Powering Our High-Speed Economy

A profile of ATP energy investments

ADVANCED TECHNOLOGY PROGRAM

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

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America has one of the best systems in the world for delivering electricity from large generation plants over an intricate network of power lines to homes, schools, hospitals, businesses, and factories. But in today's economy, the everyday lives of Americans and our economic vitality depend on power sources that are *not* connected to an electrical grid.

We are using more cell phones, PDAs (personal digital assistants), digital cameras, and laptop computers, all of which demand sources of more—and higher-density—power. In addition, our power grid is an attractive target to those seeking to disrupt American businesses and homes, making grid-independent and portable power all the more important. Unfortunately, the batteries that power the current generation of portable electronics have short runtimes, and alternative sources of electricity that can provide power to communities without a grid (such as fuel cells and solar cells) are currently too expensive for widespread use.

According to the Electric Power Research Institute (EPRI), electricity as a percentage of total U.S. energy consumption has increased from 25 percent in 1970 to nearly 40 percent today, with a projection that it will exceed 50 percent in the near future. Fueling this demand is the explosive growth of the Internet, advanced telecommunications, and computers. At the same time, our increasing dependence on electrical energy also increases our vulnerability to power blackouts and brownouts, conservatively estimated to cost the United States $29 billion a year in lost productivity. With power-quality-sensitive microprocessors becoming pervasive in America's businesses, factories, and homes, off-grid fuel cell power units are the only technology that can offer on-site, blackout-free electricity with very high (99.9999 percent) reliability.

The Advanced Technology Program (ATP) of the National Institute of Standards and Technology (NIST) is supporting new ways in which Americans utilize electricity and communicate—by developing breakthrough technologies for fuel cells, solar cells, and batteries. ATP partners with industry to invest in the development of new, innovative technologies deemed too risky for the private sector—technologies that can benefit the nation as a whole.

ATP was the first large government program to fund blackout-free distributed generation technologies such as fuel cells that can power residences and businesses, and provide improved backup power for telecommunications. The innovative technologies fostered by ATP will make these sources of distributed, off-grid power ever more compact, secure, reliable, and affordable.

Extended portable power

Today, Americans rely on 135 million cell phones, 40 million PDAs, and 11 million laptop computers. But current battery technology limits the time that these portable devices can run between charges.

One ATP-supported innovator, MTI Microfuel Cells, Inc. (MTI Micro), of Albany, New York, is developing a micro fuel cell that may provide power 5 to 10 times longer than the lithium ion batteries now used in cell phones, laptops, and PDAs. Currently, micro fuel cells are too large to be used in portable, electronic devices, but MTI Micro's new approach will miniaturize micro fuel cells. The technology combines MTI Micro's new, proprietary direct methanol fuel cell (DMFC) integrated with a microfluidic system to move the methanol fuel and recirculate water. Their 1-watt, integrated, hybrid DMFC PowerPack system could provide the same power as a conventional lithium battery, in the same space, but with greatly improved runtimes.

This ambitious project addresses a major technical barrier—high power density with high conversion efficiency. To achieve this, the fuel cell, and its microfluidic and power-control systems, must be miniaturized and integrated.

The PowerPack prototype, which was developed with ATP support, is today the size of a deck of cards. MTI Micro plans even smaller units that can be used in cell phones, laptops, and PDAs.

ATP has emerged as a leading funder of micro fuel cell research and development, with five awards totaling more than $21 million of ATP and cost-shared funding, in this rapidly developing technology.

Solutions for the hydrogen economy

Traditional technologies for storing hydrogen, a clean energy source, severely limit the utility of hydrogen as a fuel in electric vehicles and in other commercial applications.

Ovonic Battery Co. of Troy, Michigan—a subsidiary of Energy Conversion Devices (ECD)—and Crucible Materials Corp. of Pittsburgh, Pennsylvania, have succeeded in developing magnesium-hydride alloys capable of storing 7-percent hydrogen, a level that far exceeds the capability of today's metal hydride technologies. This promising breakthrough should lead to economical hydrogen storage for fuel-cell-powered electric vehicles.

ECD's new alloys enable storing of enough hydrogen to power a fuel-cell electric vehicle several hundred miles. Compared to alternative methods—onboard reforming of hydrocarbon fuels into hydrogen or high-pressure storage—carrying hydrogen as a solid in a metal-hydride matrix is very safe. For these reasons, Robert Stemple, ECD Chairman, has called this breakthrough in metal-hydride storage systems a "game changer." It will provide cost-effective, safe, and efficient means of powering the clean vehicles of the future.

