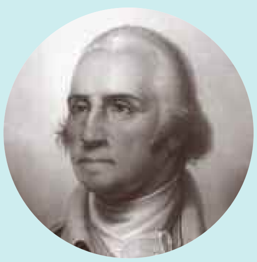
BREAKTHROUGH INSTITUTE

WHERE *Good* TECHNOLOGIES COME FROM



GEORGE WASHINGTON

Interchangeable Parts

1794

ABRAHAM LINCOLN

Railroads & Agricultural Research

1862

DWIGHT EISENHOWER

Nuclear Power

1953

JOHN F. KENNEDY

Microchips

1961

RICHARD NIXON

Biomedical Research

1971

CASE STUDIES IN AMERICAN INNOVATION

December 2010

WHERE *Good* TECHNOLOGIES COME FROM

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CASE STUDIES IN AMERICAN INNOVATION

December 2010

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INTRODUCTION

Driving directions from your iPhone. The cancer treatments that save countless lives. The seed hybrids that have slashed global hunger. A Skype conversation while flying on a Virgin Airlines jet across the continent in just five hours.

WHERE DID THESE EVERYDAY MIRACLES COME FROM?

As soon as the question is asked we know to suspect that the answer is not as simple as Apple, Amgen, or General Electric. We might recall something about microchips and the Space Race, or know that the National Institutes of Health funds research into new drugs and treatments.

But most of us remain unaware of the depth and breadth of American government support for technology and innovation. Our gratitude at being able to video chat with our children from halfway around the world (if we feel gratitude at all) is directed at Apple, not the Defense Department. When our mother's Neupogen works to fight her cancer, we thank Amgen, not NIH or NSF.

WHERE DO GOOD TECHNOLOGIES COME FROM?

One answer is visionary presidents. From George Washington to George W. Bush, under presidents both Republican and Democrat, the unbroken history of American innovation is one of active partnership between public and private sectors. Washington helped deliver interchangeable parts, which revolutionized manufacturing. Lincoln, the railroads and agricultural centers at land grant colleges. Eisenhower, interstate highways and nuclear power; Kennedy, microchips. But some of America's most important technologies came out of programs that spanned multiple presidents, as in the case of medical and biotechnology research; President Richard Nixon launched the quest to cure cancer in 1971, while funding for the National Institutes of Health tripled under Presidents Bill Clinton and George W. Bush.

Another answer is war. Interchangeable parts were developed at public armories, originally for rifles. One hundred and fifty years later, microchips, computing, and the Internet were created to guide rockets and communicate during nuclear war; today those technologies power our laptops and smartphones.

But outside of war, the United States has made decades-long investments in medicine, transportation, energy, and agriculture that resulted in blockbuster drugs, railroads and aviation, new energy technologies, and food surpluses.

America's brilliant inventors and firms played a critical role, but it is the partnerships between the state and private firms that delivered the world-changing technologies that we take for granted today.

THE ORIGINS OF THE iPHONE

There may be no better example of the invisible hand of government than the iPhone.

Launched in 2007, the iPhone brought many of the now familiar capabilities of the iPod together with other communications and information technologies made possible by federal funding:

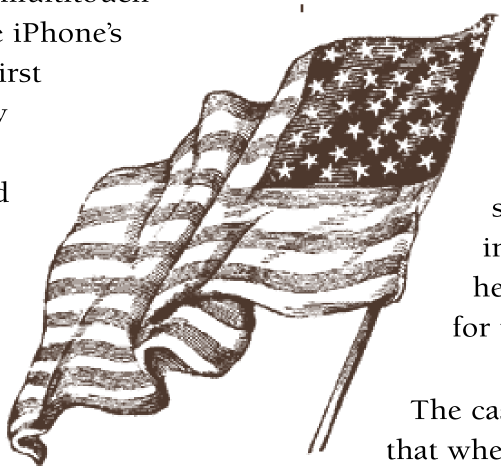
- The microchips powering the iPhone owe their emergence to the U.S. military and space programs, which constituted almost the entire early market for the breakthrough technology in the 1960s, buying enough of the initially costly chips to drive down their price by a factor of 50 in a few short years.
- The early foundation of cellular communication lies in radiotelephony capabilities progressively advanced throughout the 20th century with support from the U.S. military.
- The technologies underpinning the Internet were developed and funded by the Defense Department's Advanced Research Projects Agency in the 1960s and 70s.
- GPS was originally created and deployed by the military's NAVSTAR satellite program in the 1980s and 90s.
- Even the revolutionary multitouch screen that provides the iPhone's intuitive interface was first developed by University of Delaware researchers supported by grants and fellowships provided by the National Science Foundation and the CIA.

THE HISTORY OF AMERICAN INNOVATION

The iPhone is emblematic of the public-private partnerships that have driven America's technological leadership.

Historically, this partnership has taken two general forms. First, the government has long acted as an early funder of key basic science and applied research and development. So it was in agriculture, when the government created new land-grant colleges and expanded funding for agricultural science, leading to the development of new and better crops. In medicine, many of today's blockbuster drugs can trace their existence to funding from the National Science Foundation (NSF) and the National Institutes of Health (NIH).

In addition to providing robust funding for new scientific discovery and technological advancement, the government has also routinely helped develop new industries by acting as an early and demanding customer for innovative, high-risk technologies that the private sector was unable or unwilling to fund. Military procurement during and after World War I helped America catch up to its European rivals in aerospace technology and was key to the emergence of the modern aviation industry. Decades later, the modern semiconductor and computer industries were created with the help of government procurement for military and space applications.



The case studies herein also demonstrate that when this vital partnership between the public and private sector is severed, so too is American economic leadership. Once a global leader in wind and solar energy technology, the United States faltered and never fully recovered as public support ceased and other governments – Denmark, Germany, and Japan – increased their investments and stepped in to assume the mantle of leadership in the emerging sectors. U.S. leadership in semiconductors was also imperiled for a time, only to be restored through renewed public-private collaboration sponsored by President Ronald Reagan's Department of Defense and a consortium of the industry's leading figures.

From hybrid crops to blockbuster drugs, nuclear power to wind power, and microchips to the Internet, this report compiles a series of Case Studies in American Innovation that detail the role this key public-private partnership has played throughout more than two centuries of successful American innovation.

SOWING THE SEEDS *of* THE GREEN REVOLUTION

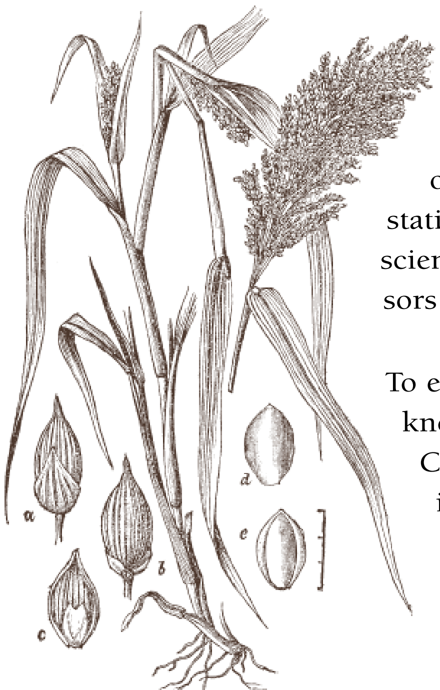
AGRICULTURE

For nearly a century, hybrid seeds and agrichemical technology have dramatically increased agricultural yields and reduced food prices. Early public initiatives to decentralize agricultural research along with sustained federal investment in agricultural science and technology made these innovations possible.

In the mid-19th century, agriculture formed the backbone of the American economy with half of the U.S. population living on farms and 60 percent of all jobs connected to agriculture. Most U.S. farming families, however, were uneducated and had little access to practical and technical training.

Recognizing the economic importance of agricultural resources, Congress established the Agricultural Division of the Patent Office in 1839 to collect, distribute, and research new varieties of seeds and plants. The new agency became the main repository for genetic plant material in the country.

Over the following decades, the government built a foundation for modern agricultural science along with the widespread diffusion of future agricultural innovations.



In 1862, Congress passed and President Lincoln signed the Morrill Land Grant College Act of 1862, providing states with land that they could sell to develop agricultural colleges where new agricultural and mechanical practices would be taught. Notable institutions including Ohio State University, Iowa State University and the University of California system, among others, all originated from the Morrill Act. Later, in 1887, Congress passed the Hatch Experiment Station Act, which funded and expanded a system of state agricultural experiment stations (SAESs), to provide a stronger scientific and research base for professors at those schools.

