Case Studies in American Innovation

A New Look at Government Involvement in Technological Development

The Breakthrough Institute

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Introduction

"It is not an exaggeration to claim that the future of human prosperity depends on how successfully we tackle the two central energy challenges facing us today: securing the supply of reliable and affordable energy; and effecting a rapid transformation to a low-carbon, efficient and environmentally benign system of energy supply."

-International Energy Agency (*World Energy Outlook 2008*)

Summary

Technology is a cornerstone of American prosperity, the primary source of our economic competitiveness, and a constant presence in our everyday lives. From the 19th century's advances in manufacturing and transportation to today's cutting-edge developments in biotechnology and computer science, Americans have been world leaders in creating, producing, and deploying innovative technology. Nobel Laureate Robert Solow's classic 1956 economic model of productivity growth demonstrated that technological progress drove at least 80% of economic growth in the United States between 1909 to 1949[1], and innovation continues to be perhaps the most powerful engine of our prosperity.

Today, America and the world are in energy crisis. Energy prices are escalating, foreign energy dependency is increasing, global warming continues unabated, and all across the world there are billions of people who continue to live without access to energy. The single greatest solution to these crises is to once again harness America's forces of innovation to make clean energy technology both cheap and abundant.

But to harness this solution we must take a new look at the process of innovation and determine the best mechanisms to catalyze and accelerate technology development. This requires looking beyond both the mythos of the lone American inventor and the market fundamentalist ideology that has dominated American politics in recent decades. Instead, we must look closely at several key American technologies and unearth the historic and seemingly ubiquitous government investments that fueled their development.

This document therefore presents seven historic case studies of American innovation, ranging from the rise of railroads and commercial flight to more recent developments in personal computing and the Internet. It also presents three shorter case studies spotlighting recent developments in energy technology and two international examples of public-sector support for clean energy development. In each example, government support was critical at one or more stages in the development and deployment of these technologies, many of which Americans now take for granted as constant facets of their everyday lives.

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[1] Solow, Robert M. (1956). "A Contribution to the Theory of Economic Growth". *Quarterly Journal of Economics* 70 (1): 65–94; and Solow, Robert M. (1957). "Technical Change and the Aggregate Production Function". *Review of Economics and Statistics* 3 (3): 312–320. Solow received the 1987 Nobel Prize in Economics for his work on his model of economic productivity and growth.

Myths, Facts, and Today's Energy Innovation Challenge

The energy supplies of America and the world are currently dominated by outdated and dirty technologies - chief among them the combustion of coal and oil using technologies initially developed in the 19th century.

The environmental consequences of this dependence on fossil fuels are well known; burning these fuels is the leading cause of greenhouse gas emissions and air pollution, leading to global warming and climate destabilization as well as health impacts like asthma.

However, environmental risks are only the tip of the iceberg. Reliance on fossil fuels exposes our economy to volatile energy prices and fosters dependence on a dwindling fuel supply that drives prices ever higher. Rising energy prices act as a dead weight on the American economy and contributed to the current economic crisis. And foreign oil and gas dependency is resulting in the largest wealth transfer in human history, propping up petro-dictatorships and funding the spread of radical Islam.

Meanwhile, from China to Brazil and India to Nigeria, billions of global citizens are hungry for affordable fuels to power their economic development. Without ready alternatives, they too will depend on fossil fuels, exacerbating each of these problems.

It's no wonder the world's chief energy watchdog, the International Energy Agency, considers today's global energy trends "patently unsustainable."[2] From economic, national security, and environmental perspectives alike, our society's addiction to fossil fuels is dangerous and irresponsible. New, clean, affordable and secure energy technologies are needed to replace the aging global energy system and power a sustainable, prosperous, and safe 21st century.

Despite this clear imperative, the energy industry is one of our economy's least innovative sectors, and new energy sources such as wind, solar, biomass, and even nuclear compose a small percentage of total energy production. Bringing clean energy sources to significant scale at affordable prices poses numerous and enormous technological challenges, from the improvement and refinement of existing energy sources to the invention of entirely new technologies.

