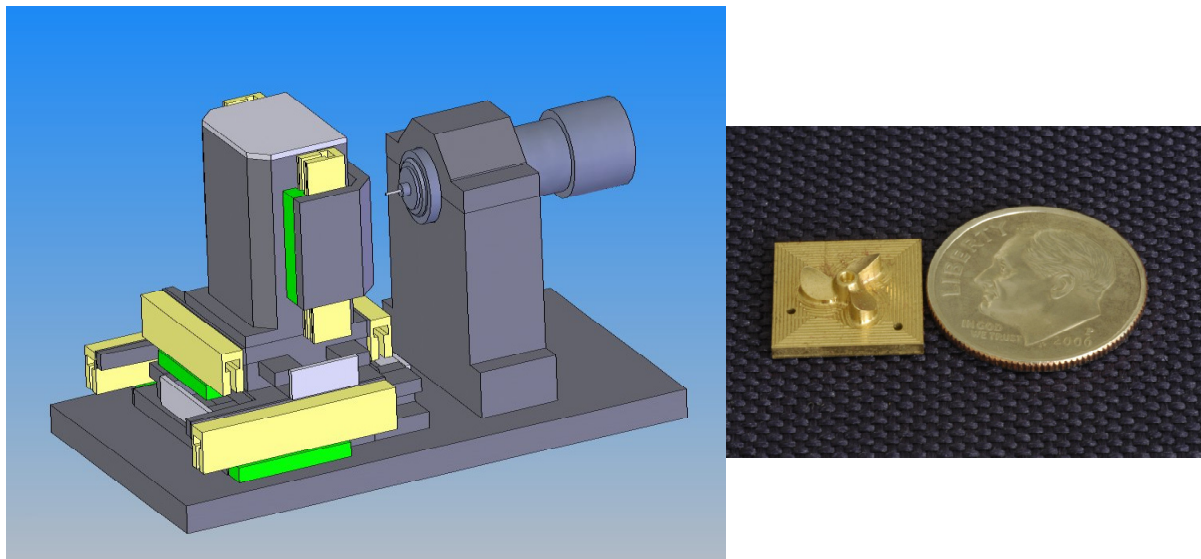


Figure 17: Left: CAD drawing of machine; Right: Machined model ship propeller.
(Images: Courtesy of Ingersoll Machine Tools, Inc.)

25 <http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=00-00-5705>

- **Stewart Automotive Research**²⁶ (SAR, Houston, TX), a small start-up company, was awarded \$2M over 3 years in October 2004 to develop a new large format milling machine to make large molds and dies for manufacturing large wind deflectors for trucks, car bumpers and dash panels, and sheet metal body parts.

The current practice for making these large tools for the automotive industry and other users is to make a rough cut in a large block of steel, refine the cut, and then send it out for final hand finishing (grinding to final contour and polishing). The entire process – design, making the tool, and putting it into production – currently can take as long as 3 years.

SAR's new machine design will have improved stiffness and accuracy and will allow molds and other tools to be machined with an accuracy that eliminates final hand grinding and polishing currently needed to produce parts such as external body panels for automobiles with a "Class-A" finish. This will reduce tooling lead time to 1/3 to 1/2 of the time required now and at significantly lower costs. This significantly shortened manufacturing cycle will allow U.S. automotive manufactures to "freshen" their car's styling designs more often and in response to consumer feedback.

Preliminary results from this on-going project suggest that key components that give the new machine design its high speed and accuracy can be retrofitted to existing machines, a feature important to the financially-strapped U.S. tool and die industry.