To ensure the diffusion of new scientific knowledge generated in the colleges, Congress passed the Smith-Lever Act in 1914, creating the Cooperative Agricultural Extension Service – a partnership among federal, state, and county governments. Extension services informed farmers of new research and technological advances relevant to their crops and local conditions, helping them to continuously boost productivity.

Together, the Morrill, Hatch, and Smith-Lever Acts transformed U.S. agriculture into a scientific and technological enterprise, and the research funded through agricultural

Hybrid seeds were responsible for dramatic reductions in food prices over the 20th century. The foundation for these and other agricultural innovations were laid by the government, through early funding for agricultural science institutions and the diffusion of practical knowledge.

extension services provided enormous benefits to a growing nation. The development of double-crossed hybrid seeds, made practical by maize geneticist Donald F. Jones at the Connecticut Agricultural Experiment Station, dramatically boosted yields and improved economic prospects for legions of American farmers. In 1934, less than one-half of one percent of U.S. land planted in corn was sowed with hybrid seed. By 1956, virtually all corn planted in the United States was hybrid corn.

Until World War II, agriculture continued to enjoy a privileged position in U.S. science and technology policy, accounting for 39 percent of federal R&D spending in 1940. Early federal investments in agriculture also spurred the growth of industry-funded R&D, which today exceeds that of the public sector. By supporting valuable agricultural knowledge and technologies, the public sector laid the foundation for the vibrant agribusiness industry that exists in America today.

Together, this public-private partnership drove innovation and productivity improvements that facilitated dramatic increases in agricultural production, even as harvested cropland and the number of people employed in the field has declined. From 1920 to 1995, harvested cropland declined from 350 to 320 million acres, the share of the labor force in agriculture declined from 26 percent to 2.6 percent, and the number of people employed in agriculture decreased by two-thirds to 3.3 million, all while agricultural production tripled.

By dramatically expanding agricultural productivity, government investment in scientific research, education, and technology adoption helped move America away from an agriculture-oriented economy and into the industrial age. It also led to the creation of some of the most important centers of research and learning in the country today.

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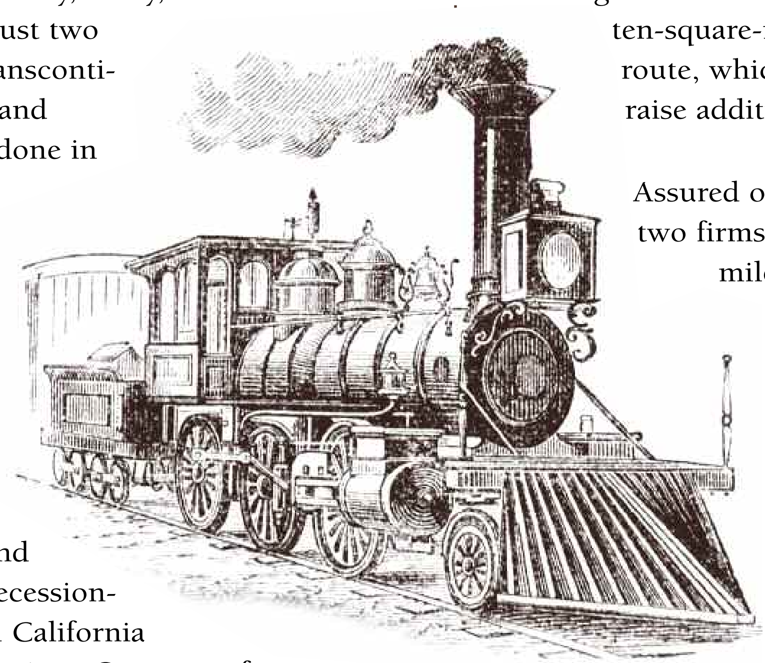
UNITING *a* NATION:
RAILROADS

In 1860, settlers embarking on the long journey to the west had to travel by horseback, foot, or covered wagon. This more than 2000-mile journey took at least six months, and disease, starvation, and natural disasters frequently threatened the lives of travelers. By 1870, however, that same journey could be completed quickly, safely, and comfortably in just two weeks on the transcontinental railroad, and today, it can be done in about three days on an Amtrak.



In 1862, westward expansion, the military imperatives of the Civil War, and the threat of a secessionist movement in California combined to convince Congress of the need to make a massive infrastructure investment in creating a national rail transport system. Aside from the sheer magnitude of such a project, private companies were further discouraged from undertaking this effort by the unpredictable cost of developing unsettled territories as well as the immaturity of railroad construction and operation practices. Given these uncertainties, the transcontinental railroad required government backing to minimize risk and instill sufficient confidence in private investors.

To this end, President Lincoln signed the Pacific Railway Act of 1862, which provided public financing in the form of $16,000 bonds per mile of tracked grade to two major private rail companies – Union Pacific Railroad Company and Central Pacific Railroad Company. They also received land grants entitling them to alternating ten-square-mile sections along the route, which the firms could sell to raise additional funds.

Assured of long-term financing, the two firms competed to lay the most miles of track. The Central Pacific Railroad Company built west from Omaha while Union Pacific started in California and began laying track eastward. In May of 1869, at Promontory Summit, Utah, the rail lines met, linking East and West via rail for the first time.

With the physical infrastructure largely complete, the rail companies needed a highly trained workforce to operate the complex system. Fortunately, strategic early 19th century policies targeted to support engineering science, largely through the United States Military Academy at West Point, provided a talented pool of engineers to survey and oversee new railway construction as projects multiplied across the nation. A study conducted in 1867 found that out of 2,218

Generous government incentives and high-caliber, Army-funded engineering training programs were critical to the expansion of rail in the 19th century. The transcontinental railroad opened the American West to settlers and commerce, uniting a divided nation.

West Point graduates, 155 went on to become civil engineers, 41 to be superintendents of railroads and other public works, 48 to be chief engineers, and 35 became presidents of railroad corporations.

The advent of the transcontinental railroad meant that trade, commerce, and travel could be conducted at a pace previously unimaginable. The rapid shipment of goods allowed cities like Chicago to become trading hubs and new marketplaces for corn, wheat and lumber. Railroad projects also opened up the vast lands of the American West to settlement and economic activity, unifying the national economy and fueling the tremendous growth that marked the era. By backing private companies, providing critical upfront capital, and investing in education, the birth of the transcontinental railroad successfully ignited a new era of economic growth.

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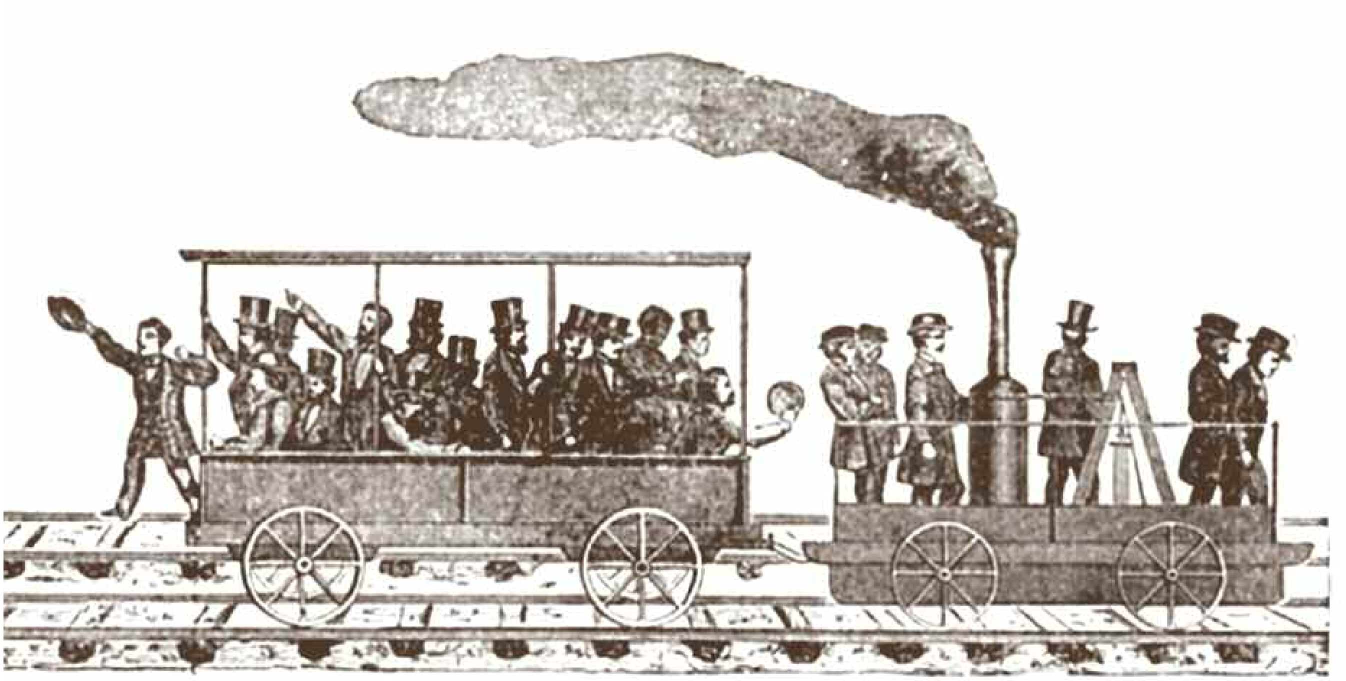
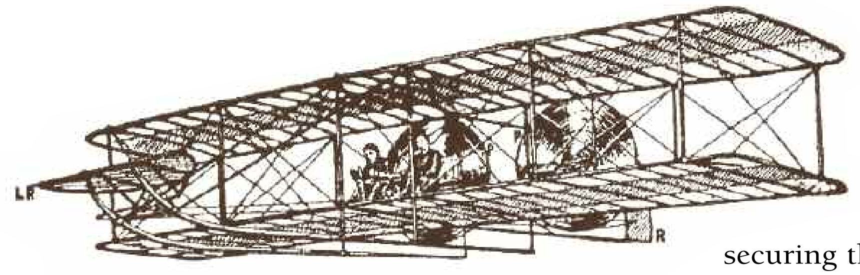