New public policies are needed to ignite the next era of American innovation and catalyze the rapid development and deployment of critical clean energy technologies. Yet to date, most of the energy and climate policy debate has centered on mechanisms to regulate and price carbon emissions and increase the cost of dirty fuels rather than strategies to promote technological innovation and deployment and drive down the costs of clean energy sources.

Carbon pricing advocates argue that by putting a price on carbon emissions – and in turn making carbon-intensive fuels such as coal and oil more expensive – policies like carbon taxation or carbon "cap-and-trade" will stimulate demand for alternatives to fossil fuels and in turn encourage innovation by the private sector. Carbon pricing thus proposes an elegant solution to

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[2] International Energy Agency (2008). *World Energy Outlook 2008*. <URL: http://www.worldenergyoutlook.org/>.

the innovation challenge: change the price signal, and the gates of innovation will burst open, driving private businesses and entrepreneurs to develop new technologies and industries.

In this account, the government is notably absent from the innovation process. Echoing the market fundamentalist ideology that has dominated the American political right, and indeed much of the mainstream political discourse for the past several decades, carbon pricing advocates often cite the inefficiency and corruption that government intervention supposedly entails. They accordingly argue that the state should only set carbon prices and 'let the market work.'

The carbon pricing narrative also dovetails neatly with the dominant mythology of American innovation, in which great advances in technology have come through the independent efforts of lone inventors and captains of industry tinkering in garage workshops and private labs. Benjamin Franklin and Alexander Graham Bell, Steve Jobs and Bill Gates – these are the heroes of the American mythos of invention.

These stories of the lone inventor and the garage genius are compelling. Ultimately however, whether spun by history textbooks or proponents of laissez-faire economics, these stories are largely myth. To be sure, proper price signals and the individual genius of American inventors and entrepreneurs are critical to technological development. But behind so many great advances in American technology lies an often-silent and neglected force: public investment.

Technologies ranging from rail transport to nuclear energy and from microchips to the Internet were all invented by government-supported researchers, developed with public funding or first deployed through government purchasing and incentives; likewise, public investments routinely trained the high-caliber human capital or built the enabling infrastructures required for the widespread deployment of many of these technologies. Far from being a hindrance to innovation, the state historically has been one of its greatest drivers, playing a critical role in the development of many of the technologies and industries that now form the bedrock of modern society.

While academics and some policymakers have long realized the importance of government investment in stimulating technological change, such awareness has been conspicuously absent from the mainstream energy and climate debate. This document is meant to reintroduce the importance of public investment to that debate. The case studies that follow offer but a few examples of how government action has directly led to many of the key technologies we take for granted in our modern lives. These case studies demonstrate that strong and targeted government investment can and must play a powerful role in the critical effort to overcome the energy innovation challenge and build a 21st century, clean energy economy.

Case Studies in American Innovation

Uniting a Nation: Railroads

A vintage steam locomotive chugs along the tracks in Sacramento, California. Generous government incentives and high-caliber engineering training programs funded by the United States Army were critical to the expansion of rail in the 19th century, opening the American West to settlers and commerce and uniting a transcontinental nation.

In 1860, settlers embarking on the long journey to the west had to travel by horseback, foot, or covered wagon. This journey of over 2000 miles took at least six months, and disease, starvation, and natural disasters frequently threatened the lives of travelers. By 1870, however, that same journey was quick and safe; it could be completed in just two weeks while sitting aboard a comfortable railroad car.

This revolutionary change transformed America, but it did not occur overnight, nor was it driven by the "invisible hand of the market" alone. It took heavy government involvement to build the physical and human infrastructure needed for the transcontinental railroad. Without government incentives, private companies would never have taken the initiative to lay down the first tracks.