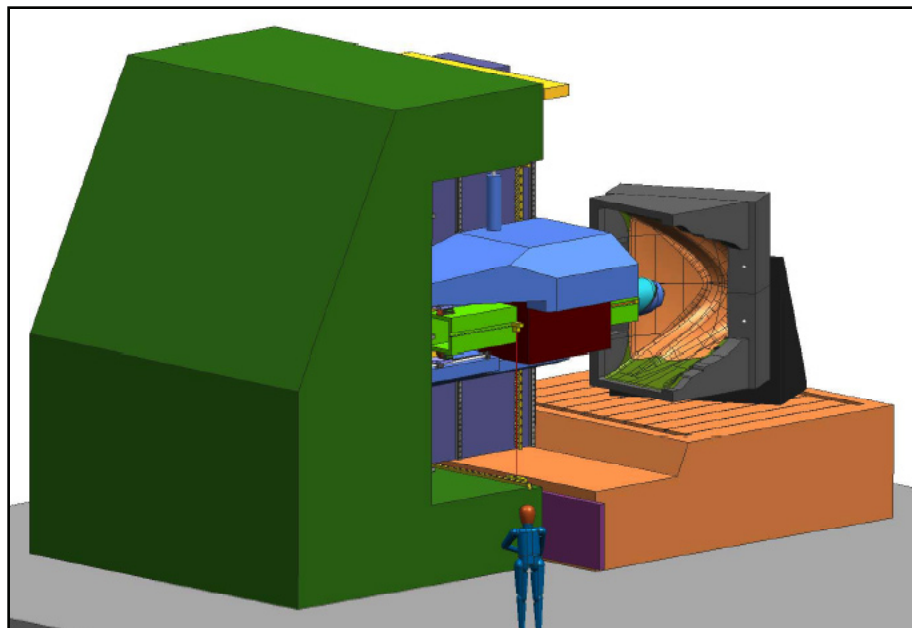


Figure 18: CAD drawing of the design for a large format milling machine machining a mold for a truck wind deflector.

(Image: Courtesy of Stewart Automotive Research, LLC)

26 <http://jazz.nist.gov/atpcf/prjbrieffs/prjbrief.cfm?ProjectNumber=00-00-6905>

Power Generation and Storage Manufacturing

Power generation and storage manufacturing develops advanced technologies that transform electrochemical and physical properties of starting materials, and may integrate process and materials advancements into efficient and reliable energy devices, components or systems.

Application areas include fuel cells, photovoltaics, batteries and ultracapacitors.

Manufacturing innovations include new material processing technologies as well as enhancements to existing processing.

- **Evergreen Solar, Inc.**²⁷ (Waltham, MA) was awarded \$2M over 3 years in November 2000 to develop an innovative unique approach to overcome one of the barriers to wide-spread photovoltaics commercialization: the manufacture of inexpensive crystalline silicon. Traditional manufacturing processes involve material losses from cutting and polishing of wafers from cylindrical crystal ingots called “boules.” The new process pulls silicon directly from the melt as ultrathin ribbon, ready for material deposition steps to create photovoltaic cells.

The company estimates the cost of solar-electric power will be reduced from the present \$7 per watt to \$2 per watt based in part on improved energy efficiency of the process and reduced material losses.

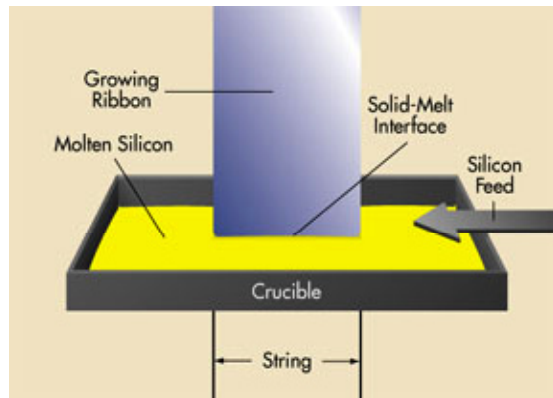


Figure 19: Left: Four silicon wafer pulling machines; Right: A pair of “strings” pulling silicon from a crucible.
(Images: Courtesy of Evergreen Solar, Inc.)

- **Carbon Nanotechnologies, Inc.**²⁸ (Houston, TX), along with Johnson Matthey Fuel Cells, Inc. (West Chester, PA) and Motorola Inc. (Tempe, AZ) was awarded \$3.6M over 3 years in October 2004 to develop free-standing single-walled carbon nanotube (SWNT) electrodes for fuel cells. This technology is based on innovations developed by Nobel Laureate Dr. Richard Smalley.

The electrodes will be used in small fuel cells to recharge first responder's radios and other hand-held electronic devices. It is projected that the SWNT-based electrodes will be able to overcome inefficiencies in polymer-membrane-based fuel cells, unacceptable service lifetimes, and manufacturing complexities.

If successful, the technology would not only dramatically improve compact polymer electrolyte membrane (PEM) fuel cells for a number of hand-held electronic devices, but would also enable the design and commercialization of more powerful next generation "wireless" communication devices. The new technology has the potential to place the United States in a commanding position in the portable electronics power market, which now is dominated by foreign firms.