The AVIATION INDUSTRY



Human flight once conjured the harsh lesson in hubris learned by Icarus, the mythical boy who flew too close to the sun on man-made wings and perished. Today, unconcerned with hubris, millions of Americans take to the skies every day, crediting innovators like the Wright brothers and Boeing with the ingenuity that made it possible. Yet when it comes to the development of the modern aviation industry, it is the federal government that looms large.

Just a few years after Kitty Hawk, America was already lagging in the mastery of aviation while European governments, compelled by the military demands of World War I, poured resources into aeronautics. In 1913, America ranked 14th in government spending on aircraft development, languishing in the company of Brazil and Denmark while Britain, France and Germany excelled in aviation design.

By mid-century, however, the United States was well on its way to restoring its place at the forefront of civilian and military aviation. Government involvement – from research support and deployment initiatives to the creation of a carrier network and the enactment of federal regulations – was the critical catalyst for this remarkable turnaround, securing the foundation for America's modern aviation industry.

The unassuming establishment of the National Advisory Committee for Aeronautics (NACA) under the Naval Appropriations Bill of 1915 marked the first step toward America's renewed success in aviation. With NACA, the government was finally taking the nascent aviation industry – and its vast potential in the commercial and military sectors – seriously.

NACA spearheaded many game-changing innovations as early planes developed and improved. Its first major accomplishment was the construction of a sophisticated wind tunnel that allowed for the systematic testing and observation of various shapes for wings and propellers. NACA also oversaw the development of the cowling, an engine improvement that reduced drag and turbulence, saving huge quantities of fuel. Within five years, the cowling was standard equipment on every new plane produced.

Meanwhile, government demand during the First World War gave airplane manufacturers a major boost at a time when private interest in their products was lacking. Production fell again after the war ended, but revived with the passage of new military procurement acts during the 1920s.

Government purchases enabled the application of new advances in technology to domestic manufacturing. Among the companies sustained by government contracts was a little-known manufacturer named Boeing.

In 1925, the Kelly Airmail Act spurred the development of a mail transport system by the U.S. Postal Service, which served as a major catalyst for the budding aviation industry. Airmail paved the way for passenger aviation, as private mail carriers began targeting passengers as a way to earn extra income.

Powered human flight was invented in the United States, but by the First World War, America lagged behind in the emerging field of aviation. By mid-century, government support, ranging from R&D programs to deployment contracts, had restored U.S. expertise in aeronautics and laid the foundations for the modern aviation industry.

Although early passenger aviation was slow to catch on due to safety concerns, it was not long before the advantages of flight outweighed the high cost and safety risk. The passage of the 1926 Air Commerce Act allowed federal regulation of air traffic rules, and for the first time systemically addressed these safety risks. Notably, the private airline industry supported the new regulations, believing the government was essential to realizing the full market potential of passenger aviation.

Throughout the 1930s, government support continued to drive technical advances that complemented the efforts of the private sector. For example, Douglas Aircraft Company developed the DC-3 in 1935, which revolutionized air travel by greatly increasing the speed of flight and the distance possible in a single voyage. The plane's introduction enabled long-range air travel, and paved the way for the modern American airline industry. But while Douglas' in-house engineers came up with its overall design, the DC-3 was full of components and technologies developed through years of military research and deployment.

By the early 1940s, the U.S. aviation sector had expanded dramatically, in large part through the timely actions of the federal government. The foundations of today's massive aviation industry had been laid.

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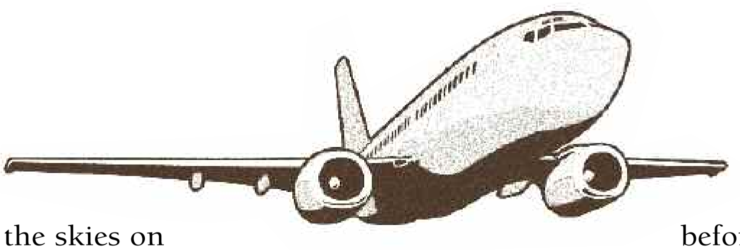
A MARKET *for* SPEED

JET ENGINES



In 2009, 4.8 billion passengers traversed the skies on jet airplanes. On a typical day, upwards of 2 million Americans are airborne, traveling at speeds approaching 600 miles per hour to nearly any destination on the planet.

The speed and efficiency of commercial aviation today is due almost entirely to a demanding U.S. Air Force constantly pushing the private sector to innovate and improve jet engine technology for military application. This public-private partnership eventually led to the development of a commercial jet aviation industry that has allowed the miracle of human flight to become the commonplace, if still incredible, form of transportation that it is today.

In the mid-1930s, Frank Whittle in the UK and Hans von Ohain and Max Hahn in Germany developed early jet engine prototypes. For most of that decade, the United States, under the leadership of President Franklin Delano Roosevelt, put relatively little faith in military aviation, directing most military procurement towards naval technologies. But by the onset of World War II, the United States felt the urgent need for advancements in military aircraft. Though major U.S. efforts to develop jet engine technology were initially based on the British technology pioneered by Whittle, it was not long before the United States sought to overcome the persistent shortcomings of both the early British and German jet engine designs. A dynamic partnership between the United States Army Air Force and private R&D efforts led to a revolution in both warfare and commercial human transit.

By the end of 1930s, Whittle, a Royal Air Force (RAF) pilot and engineer, had developed a relatively simple centrifugal flow engine and had begun receiving military funding to continue improving it. The United States built off the UK's success. After Congress passed emergency legislation to expand aircraft manufacturing and increase government support for military aviation, the chief of the Army Air Force and U.S. firms arranged to transfer British jet engine technology to the GE turbojet division. A bevy of private companies including GE, Westinghouse, Pratt &Whitney, and Lockheed began receiving government R&D funding in the hopes that a jet could quickly be developed to aid U.S. war efforts. By 1942, GE had developed the U.S. military's first jet engine – the I-A, followed by the J33 in 1944 – both based on the Whittle engine. These advancements were completed too late for use in combat, however.

A series of incremental innovations eventually led to the development of the J57 by P&W – the first jet engine with 10,000 pounds of thrust, doubling the power of most of its competitors and becoming the springboard for the development of both military fighter jets and eventually, commercial aviation.

Initially, U.S. passenger air carriers were hesitant to support the construction of jet airliners, a technology they viewed as too risky and costly to adopt hastily. However, by 1952 Pan American Airways began pursuing the dream of nonstop transatlantic flight and soon became a pioneer in commercial jet aviation. In 1955, Pan Am signed contracts with Boeing and Douglas for the 707 and the DC-8, respectively, two early jetliners. By 1958, the company had flown its inaugural New York to London route, opening a whole new realm of possibilities for civilian aviation.