Texaco, now ChevronTexaco, has two joint ventures with ECD under Texaco Ovonic Hydrogen Systems and Texaco Ovonic Battery Systems, to develop and commercialize new technology for use within the energy and automobile industries. Texaco purchased 20 percent of ECD in 2000.

The fuel cell alternative

Fuel cells could be affordable and reliable alternatives to grid power, but significant technological challenges must be overcome before this form of distributed power can achieve widespread commercial viability.

Plug Power LLC of Latham, New York, has made substantial advances in proton-exchange membrane (PEM) technology for fuel cells. Likewise, Materials and Systems Research, Inc. (MSRI), of Salt Lake City, Utah, has achieved breakthroughs in solid-oxide fuel cell (SOFC) technology.

Selected components in existing PEM-based fuel cells are—like people—easily poisoned by trace amounts of carbon monoxide (CO), which is produced when any hydrocarbon fuel is converted to hydrogen. In short, poor CO tolerance kills fuel-cell performance or requires expensive fixes.

With ATP support, Plug Power, a world leader in fuel cell manufacturing, and its partners—SRI International, Polyfuel, and Celanese—improved the CO tolerance of PEM technology by a factor of up to 1,000, overcoming a major technical bottleneck.

This breakthrough in CO tolerance paves the way for a significantly less expensive, smaller, and more reliable fuel processing unit that could provide reliable and affordable power to individual homes and businesses. With this new technology, Plug Power can offer the country a power source unencumbered by brownouts or power surges and practical for remote locations inaccessible to the grid. Fuel cells are much cleaner than conventional power plants—they emit almost no SO_x or NO_x, and they produce less CO_2 because of their higher efficiency.

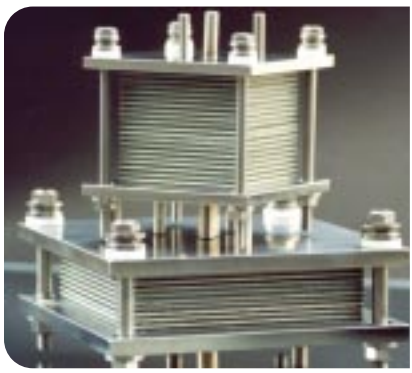
MSRI has developed a solid-oxide fuel cell that also has the potential to provide reliable, affordable power. MSRI's SOFC, which uses hydrogen and carbon monoxide produced from natural gas or other combustible vapors as fuels, can outperform other types of fuel cells because of its solid-state design, ability to operate at high temperatures, and potential to achieve greater-than-50-percent efficiency. In contrast, the efficiency of a state-of-the-art gas turbine power plant is in the 30-percent range. SOFC fuel cells have the potential to achieve even higher overall efficiencies by using the heat they generate for water or space heating.

PEM- and SOFC-based fuel cells will likely be applied first for emergency or remote power generation, and in areas that suffer from frequent power outages or high energy costs. As fuel cell manufacturers progress along the learning curve, fuel cells will become increasingly common in the general marketplace.

Compact power storage for surge demand

Today's generation of portable electronic devices require bursts of power at certain points—generally at startup—and steady power at other times. Fuel-cell-based micropower systems can provide reliable, steady power, and also a means for delivering pulses of energy.

The PowerStor® aerogel supercapacitor



MSRI's solid oxide fuel cell stack

A new supercapacitor developed by PowerStor Corporation of Dublin, California (now a part of Cooper Bussman, Inc., of St. Louis, Missouri), can deliver pulses of energy to either portable or fixed devices. The super capacitor charges quickly and can be cycled hundreds of thousands of times without significant degradation in performance. PowerStor's supercapacitor uses an unusual element called aerogel carbon. Nicknamed "frozen smoke," aerogel is one of the lightest solids ever made, able to support more than 1,000 times its own weight. It has an extremely high surface area and a large number of ultrafine pores. Carbon aerogels have helped to radically boost the performance of the supercapacitor.

The successful completion of the PowerStor project has resulted in the commercialization of a new series of compact, flat, aerogel supercapacitors that deliver power with low energy leakage, long life, and the ability to be recharged millions of times. Aerogel supercapacitors can deliver short, high-current pulses of power, like those required at computer start-up, and provide bridge power to a device or other equipment for a few seconds or even a few days if the main power is interrupted. They have proved to be ideal in portable electronic devices—e.g., in wireless transmitters and medical instruments, and are being incorporated into fuel-cell-based micropower systems.

The investment by ATP in multiple energy storage research projects like MTI, Ovonic Battery, and PowerStor demonstrates the program's willingness to back more than one horse in a race and nurture multiple breakthrough technologies in the same category.

The String Ribbon solution

Current production methods for solar cells are expensive due to the large amount of crystalline materials required.