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 merits of developing the nation's transport infrastructure. Private companies were unwilling to begin the project on their own because of the risks associated with such a massive infrastructure investment. To construct a railroad, they would have to push into unsettled territory, land with limited possibilities for agricultural settlement and therefore of uncertain value. In addition, railroad construction and operation practices were not fully developed, transportation systems were crude, and the possibilities of dangerous encounters along the route posed risks developers were simply unwilling to take. Facing these risks and with no incentive of profits from land, a rational financier would do better concentrating on more attractive projects. The transcontinental railroad was a venture that required government backing to be carried out, and to instill sufficient confidence in private investors.

To this end, Congress passed the Pacific Railway Act of 1862, which provided financing for two major private companies to begin the railway's construction. The Union Pacific and Central Pacific railroad companies received the critical capital investment they needed, in the form of government-issued, thirty-year, six percent bonds in the amount of $16,000 per mile of tracked grade, with more given for track laid in the high plains and mountainous areas. The companies also received land grants entitling them to alternating ten-square-mile sections along the route, which they could sell to raise additional funds. The railroad itself and all of its fixtures constituted the collateral for the government loan.

Assured of long-term financing, the competition was on to see which company could 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 the East to the West via rail for the first time.

By that time, the new physical infrastructure of the nation's transportation system was largely complete, but it could not be sustained without a highly trained workforce as well. Fortunately, the government had strategically targeted policies to support engineering science from the beginning of the 19th century in order to spur economic development. In fact, the majority of the expert surveyors and engineers in the United States were Army engineers, schooled at the United States Military Academy at West Point. After the construction of the transcontinental railroad, these engineers were supplied by the government to survey and oversee new railway construction as projects multiplied across the nation. A study conducted in 1867 found that of 2,218 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 completion of the transcontinental railroad meant that trade, commerce, and travel could happen at a pace previously unimagined. The rapid shipment of goods allowed cities like Chicago to become trading hubs and new marketplaces for corn, wheat and lumber. Because of the efficiency of the railroad, cities like St. Louis that still depended on steamboats were surpassed economically. 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 United States government enabled the construction of the transcontinental railroad and catalyzed a new era of economic growth.

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From Kitty Hawk to Boeing Field: the Aviation Industry

The Wright Flyer on display in the National Air and Space Museum. 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.

American names like Samuel Langley and the Wright brothers loom large in the history of early flight. But just a few years after Kitty Hawk, America was already lagging behind other nations in the mastery of aviation. European governments poured resources into aeronautics over the early 20th century, compelled by the military needs of the First World War. In 1913, America ranked 14th in government spending on aircraft development, languishing in the company of Brazil and Denmark. Even as Britain, France and Germany made leaps and bounds in aviation design, Langley's “Aerodrome” lay dusty and abandoned in a Smithsonian lab.

By mid-century, however, the U.S. was well on its way to restoring its place at the forefront of civil and military aviation. U.S. factories were churning out better planes, ever faster and cheaper, and American researchers were pioneering radical improvements in aircraft design. Government involvement, from research support to deployment initiatives, was the critical catalyst for this remarkable turnaround, laying the foundations for America's modern aviation industry.

The first step toward America's success came in the form of an unassuming piece of legislation, tacked onto the Naval Appropriation Bill of 1915, which quietly established the National Advisory Committee for Aeronautics (NACA), America's first government aviation initiative. With NACA, the government was finally taking the nascent aviation industry – and its vast potential in the commercial and military sectors – seriously. The new agency quickly set about performing the vital research and development that no individual firm could accomplish alone. Its first major accomplishment was the construction of a sophisticated wind tunnel, to be used in testing various shapes for wings and propellers. By systematically testing and observing many shapes and designs, NACA achieved significant breakthroughs that helped restore America's expertise in technically advanced aeronautics. Among these was the NACA cowling, an engine improvement that reduced drag and turbulence and saved huge amounts of fuel. Within only five years, it was standard equipment on every new plane produced. Another significant achievement was the NACA airfoil program, which tested and documented numerous wing designs to be matched with planes of different sizes.