Through the following decades, military demands for ever-better aircraft and engines continued to drive innovative new improvements to jet engines, creating advancements that progressively spilled over into commercial jet aviation.

Jet engines enable over 2 million Americans to travel through the air every day. The demanding procurement of the U.S. military gave rise to the modern jet engine and continues to drive improvements in the speed and efficiency of this revolutionary technology.

By pushing private companies to innovate nascent gas turbine jet engines for military use, the U.S. government assured companies like GE and P&W of a market for these advanced engines. The birth of commercial aviation, as a result of this transformative technology, demonstrates the dynamic effects of public-private partnerships to enhance and accelerate the development, deployment, and commercialization of technological innovations. Even today, the U.S. military and Air Force work with private corporations like GE and P&W as part of the Integrated High Performance Turbine Engine Technology (IHPTET) program, designed to leverage public and private efforts to drive jet engine innovation forward.

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SPOTLIGHT

A Breakthrough Gas Turbine

In 1992, the Department of Energy established the Advanced Turbine Systems (ATS) program to overcome major obstacles to efficient turbine-based power systems. The program supported new research and product development, forging links between university researchers, federal laboratories, and private sector partners working toward specific technology targets. Less than a decade later, and building on innovations developed through the program, GE unveiled its GE H System Turbine, which effectively reduced carbon dioxide emissions and broke the existing temperature barrier for gas turbines – setting a new world record for turbine efficiency in the process. The H System relies upon a number of innovative heat resistant parts developed through the DOE program and drew upon ATS financial support throughout the course of its research and development.
After extensive testing and extended operation at a South Wales, UK facility, in 2005 GE signed a deal to construct a 775 megawatt power plant using H System technology in Southern California, and a second contract to build a new H System-based power plant in Japan.

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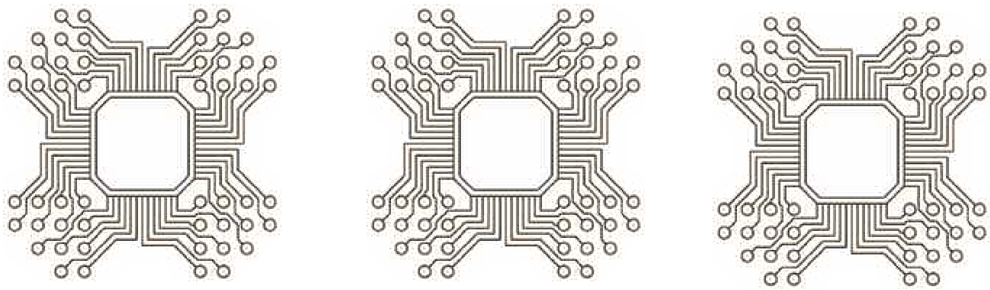
MICROCHIPS



Today, microchips are critical to most of the technologies we rely on in our modern lives – they can be found in everything from automobiles to iPhones – allowing us to communicate and process information almost instantaneously. As of 2009, the development and manufacture of microchips was a $225 billion industry. But microchips were not always so cheap and easy to make. It required a massive procurement effort by the federal government to help improve manufacturing processes and drive down the price of these chips enough to make them widely applicable and accessible.

Microprocessors arose out of the need for a reliable circuit that could drive the increasingly sophisticated electronics being developed in the 1950s. Complex electronic processes required circuits involving many transistors, each of which had to be painstakingly soldered together, and still the connections were unreliable.

In 1958, a truly groundbreaking idea was finally realized in the laboratories of Texas Instruments (TI). Jack Kilby, a TI engineer, realized that this connection problem – known to the electronics industry as the "tyranny of numbers" – could be solved by making each transistor in a circuit, as well as their connections, out of a single piece of material. By late summer of that year, Kilby carved a complex circuit out of a single piece of germanium metal, and the "integrated circuit" – also known as the microchip – was born.

Other engineers, most notably Robert Noyce of Fairchild Semiconductor, quickly improved on Kilby's design, turning a prototype into a promising new innovation that could revolutionize computing. But the future of the microchip was by no means certain. It took the buying power of the U.S. government under President Dwight Eisenhower, and later President John F. Kennedy, to make the microchip into a mass-produced, affordable, and ubiquitous technology.

The Air Force was the first big microchip buyer. Kilby's and Noyce's innovation competed with other next-generation circuit designs – including some envisioned by government researchers – but Air Force engineers decided that the microchip best fit their needs for mass-produced, powerful processors to guide the new Minuteman II missile. The resulting demand built an industry practically overnight, as the Air Force purchased thousands of chips a week from several firms. Assembly lines dedicated to microchips were established, enabling production of huge quantities of devices cheaply and quickly.

But the Air Force was not alone in its voracious demand for microchips. In the 1960s, NASA, deep into planning for the Apollo Project, needed advanced circuits for the Saturn rocket's onboard guidance computer. Soon, private companies were churning out massive amounts of purpose-built Apollo Guidance Computer microchips. In fact, NASA bought so many that manufacturers were able to achieve huge improvements in the production process, driving the price of the Apollo microchip down from $1000 per unit to between $20 and $30 per unit in the span of a few years.

As computers became more common in the 1960s, various agencies were buying hundreds of thousands of chips a year, virtually every microchip firms could produce. This insatiable demand for microchips rapidly and massively expanded manufacturing capacity and industrial expertise, paving the way for cheap, mass-produced microchips that could be sold to businesses and ordinary Americans, and setting the digital era in motion.

A PARTNERSHIP TO SAVE SEMICONDUCTORS: SEMATECH

By the mid-1980s government and private businesses coveted microchips not only for their vast technological potential but also for the immense economic benefits inherent to their manufacture. Despite early U.S. dominance in semiconductor innovation, Japan surged ahead in manufacturing the technology, a terrifying prospect for U.S. companies who sensed the market for semiconductors would only become more profitable. President Reagan's Defense Department was also concerned about the military implications of a dependency on imported semiconductors, used widely in Cold-War era weapons programs.

Thus, in 1987, 14 highly competitive domestic semiconductor manufacturers joined with the federal government to form a consortium called Sematech (SEmiconductor MAnufacturing TECHnology). The new partnership was conceived as an experimental effort to regain U.S. share of the global microchip market and increase domestic semiconductor manufacturing expertise.

The purchasing power of the federal government made the microchip an affordable and ubiquitous technology. Government procurement drove the price of microchips down by a factor of fifty in just a matter of years. Consider this: without these public investments in the semiconductor revolution, your iPod would cost $10,000 and be the size of a room.

The effort fostered an unprecedented degree of collaboration among highly competitive U.S. firms.

By 1992, the semiconductor disaster had been averted and the United States was regaining its place in the global market for microchips. Vice President Al Gore called semiconductors the 'V-8 engines of the information superhighway' because they were driving the U.S. economy. Near the end of 1994, Sematech CEO Dr. William Spencer announced the consortium's self-sufficiency and plans to relinquish federal funding — an ideal end to a productive public-private partnership.

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PERSONAL COMPUTING

Computers were once custom-built colossi that occupied entire rooms. Today, personal computers are so portable and compact that many people feel as though their MacBook or HP Pavilion is merely an extension of their own body – something central to both their professional and personal lives.

The stereotypical legend of the personal computer (PC) emphasizes individual brilliance and initiative, conjuring romantic images of today's industry titans, like HP and Apple, evolving from disheveled college dropouts furiously tinkering away in garage workshops. Of course, the government is conspicuously absent from a narrative that, while compelling, has more to do with embellishment than historical fact.

While the role of individual innovators can hardly be understated, the active involvement of the federal government – especially through military and agency procurement – was critical to the rise of the nation's computer innovation hub, Silicon Valley. Indeed, today's personal computer embodies a decades-long collaboration between private innovators and an active and demanding federal government.

From the beginnings of the computer industry, federal and military agencies promoted vital basic research into computing hardware and government agencies often served as early adopters for the first computers. In fact, the ENIAC, the first electronic computer, was built in 1945 to crunch numbers for the Army Ballistics Research Laboratory. In the 1950s, the Army Signal Corps funded research into semiconductors, and weapons labs at the Atomic Energy Commission were the first purchasers of supercomputers, the ancestors of today's desktop PCs. NASA, the Department of Defense, the National Center for Atmospheric Research, and the U.S. Weather Bureau commissioned their own supercomputers soon after. Sensing the administrative benefits of computing, the Social Security Administration was also an early adopter of computers, acquiring one of the first electronic computers in 1951 and fully functioning computers with storage in 1956.