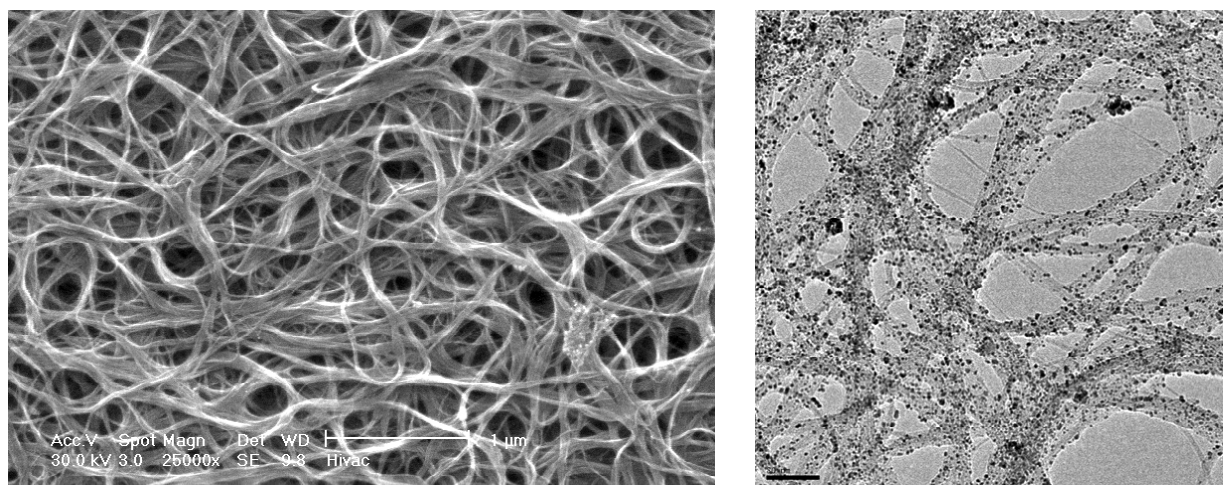


Figure 20: Left: Scanning Electron Microscopy (SEM) of electrode material composed of a "mat" of single-walled nanotube (SWNT) ropes without catalytic material attached (scale bar 1µm); Right: High Resolution Transmission Electron Microscopy (HRTEM) of SWNT electrode material with platinum catalyst particles attached (scale bar 50 nm).

(Image: Courtesy of Carbon Nanotechnologies, Inc.)

28 <http://jazz.nist.gov/atpcf/prjbriefs/prjbrief.cfm?ProjectNumber=00-00-6962>

What is ATP's Legacy in Manufacturing?

Congress created the Advanced Technology Program to address a critical funding gap deficiency for early stage, high technical risk development. The resulting technologies could be rapidly commercialized to provide significant growth for the national economy. U.S. manufacturers, through this support, have had a number of positive and lasting impacts on the companies and industries funded through ATP awards. Industry, participating in this public-private partnership, has shaped the focus and direction of research projects, and the knowledge gained by the participating organizations will continue to influence future innovative R&D. Examples of the ATP legacy being fully realized today include:

- ATP's unique selection criteria for industry-led projects has aided companies in partnering effectively with universities to accelerate development of emerging and enabling technologies that led to revolutionary new products and industrial processes and services that can compete in rapidly changing world markets.
- ATP encouragement of government-industry partnerships has resulted in an almost dollar-for-dollar matching in cost-shared research and development.
- ATP's ability to facilitate public forums about technology-focused competitions enabled more complete collaboration early on which led to a number of "firsts", such as manufacturing development in distributed power.
- ATP commitment to broad-based economic benefits during the formation of collaborations and partnerships results in long-lasting relationships after the end of the award period. These collaborations can include other companies, national laboratories or universities.

ATP's accomplishments have been well documented in some fields. In other areas, such as manufacturing, the successes are just beginning and ATP's legacy will continue to unfold in the future:

- ATP has been at the forefront of encouraging industry to address the technological needs of emerging manufacturing sectors.
- Manufacturing collaborations have been particularly effective at utilizing the capabilities of universities.
- Manufacturing patents, citations, and publications will continue to disseminate new scientific and engineering knowledge.

Through this support, ATP contributes to continued leadership and creating new opportunities for U.S. industries. ATP-funded manufacturing technologies will continue to support U.S. industrial growth for decades to come.

"Manufacturing is an essential part of our economy..."

Appendix: Further Details on ATP's Competitions and Awards

ATP uses two formats for its proposal solicitations: General Competitions and Technology-Focused Competitions. General competitions have been held every year from 1990 to 2004 and are open to any area of technology. In addition, between 1994 and 1998, ATP developed seventeen technology-focused areas where specific technology-sector investments were considered. These technology concentration areas were defined by working with industry through public forums. Awards from technology-focused competitions satisfied ATP's selection criteria for technical and broad based economic benefits as well as the specific technical scope defining the technology-focused area. After 1998, ATP returned to only general competitions, which were referred to as Open Competitions.

Open and focused competitions both have unique advantages. Open competitions ensure all good ideas receive consideration, irrespective of the technology area. Focused competitions achieve synergy and build technical momentum in specific industry-defined areas by addressing critical investment gaps in the market place.