Evergreen Solar, Inc., of Waltham, Massachusetts, has created wide, ultra-thin, silicon ribbons from molten silicon, eliminating much of the waste and cost of the current method for producing solar cells—sawing solid blocks of crystalline silicon into wafers.

In Evergreen's String Ribbon technique, two high temperature strings are pulled vertically through a shallow silicon melt, and the molten silicon spans and freezes between the strings to form a ribbon of silicon. String Ribbon can yield more than twice as many solar cells per pound of silicon as conventional methods.

As a result of this ATP-supported project, Evergreen's production of solar cells grew 10-fold in just 24 months and attracted investment funding to build a new manufacturing plant. Evergreen is pursuing further advances in its String Ribbon technology, including thinner ribbons and the ability to grow more than two ribbons from a single, more energy-efficient furnace. To date, more than 30,000 String Ribbon panels have been shipped worldwide.

One-step purification of natural gas

One-third of U.S. natural gas reserves cannot be used because of excessive contamination with nitrogen and/or carbon dioxide.

A new purification technology called Molecular Gate®, developed by Engelhard Corporation of Iselin, New Jersey, economically removes contaminant nitrogen and carbon dioxide from natural gas at the well head in a simplified, one-step process. Engelhard's proprietary Molecular Gate adsorbent consists of a titanium silicate molecular sieve, which has the unique ability to adjust pore size openings so that methane molecules are unaffected, while the slightly smaller contaminants, such as nitrogen and carbon dioxide, are readily admitted. The contaminants are trapped in a fixed bed of the adsorbent material, while letting methane (the primary component of natural gas) flow through at high pressures. The technology can reduce nitrogen levels as high as 30 percent to the 4 percent required for natural gas in pipelines. Carbon dioxide contamination can be reduced from 30 percent to the 2-percent pipeline requirement. Co-removal of nitrogen and carbon dioxide can be carried out for individual contaminant levels as high as 20 percent. In addition, Molecular Gate systems remove residual water and can recover liquefied petroleum gas components such as propane and butane.

The initial target market for this new technology will be in the recovery of coal-bed methane. The market for coal-bed methane is growing at 15 percent per year (5-year doubling time) and currently provides about 7 percent of U.S. production. Engelhard recently announced its first sale of a commercial Coal-Mine Methane Recovery Unit, with startup in summer 2003.

Engelhard's Molecular Gate technology might not have gone forward due to lack of funding. It was considered too preliminary and too high risk despite its potential benefits. ATP support enabled the development of this promising technology, and provided the means for Engelhard to partner with universities possessing the special scientific and engineering expertise needed to bring Molecular Gate technology to fruition.

String Ribbon solar cells emerge from a processing furnace

Snapshots of profiled projects

DMFC/EC Capacitor Powerpack
Sponsor: MTI MicroFuel Cells, Inc. (formerly Mechanical Technology, Inc.), Albany, NY
ATP funding: $4.7 million*
Oct. 1, 2001 to Sept. 30, 2004
Other participants: E.I. du Pont de Nemours & Company, Wilmington, DE

Metal-hydride Battery
Sponsor: Ovonic Battery Co., Troy, MI
ATP funding: $8.2 million*
Oct. 1, 1997 to April 30, 2001
Other participants: Crucible Materials Corp., Crucible Research Center, Pittsburgh, PA

Aerogel Supercapacitor
Sponsor: PowerStor Corporation
ATP funding: $2 million
Nov. 1, 1998 to June 30, 2001

CO-tolerant PEM Technology
Sponsor: Plug Power LLC, Latham, NY
ATP funding: $4.7 million*
May 10, 1999 to May 31, 2002
Other participants: Polyfuel, Inc., Menlo Park, CA; SRI International, Menlo Park, CA

Solid Oxide Fuel Cell
Sponsor: Materials and Systems Research, Inc., Salt Lake City, UT
ATP funding: $2 million
Nov. 1, 1998 to Oct. 31, 2001

Silicon String Ribbons
Sponsor: Evergreen Solar, Inc., Waltham, MA
ATP funding: $1.4 million
Oct. 1, 1997 to Sept. 30, 2000

Molecular Gate®
Sponsor: Engelhard Corporation, Iselin, NJ
ATP funding: $1.8 million
Dec. 1, 1999 to Nov. 30, 2002

**Joint venture*

Fueling economic growth

More than half of U.S. economic growth depends on advances in technology. We'd live in a different and less prosperous nation without them. NIST's Advanced Technology Program (ATP) helps to fuel the engine of economic growth by providing vital funding for high-risk, enabling technologies.