Perhaps most importantly, the Air Force's SAGE air defense project generated numerous innovations in computing design and production during the early 1950s, including cheap manufacturing of computer memory, communication between computers, and the use of keyboard terminals. As the economist Vernon Ruttan writes, “The role of the military in driving the development of computer, semiconductor and software technologies cannot be overemphasized. These technologies were, until well into the 1960s, nourished by markets that were almost completely dependent on the defense, energy and space industries.”

The government was also heavily involved in the development of computer software. Defense agencies funded the basic R&D that led to early computer programs and programming languages. During the 1970s, in fact, defense spending fueled over half of all academic computing research, and grants from the military's Advanced Research Project Agency (ARPA) established the first university computer science programs at MIT, Stanford, Carnegie Mellon and elsewhere. In 1962, ARPA's computer research budget exceeded that of all other countries combined; by 1970, its funding had increased fourfold. The Department of Defense was the single largest purchaser of software well into the 1980's, ensuring consistent market demand that fueled an ever-growing industry.

In addition to producing major computing advances through research funding and direct acquisition, the federal government also cultivated the innovators and engineers of the modern computer industry. Many of the minds behind the groundbreaking work at Xerox’s infamous Palo Alto Research Center (PARC) and at corporations like Microsoft and Apple came straight from government agencies. Bill Gates and Steve Jobs might be famous names today, but others were crucial in the PC's development – men like J.C.R. Licklider, a pioneer theorist of human-machine interactivity and computer networking, and Ivan Sutherland, whose government-funded Sketchpad project created the first interactive graphics program and led to the invention of the computer mouse.

> The story of the PC is usually a romantic tribute to the unrestrained genius of lone inventors tinkering in garage workshops. Yet history shows that the active support of the federal government, particularly the U.S. military and space programs, was critical to the rise of Silicon Valley. Indeed, today’s personal computer embodies a decades-long collaboration between private innovators and an active government.

No less important, however, were the innumerable programmers, system designers, and computer theorists who cut their teeth at ARPA. So many veterans of ARPA and ARPA-supported university programs came to work at Xerox PARC that insiders there jokingly referred to an “ARPA Army.” These numerous veterans of government-funded programs helped Xerox PARC develop the graphical user interface and the Alto, the world’s first modern PC. Later, these same innovators scattered to run startup firms like Apple, Microsoft, and Adobe.

As Bill Gates himself acknowledges, “The Internet and the microprocessor, which were very fundamental to Microsoft being able to take the magic of software and having the

PC explode, were among many of the elements that came through government research and development."

So while popular PC folklore makes little mention of the government, in reality, public funding built the foundations of personal computing. The government's prescient investments in computer research, hardware and software deployment, and computer science education unleashed a transformative technology and helped build a massive industry from the ground up.

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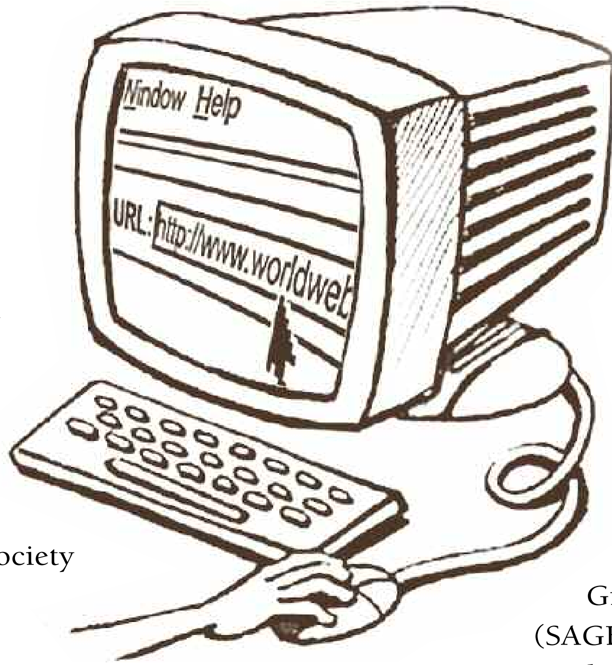
FROM ARPANET TO THE WORLD WIDE WEB

The INTERNET



Google. Twitter. Facebook. Pandora. Ebay.

These companies and the services they provide have rapidly and immeasurably altered our daily lives and the way that we communicate with one another – all thanks to the connective power of the World Wide Web. In fact, the Internet is so thoroughly ingrained in our modern society that most people pay little attention to its origin. While we look to these companies as the pioneers of the Internet, the United States government – and in particular the U.S. military – was responsible for developing and demonstrating the core technologies that led to the Internet.

The Internet has its origins in the Space Race and the Cold War. After the Soviet Union's launch of the Sputnik satellite, the U.S. government responded to the threat posed by Russia's newly displayed technological prowess by creating the Advanced Research Projects Agency (ARPA), whose purpose was to drive American technology advancement in critical defense-related fields. It was this government agency – renamed the Defense Advanced Research Projects Agency (DARPA) in the 1970s – that made major investments in the technologies that would lead to the birth of the Internet.

One of the Department of Defense's primary challenges during the Cold War was to find a way to protect its communications systems from nuclear strike. In the 1950s, the first computers were used by the military as Semi-Automatic Ground Environment (SAGE) sites to simultaneously monitor multiple radar systems. This technology allowed the air force to track Soviet bombers and respond quickly in the case of an assault, however the SAGE sites were highly vulnerable to Soviet attack, potentially rendering the military deaf and dumb, unable to regroup and respond. ARPA needed to create a more flexible communications network with the resilience to survive an attack upon a central location.

To meet this challenge, ARPA sought the top minds in the country at American universities and funded their research, while simultaneously targeting individuals in the private sector who could help create a communications network of multiple computer systems. J.C.R Licklider, an MIT professor, was hired in 1962 as part of the agency's Information Processing Techniques Office (IPTO). He envisioned a system of "time sharing" in which central terminals could be accessed remotely via a telephone connection. Licklider wanted to engineer computers that could quickly assemble information, allowing humans to devote more time to final decision-making.

At the same time that ARPA was investing in communications research, another government-funded institution, RAND, was also working on durable communications switching. This nonprofit think tank had hired Polish-born Paul Baran to work in the organization's computer science department. His innovative "packet-switching" concept would become the foundation of the Internet. Licklider's "time sharing" method still left central terminal stations vulnerable to attack, but with Baran's new method, "packets" of information could be automatically transmitted from computer to computer. Most importantly, the system created a true peer-to-peer network, allowing a pair of computers to link up directly with one another. This bypassed the need for a central control station, effectively eliminating the threat of a centralized attack.

With the core ideas behind the Internet in hand, the next step was a successful demonstration of RAND's design. The Air Force appealed to AT&T to build the infrastructure and supply the telephone service needed to demonstrate the technology. AT&T turned it down, but the state-run British Post Office accepted the offer, and with federal funding, demonstrated the viability of the technology within a year.

ARPA continued to develop this infrastructure by connecting a number of universities on the west coast. It attempted at first to commission IBM to build a personal computer that would be supported by the new network, but IBM rejected the offer. The company had been successful producing mainframe computers, central terminals that were the standard computing systems of the 1950s and 60s, and saw the new networking idea as a threat to business. Instead, ARPA employed a small, Massachusetts-based firm -- Bolt, Beranek and Newman -- to create the computers and the communications network that would support it.

Within nine months, the beginnings of "ARPANET" took shape. The first ARPANET connection was successfully demonstrated in October 1969 when an AT&T telephone line was used to link two computers, one located at the University of California, Los Angeles, the other at Stanford Research Institute. By 1971, 15 sites had been linked. In 1972, the fledgling Internet was demonstrated at the International Conference on Computer Communication, where skeptics were impressed by the responsiveness and robustness of the system. An outgrowth of the conference was the International Network Working Group, composed of researchers who were exploring packet switching technology. Several of these participants went on

> The ubiquitous World Wide Web now enables instantaneous communications connecting the far corners of the world. Despite the high profile of Internet icons like Google and Facebook, the United States government was responsible for the core innovations and key technologies that become known as the Internet.

to create an international standard for packet switching communication, resulting in the development of commercial packet switching in the United States and paving the way for the World Wide Web. The 1972 conference provided the crucial launching point for the Internet to become a widespread commercial technology, exceeding applications for military defense.