ATP makes awards to either a single company or joint venture collaborations:

- A single company (SA) award provides co-funding for direct research costs incurred by a U.S. incorporated for-profit company. Technical work can include subcontractors. With a maximum co-funding of \$2M from ATP for up to three years, the company covers all indirect research costs, and may contribute to the direct research. After 1997, the rules were changed to require a single large²⁹ company to cost-share at least 60 percent of direct research costs in addition to their indirect costs.
- A joint venture (JV) award provides co-funding for two or more U.S. incorporated for-profit companies and can include subcontractors, non-profit (NP) and independent research organizations (IRO).³⁰ There is no dollar limit on the ATP share of the award, the joint venture is required to cover more than half the project costs, and can run for up to five years.

Single company awards constitute 72 percent of all ATP awards, have received 44 percent of ATP's co-funding, and have cost-shared 34 percent of the award costs as summarized in Table 4.

29 Company size is defined as: a large company is on the Fortune 500 list; a small company has less than 500 employees; and a medium-size company has more than 500 employees, but is not on the Fortune 500 list.

30 Not-for-profit organizations (NP) and independent research organizations (IRO) can lead or participate in a joint venture, but after the American Technology Preeminence Act of 1991 they became ineligible for SA awards.

Enhancing America's Manufacturing Competitive:
A Review of the NIST ATP Investments in Manufacturing Technologies

Table 4: Distribution of All ATP Awards by Award Type and Lead (1990-2004)

Type of Lead	Number of Awards			ATP Co-Funding (\$M)			Industry Cost Share (\$M)		
	SA*	JV*	Total	SA	JV	Total	SA	JV	Total
Small	433	75	508	\$796	\$406	\$1,202	\$483	\$438	\$921
Medium	57	34	91	\$104	\$218	\$322	\$112	\$241	\$353
Large	58	72	130	\$98	\$347	\$445	\$118	\$367	\$485
NP/IRP*	2	37	39	\$3	\$297	\$300	\$4	\$339	\$343
Total	550	218	768	\$1,001	\$1,268	\$2,269	\$717	\$1,385	\$2,102
Percent	72%	28%	100%	44%	56%	100%	34%	66%	100%

* SA - Single Applicant; JV - Joint Venture

* NP/IRO – Not for Profit / Independent Research Organization

The distribution of funding of ATP's 208 direct manufacturing awards is shown in Table 5. Compared to all of ATP's awards, a greater proportion of funding is seen to go to collaborative research represented by joint ventures.

Table 5: Distribution of Funds for Direct Manufacturing Awards by Award Type and Lead (1990-2004).

Type of Lead	ATP Share (\$M)			Industry Share (\$M)			Total (\$M)		
	SA*	JV*	Total	SA	JV	Total	SA	JV	Total
Small	\$166.5	\$87.0	\$253.5	\$98.0	\$92.7	\$187.1	\$264.5	\$179.7	\$444.2
Medium	\$22.7	\$31.4	\$54.1	\$13.5	\$32.3	\$45.7	\$36.2	\$63.7	\$99.9
Large	\$42.6	\$136.6	\$179.2	\$43.0	\$141.3	\$188.0	\$85.6	\$277.9	\$363.5
NP/IRO*	\$1.2	\$141.6	\$142.8	\$0.7	\$159.6	\$160.3	\$1.9	\$301.2	\$303.1
Total	\$233.0	\$396.6	\$629.6	\$155.2	\$425.9	\$581.1	\$388.2	\$822.5	\$1,210.7
Percent	37%	63%	100%	27%	73%	100%	32%	68%	100%

* SA - Single Applicant; JV - Joint Venture

* NP/IRO - Not for Profit / Independent Research Organization

The distribution of funding for ATP's 85 indirect manufacturing projects is shown in Table 6. As was the case for direct manufacturing awards, a greater proportion of awards for indirect manufacturing went to joint ventures.

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Table 6: Distribution of Funds for Indirect Manufacturing Awards by Award Type and Lead (1990-2004).

Type of Lead	ATP Share (\$M)			Industry Share (\$M)			Total (\$M)		
	SA*	JV*	Total	SA	JV	Total	SA	JV	Total
Small	\$75.1	\$49.5	\$124.6	\$48.1	\$53.2	\$101.3	\$123.2	\$102.7	\$225.9
Medium	\$10.7	\$51.8	\$62.5	\$10.1	\$58.8	\$68.9	\$20.8	\$110.6	\$131.4
Large	\$15.2	\$70.2	\$85.4	\$17.3	\$78.3	\$95.6	\$32.5	\$148.5	\$181.0
NP/IRO*	\$2.0	\$14.2	\$16.2	\$0.3	\$14.5	\$14.8	\$2.3	\$28.7	\$31.0
Total	\$103.0	\$185.7	\$288.7	\$75.8	\$204.8	\$280.6	\$178.8	\$390.5	\$569.3
Percent	36%	64%	100%	27%	73%	100%	31%	69%	100%

* SA - Single Applicant; JV - Joint Venture

* NP/IRO - Not for Profit / Independent Research Organization

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