From its inception in 1990 through July 2003, ATP has awarded $2 billion in funding to companies for 665 innovative projects. Industry matched this funding with $1.9 billion in cost-sharing. Half of the projects funded in this time frame have been successfully completed. Many more are in the works. ATP's portfolio of investments to date is expected to return at least $15 billion in benefits to the American people, delivering broad quality-of-life improvements, consumer savings, and productivity gains, adding to Treasury receipts (through taxes), and spurring whole new industries.

ATP's unique and vital role

It takes capital to turn ideas into new products and industries. Yet for many high-risk initiatives, initial investments will not be recovered for years or even decades, making them unattractive to private-sector companies. New ideas often fall into a "valley of death" between basic research and product development, a void where risk aversion and a resulting lack of investment capital kills innovations.

ATP funding plays a critical role in bridging this investment gap. With venture capital firms, state governments, and universities contributing only 8 to 16 percent toward early stage technology development, federal programs, such as ATP, account for between 21 and 25 percent. By sharing the costs of innovation, ATP catalyzes private-sector investment and risk-taking.

New products benefit the economy

Of the first 50 ATP projects completed, 80 percent brought new products or processes into the marketplace and many delivered far-reaching benefits to our society. Consider a few examples: a data storage technology that could return $3.7 billion in consumer benefits; flow-control machining that might increase returns in the auto industry by $142 million annually; and, component-based software projected to yield $840 million in public and private returns. These projects have also spurred company growth and job creation. Three out of five small, single-applicant companies have at least doubled in size, and 13 percent have grown by more than 1,000 percent. The bottom line: The projected economic impact of a handful of these early ATP projects would pay for every ATP project funded since 1990.

Putting private-sector ingenuity to work

ATP partners with companies of all sizes as well as universities and nonprofits, encouraging these organizations to take on and overcome national technical challenges that they could not or would not accept alone. In this way, ATP seeks to reap major potential benefits for the nation—benefits that extend well beyond the participating organizations themselves to broad applications that benefit society.

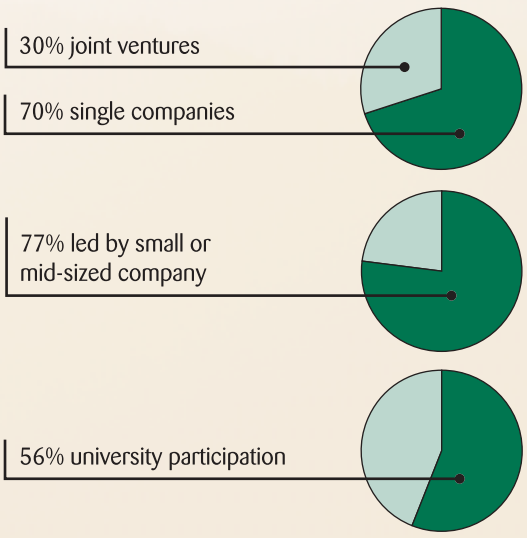
ATP accepts proposals in all industries and fields of science and technology, and awards funding as the result of open, peer-reviewed competitions. In 43 competitions to date, 665 winning projects have been selected from 5,587 submitted proposals. Proposals are evaluated by one of several technology-specific boards that are staffed with experts in particular fields. Proposals are assured an appropriate, technically competent review even if they involve a broad, multidisciplinary mix of technologies. Awards are made based on high-risk technologies that:

- Extend their benefits well beyond the companies involved in the project.
- Have broad potential applications, particularly across different industrial sectors.
- Open new potential markets or make possible wholly new products or industrial processes.

The seven innovative energy technologies profiled in this brochure represent the mission of ATP, to bridge the gap between the research lab and the marketplace, stimulating *prosperity through innovation*.

ATP at a Glance

665 projects funded from 1990 to July 2003, resulting in 800 new patents. At the time of award,



To innovate or not to innovate?

What would have happened without ATP funding? In many cases, innovation would have been slower or nonexistent. A survey of companies that submitted non-winning proposals to ATP in 1998 reveals that over 60 percent did not proceed with their proposed projects in any way. Of the rest, about 30 percent went ahead on a smaller scale. Similarly, a 1990-1992 survey of awardees indicates that 70 percent would not have pursued technology development in the absence of the ATP award.

Time-to-market, a critical success factor for new technologies, also suffers without ATP funding. Surveys from 1993 to 1998 indicate that ATP funding accelerated the R&D cycle for nine out of ten awardees. Reduction in time-to-market by two years or more is anticipated for about 60 percent of planned commercial applications by ATP awardees.

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The Advanced Technology Program is part of the Department of Commerce's National Institute of Standards and Technology. ATP's mission is to *accelerate the development of innovative technologies for broad national benefit through partnerships with the private sector.*

Cover image: provided by MTI Microfuel Cells, Inc.

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