What began as a solution to a military challenge has now become the foundation of our modern communications age. The U.S. government, through ARPA/DARPA, the Air Force, and RAND, guided the creation of the Internet from its origins in defense to its commercialization as a worldwide communications system. Without the government's investments in R&D, demonstration, and deployment, the Internet revolution would not have occurred.

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SPOTLIGHT

The Global Positioning System (GPS)

GPS (Global Positioning System) is a collection of 24 satellites that can pinpoint your precise location, aiding everyday navigation tasks. Now a common feature of most automobiles and cellular phone devices, the roots of this now familiar technology lie entirely within the Department of Defense.

In the early 1960s, DOD programs developed the original foundations of GPS to enable precision weaponry and coordinate military activities. The Navy sponsored two programs, Transit and Timation, which were predecessors to GPS. Transit was the first operational satellite-based navigational system, and was originally designed to track ballistic missile submarines and other ships at the ocean's surface. Timation was a space-based navigation program used to advance the development of two-dimensional navigation. Simultaneously, the Air Force was working on a similar technology to pinpoint the positions of aircraft to within a hundredth of a mile.

By 1983, the GPS ceased being solely a military system and was made available for public use, enabling a whole new class of services and applications. By 1995, what had become known as the NAVSTAR GPS system was fully operational.

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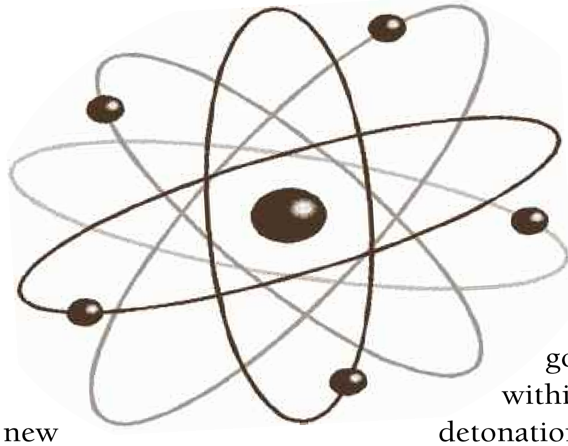
ATOMS *for* PEACE

NUCLEAR POWER



More than 400 nuclear power plants successfully supply massive amounts of carbon-free, reliable energy all over the world. Nuclear power is the only significant new carbon-free energy source pioneered and widely deployed in the latter half of the 20th century. This indispensible technological feat was primarily accomplished through publicly funded research, demonstration, and deployment.

America's nuclear power industry has its origins in the Manhattan Project to develop atomic weapons during World War II. In 1941, President Franklin Delano Roosevelt, aware of Germany's ongoing efforts to develop nuclear weapons, authorized an aggressive initiative to control nuclear fission for incorporation into armaments. By December 1942, an Army-backed research team achieved controlled nuclear fission underneath a University of Chicago rackets court. It was the first such demonstration in world history.

From 1942 to 1945, the United States invested $20 billion (in 2003 dollars) into a massive nuclear research and deployment initiative. The Manhattan Project created the first National Laboratories at Oak Ridge, Hanford, and Los Alamos, research centers at several American universities, and funded labs and production facilities from coast to coast. This massive government effort succeeded within three years, with the detonation of the first nuclear bomb at a New Mexico test site in July 1945.

This achievement marked the beginning, not the end, of America's investments in nuclear technology. President Eisenhower's "Atoms for Peace" address in 1953 and the 1954 Atomic Energy Act (AEA) committed the United States to develop peaceful uses for nuclear technology, including commercial energy generation. Simultaneously, the Atomic Energy Commission announced a Power Demonstration Reactor Program, which included federal cooperation with two firms to demonstrate a first-generation nuclear reactor in Pennsylvania.

The new National Laboratory system, established by the Manhattan Project, was maintained and expanded, and the government poured money into nuclear energy research and development. Federal research, in turn, produced advanced technologies like the Boiling Water Reactor, first demonstrated at the Idaho National Labs and the Pressurized Water Reactor, developed at Oak Ridge National Laboratory, both nuclear technologies currently deployed throughout the world.

From the Manhattan Project to "Atoms for Peace," public investments in nuclear energy led to the development and commercialization of the only new carbon-free energy source widely deployed in the latter half of the 20th century.

Recognizing that research was not sufficient to spur the development of a nascent, capital-intensive industry, the federal government created financial incentives to spur the deployment of nuclear energy. For example, the 1957 Price Anderson Act limited the liability of nuclear energy firms in case of serious accident and helped firms secure capital with federal loan guarantees. In the favorable environment created by such incentives, more than 100 nuclear plants were built in the United States by 1973. Today, these plants generate nearly 20 percent of US electric power and have a peak capacity of over 100,000 megawatts.

Meanwhile, other countries seized on America's advances to meet their own energy needs. Today, France generates over eighty percent of its electricity with nuclear fission, Japan thirty percent, and South Korea forty percent. In total, 441 nuclear plants are currently in operation worldwide – all based on the process of nuclear fission first pioneered by U.S. government-supported initiatives.

Despite the current political and financial obstacles to new deployment in the United States, nuclear energy remains a prime example of a valuable technology created by strong and consistent government support. Any initiative to develop next-generation energy resources will undoubtedly look back to the bold precedent set by the federal government's development of atomic energy.

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MYTH *and* REALITY

SYNTHETIC FUELS

Established in 1980, the Synthetic Fuels Corporation (SFC) was launched by Congress as an attempt to develop significant alternative domestic fuel production in light of the Arab oil embargoes in the 1970s. The Corporation, a government-funded, public-private initiative, would oversee an $88 billion program (over $200 billion in today's dollars) aimed at producing fuels from U.S. coal and oil shale, including R&D funding for basic technologies, price guarantees and purchasing commitments for produced fuel, loans to the private sector, and subsidies for fuel plant construction. Its architects promised massively expanded production of "synfuels" within years, offsetting nearly half of America's petroleum imports by the early 1990s.

Of course, these rosy visions never materialized. With oil prices falling by the late 1980s, the SFC was unable to produce price-competitive fuels. Wracked with administrative problems, and suffering from negative public opinion, the SFC was terminated in 1986, and today, synfuels are an insignificant component of America's oil-intensive energy economy.

The failure of the SFC is frequently cited as an argument against any significant government intervention in technology development and commercialization. However, the reality is that the SFC actually succeeded in its technological mission. The experiment succeeded at creating fuel that would have been price competitive with oil at $60 per barrel – well below the price of oil at the time the Corporation was created. It was the collapse of oil prices in the global market that ultimately doomed the program, not a failure of the technological endeavor.

In addition, North Dakota's Great Plains chemical plant, built with SFC funding in the early 1980s, was a key demonstration of both coal gasification technology and large-scale carbon capture and storage – technologies that are now the subject of great interest as concerns about climate change mount.

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Not every federal investment in technology has gone according to plan. One technology development program, the Synthetic Fuels Corporation (SFC), is routinely invoked as an example of federal technology policy gone awry. Yet the program actually succeeded in its technological mission, and while it failed to spark a new industry, it provided the underpinnings for carbon capture and storage technology.

COMMERCIAL WIND POWER

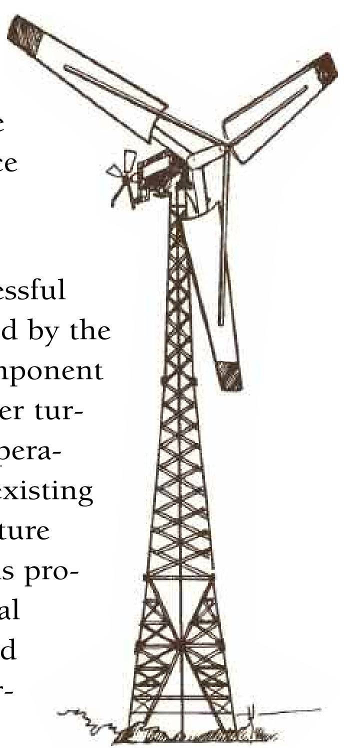
Rising high above the cotton fields in the town of Roscoe, Texas, (population 1,300) 627 wind turbines make up what is currently the largest wind farm in the world. At 781.5 megawatts, the massive wind project supplies power to more than 250,000 Texan homes. Organized by a local cotton farmer from Roscoe, the farm is just one of many wind energy projects reviving the local economies in West Texas and throughout the United States.

It is not just the United States getting in on the wind energy action; wind energy is one of the fastest-growing energy industries in the world, and is expected to remain so over the next decade. Globally, the industry has grown from 17,000 megawatts in 2000 to 160,000 megawatts in 2009, an annual growth rate of nearly 29 percent.

The modern industry has changed dramatically from its humble beginnings in the early 1970s, when the public response to oil crises and environmental concerns prompted a renewed look at the technology. Over the subsequent decades, technological innovation in the sector proceeded quickly; from 1980 to 1990, the cost of wind-generated electricity declined by a factor of five, from 38 cents per kilowatt-hour to eight cents per kilowatt-hour. Today, prices are lower still, and approach competitiveness with conventional fossil fuels in some geographic areas.

From the start, the federal government played a key role in driving technological innovation in the wind energy sector by funding the development, demonstration, testing, and deployment of new wind turbines. Federal support helped private companies like GE Wind, the world's second largest turbine manufacturer, improve their technology and gain a foothold in early markets.

In the 1980s, the federal government pursued two different R&D efforts for wind turbine development. The first was a "big science" effort by NASA and the Department of Energy (DOE) to use U.S. expertise in high-technology research and products to develop new large-scale wind turbines for electricity generation, largely from scratch. Perhaps predictably, this effort was less successful, because it was relatively detached from the private sector and the operational experience of wind turbines.



A second, more successful R&D effort, sponsored by the DOE, focused on component innovations for smaller turbines that used the operational experience of existing turbines to inform future research agendas. This program led to substantial improvements in wind turbine efficiency during the 1980s. Joint

Today wind generated electricity is nearly competitive with conventional energy technologies. This wasn't always the case. Through funding for R&D and incentives to spur demand, the federal government helped lower the price of wind power by a factor of five over a decade, falling further thereafter.

research projects between the government and private firms produced a number of innovations that helped increase the efficiency of wind turbines, including twisted blades and special-purpose airfoils. Of that era's 12 key innovations in turbine components, seven were funded, at least in part, by the federal government.

Publicly funded R&D was coupled with efforts to build a domestic market for new turbines. At the federal level, this included tax credits and the passage of the Public Utilities Regulatory Policy Act (PURPA), which required that utilities purchase power from some small renewable energy generators at avoided cost. Most of the market for wind turbines in the 1980s was in California, where the state's implementation of PURPA was particularly generous, and importantly, permitted long-term power purchasing contracts, which helped reduce risk for project developers. The state government also passed state-level tax credits and conducted resource assessments to determine optimal geographic sites for wind power.

Both federal and state support for wind turbine development helped drive costs down considerably, but policy incentives at both the federal and state level were discontinued at the end of the decade, leading to a breakdown in the public-private partnership that had driven the industry and a stagnating domestic market.

As policy incentives disappeared in the United States, Denmark, today a global leader in the wind energy industry, increased investment in the sector. From 1979 to 1989, the government covered 30 percent of wind energy investment costs and paid above-market prices for electricity generated from wind turbines. Denmark also provided robust support for wind energy research through the government's leading research center, Risø National Laboratory, which introduced innovative standards for wind turbines and worked with private firms to ensure their safety and reliability. The strong public-private partnership developed by Denmark's national wind energy policies built a world-leading industry that remains competitive to this day. Vestas, a Danish wind energy company, is the number one wind turbine manufacturer in the world.

After a nearly five-year federal policy hiatus in the late 1980s, the U.S. government enacted new policies to support the industry in the early 1990s. The National Renewable Energy Laboratory (NREL) continued its support for wind turbine R&D, and also launched the Advanced Wind Turbine Program (AWTP), with three phases, including concept design, near term product development, and next generation product development. The goal of the AWTP was to reduce the cost of wind power to rates that would be competitive in the U.S. market. Policymakers also introduced new mechanisms to spur the demand of new wind turbines and boost the domestic market, including a 1.5 cents per kilowatt-hour tax credit (adjusted over time for inflation) included in the 1992 Energy Policy Act.

While the new production incentive helped narrow the price gap between wind energy and fossil fuels, this gap persisted. Consequently, the government funded additional programs to support the deployment of a new generation of turbines being developed by U.S. manufacturers with support from NREL R&D efforts. In 1992, NREL, in partnership with the Electric Power Research Institute (EPRI), a private-sector consortium, launched the Utility Wind Turbine Performance Verification Program. Though the program only resulted in four utility installations totaling less than six megawatts, it allowed wind turbine manufacturers to test new designs and improve their performance after initial market experience.

One of the firms that benefited immensely from federal technology development efforts was Zond, Inc. Zond, which later became Enron Wind Corp., relied on the DOE for one-third to one-half of its technology development funding. Resources provided by NREL through the second phase of its Advanced Wind Turbine Program contributed to the development of Zond's first commercial turbine, the Z-40, and the joint NREL/EPRI verification program provided its first market. AWT phase three funding led to the development of a new, larger turbine, the Z-46, which was later selected in a number of new wind farm solicitations supported by state-level policies. In 2002, Enron Wind Corp., was purchased by GE and became GE Wind. Thus, both Vestas in Denmark and GE Wind in the United States, the number one and two global wind turbine manufacturers, respectively, have their origins in the same kind of active public-private technology partnership responsible for so many other important American innovations.

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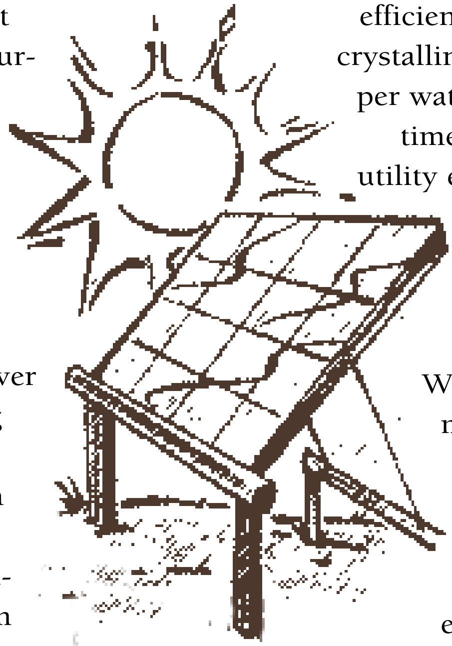
A LIMITLESS ENERGY SOURCE

SOLAR POWER



In March 2010, American firm First Solar, the world's leading manufacturer of thin-film photovoltaic solar cells, signed an agreement to supply one of the largest photovoltaic plants in the United States. At 550 megawatts, the plant would provide enough electricity to power nearly 160,000 homes. First Solar has stormed onto the solar scene over the last five years as manufacturing innovations and advancements in its technology have helped the firm secure a position as the global cost leader in photovoltaics. The company uses the less expensive cadmium telluride as a semiconductor for its cells as opposed to the more common crystalline silicon, and it recently brought its manufacturing costs below $1 per watt, a milestone in the field.

First Solar's success would not have been possible had it not been for the federal government acting as a key partner in the development of solar photovoltaics (PV) – a technology industry the federal government single-handedly created by acting as the technology's initial customer in the mid-20th century.

Solar PV technology was born in the United States, when Daryl Chapin, Calvin Fuller, and Gerald Pearson at Bell Labs first demonstrated the silicon solar photovoltaic cell in 1954. The first cells recorded efficiencies of four percent, far lower than the 25 percent efficiencies typical of some silicon crystalline cells today. At a cost of $300 per watt, more than one hundred times more expensive than typical utility electricity rates at that time, the early cells were far too expensive for wide-scale commercial adoption.

With the cost out of reach for most applications, developers of the new technology had to look elsewhere for an early market. As it turned out, solar PV did make economic sense in one market segment: aerospace. The United States Army and Air Force viewed the technology as an ideal power source for a top-secret project on earth-orbiting satellites. The government contracted with Hoffman Electronics to provide solar cells for its new space exploration program. The first commercial satellite, the Vanguard I, launched in 1958, was equipped with both silicon solar cells and chemical batteries. The latter lasted only a week, while the PV cells, which were used to power its radios, allowed the satellite to continue communicating with stations back on Earth for years. By 1965, NASA was using almost a million solar PV cells. Strong government demand and early research support for solar cells paid off in the form of dramatic declines in the cost of the technology and improvements in its performance. From 1956 to 1973, the price of PV cells declined from $300 to $20 per watt.

First Solar leads the world in the manufacture of relatively inexpensive thin-film solar PV cells. But First Solar would have never succeeded if the federal government had not created the solar industry by acting as a demanding initial customer as well as a frugal funder.

Beginning in the 1970s, as costs were declining, manufacturers began producing solar PV cells for terrestrial applications. Solar PV found a new niche in areas distant from power lines where electricity was needed, such as oilrigs and Coast Guard lighthouses. The government continued to support the industry through the 1970s and early 80s with new R&D efforts under Presidents Richard Nixon and Gerald Ford, both Republicans, and President Jimmy Carter, a Democrat.

During this period, the U.S. government investment hundreds of millions of dollars in solar PV R&D, peaking at $325 million in 1980 – more than twice that of its nearest competitors in the industry. As a result, the U.S. dominated the solar market with 76 percent of global production.

Throughout the mid-1980s, however, public funding for R&D declined sharply under President Ronald Reagan. Most critically, the United States failed to craft effective policies to stimulate the deployment of new PV modules as they became relatively less expensive. As a result, the United States forfeited its market leadership to Japan (and later Germany). By 1986, Japan's market share was 46 percent, compared to the United States' 26 percent. Of particular concern was Japan's growing lead in amorphous silicon (a-Si) "thin-film" PV cell research – cells that were less efficient but cheaper to manufacture than traditional crystalline technologies.

The federal government responded to this threat by becoming the first country to leverage cost-sharing arrangements between public agencies and the private sector to speed the commercialization of PV technologies. Even though federal investment in solar PV R&D declined in the mid-1980s, the amount of money that the government invested in public-private partnership projects rose throughout the 1980s and 1990s.

One such project was the Thin Film PV Partnership, managed by the DOE-funded National Renewable Energy Laboratory (NREL), which conducted joint research projects with private firms to increase thin film cell efficiency. The first subcontract in the Thin Film PV Partnership was awarded in 1991 to Solar Cells Inc., a small start-up firm that would later become PV giant First Solar, today's leading thin film PV manufacturer.

As a direct result of government involvement in solar PV development, 13 of the 14 top innovations in PV over the past three decades were developed with the help of federal dollars, nine of which were fully funded by the public sector. America's decades of public support have both facilitated the emergence of private sector success stories like First Solar, while encouraging the critical solar R&D that helped to dramatically drive down the costs of solar cells.

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SPOTLIGHT

Printable Solar Cells

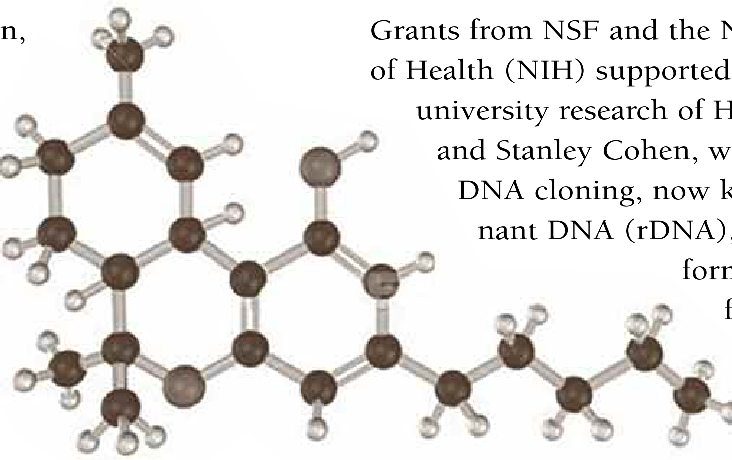
Nanosolar is a leading Silicon Valley photovoltaic firm that has helped to push forward a new wave of solar technologies that could revolutionize the industry. It is particularly well-known for its roll-printed thin-film solar cells which have dramatically lowered costs and improved efficiency of producing solar cells.

Founded in 2001, Nanosolar has worked on both civilian and military technologies, and its technological breakthroughs have been intertwined with support from federal and state agencies. In 2002, Nanosolar received $1 million from the Air Force. In 2003, Nanosolar was awarded funding from both the National Science Foundation and the California Energy Commission. In 2004, DARPA (the Defense Advanced Research Projects Agency) awarded Nanosolar a $10.3 million contract to develop solar cells. Separately, a Phase I and Phase II Small Business Innovation Research (SBIR) grant through DARPA awarded in 2004 and 2005 helped to improve the manufacturing processes for Nanosolar's printable solar cells. Another SBIR grant in 2006/2007 – this time from the Department of Energy (DOE) – supported Nanosolar's efforts to improve the efficiency of its printing process. The DOE, in total, awarded nearly $20 million of funding to Nanosolar through grants or contracts made through the SBIR program, the National Renewable Energy Laboratory, and the Solar American Initiative.

The firm has also collaborated with Stanford University, Sandia National Laboratory and Lawrence Berkeley National Laboratory, among others, in the development of its technologies.

This section excerpted and adapted, with permission from the authors, from Keller, Mathew R. and Fred Block (2008). "Hidden Success Stories: Highlights of Federally Supported Innovations." University of California Davis.

RECOMBINING *for* THE CURE
BIOTECH



What do Epogen, Neupogen, and Rituxan have in common? They are all blockbuster biotechnology drugs that netted their manufacturers, Amgen and Genentech, a combined $10 billion in 2009—and they were all made possible by federal investment in recombinant DNA technology.

The traditional story of the development of these drugs is one of scientific discovery, followed by those discoveries being exploited by entrepreneurs in the private sector and translated into new commercial drugs motivated by the pursuit of profit in the free marketplace. Absent from the traditional account, however, is the instrumental role that the federal government played in developing the modern biotech industry.

The biotechnology industry has its origins in decisions made by President Richard Nixon in 1969, to convert the nation's well-funded biological weapons program into a bio-medical research effort. Worried about the United States' competitive position in biological sciences relative to rivals like the Soviet Union and Japan, Nixon made a strategic decision to expand non-military research funding and diversify research efforts through universities and non-military agencies like the National Science Foundation (NSF).

Grants from NSF and the National Institutes of Health (NIH) supported the pioneering university research of Herbert Boyer and Stanley Cohen, who invented DNA cloning, now known as recombinant DNA (rDNA), a process that formed the technical foundation of the modern biotech industry. Recombinant DNA gave scientists an unprecedented degree of control over genetic material, allowing them to modify and augment existing genes to create new molecular entities (MNE's) with potentially large medicinal benefits.

By 1976—the same year that Boyer founded Genentech—NIH was funding 123 biotech-related projects. NIH officials viewed rDNA techniques as likely to yield progress in the fight to cure cancer, and by 1987 the federal agency invested more than $100 million toward new cancer research. Encouraged by robust federal support, academic scientists as well as biotech and pharmaceutical companies viewed molecular biological research as the "research line of choice," spurring growing private sector investments in the new field.

Under Presidents Jimmy Carter and Ronald Reagan, the government also worked to accelerate private sector commercialization of new biotech discoveries by enacting a number of important pieces of legislation.

Federal investment in recombinant DNA technology over the last four decades helped build a multi-billion U.S. biotechnology industry

The 1980 Bayh-Dole Act enabled scientists, universities, and corporations receiving federal research grants to patent and license their discoveries for the first time, encouraging stronger university-industry relations. Also passed in 1980, the Stevenson-Wydler Technology Innovation Act greatly encouraged the transfer of scientific discoveries made in university or government laboratories to the private sector. The law mandated the creation of technology transfer offices at all federal agencies to establish intellectual property rights and provide incentives for commercially relevant research. The Federal Technology Transfer Act of 1986 authorized cooperative research and development agreements (CRADAs) between industry and government, allowing commercial firms to draw on the unique resources of federal laboratories. These and other policies accelerated the development and commercialization of new innovations in biotechnology, along with numerous other sectors.

Since the 1980s, the federal commitment to health research has only grown. From 1995 to 2008, under both President Bill Clinton and President George W. Bush, funding for the NIH nearly tripled from $11 billion to $29 billion per year.

The impact of federal funding on the biotechnology industry has been dramatic. Of the fifteen U.S.-developed "blockbuster" biotechnology drugs (those with over $1 billion in annual sales), thirteen received significant government support for drug discovery and development or for clinical trials. For eight of the thirteen drugs, the federal government either funded research conducted in university labs, or NIH scientists made the key discoveries in government labs. These blockbuster drugs, in turn, have shaped the market position of world-class biotech firms.

It is not an exaggeration to say that the world-leading U.S. biotech industry would not have taken root without an active and robust partnership between the private sector and the federal government. Beyond the field of medicine, government investment in biotechnology has also made possible advances in agricultural production and tailored organisms enabling new industrial processes, and continues to push the limits on biotechnological innovation.

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