Meanwhile, government demand, beginning during the First World War, gave airplane manufacturers a major boost at a time when private interest in their products was lacking. In 1916, American firms produced 411 planes in total. But in nine months between 1917 and 1918, domestic factories churned out over 12,000 airplanes and nearly 42,000 engines. Production fell 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, and equally importantly, nurtured the emerging companies of the American aviation industry. Among the companies sustained by government contracts was a little-known manufacturer called Boeing.

The technical advances stimulated by government support were significant achievements on their own, but they also complimented the efforts of the private sector. For example, Douglas' DC-3, developed privately in the 1930s, 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 been revived and dramatically expanded, in large part through the timely actions of the federal government, and the foundations of today's massive aviation industry had been laid. The early history of American aviation shows the crucial role that government support can and must play in ensuring the success of nascent industries of national interest.

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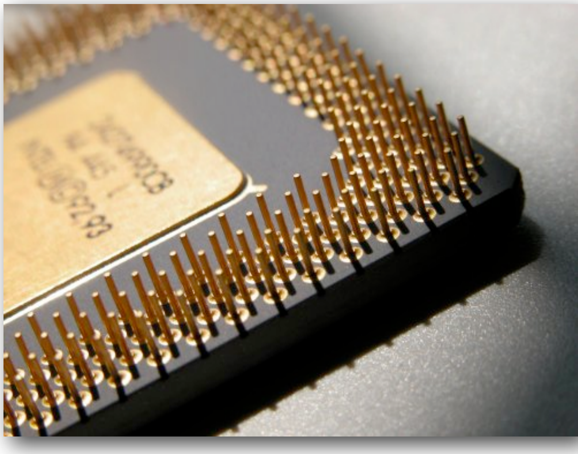
The Semiconductor Revolution: Microchips



A modern microprocessor. 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!

In 1958, a truly groundbreaking idea was finally realized in the laboratories of Texas Instruments (TI). For years prior, engineers had struggled to design circuits that could drive the increasingly sophisticated electronics of the time. Complex electronic processes required circuits involving many transistors, which had to be painstakingly soldered together, and the connections were unreliable and difficult to produce.

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 all the transistors in a circuit, as well as their connections, out of a single piece of material. In the late summer of 1958, 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. But the future of the microchip was by no means certain. It took the buying power of the U.S. government to make the microchip into a mass-produced, affordable and ubiquitous piece of technology.

In the early 1960s, computers were already becoming common; many private firms used massive mainframe computers to keep track of customers and assets. But the demand for sheer computing power – and, in turn, for microchips – was greatest among government agencies. Within a few years of the first microchip patents, these agencies were buying hundreds of thousands of chips a year. Throughout the early 1960's, the federal government bought virtually every microchip firms could produce.

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 wasn't the only player in this game. NASA, deep into planning for the Apollo Project, needed advanced circuits for the Saturn rocket's onboard guidance computer. Microchips promised unparalleled computing power at a small size, but they were unproven in the marketplace and had never been produced on a large scale. Nonetheless, Eldon Hall, a NASA official, decided to take a risk on the promising new technology. 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 – so much so, in fact, that the price of the Apollo microchip fell from $1000 per unit to between $20 and $30 per unit in the span of a couple years.

The government's insatiable demand for microchips rapidly and massively expanded manufacturing capacity and industrial expertise during the 1960's, paving the way for cheap, mass-produced microchips that could be sold to businesses and ordinary Americans. Public procurement single-handedly kick-started the microchip industry and set the digital era in motion.

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Silicon Valley Garage or Government Lab: Personal Computing

An antique Apple II, one of the first commercial personal computers. 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.

The legend of the personal computer (PC), as it's normally told, emphasizes individual brilliance and initiative. The origins of today's industry titans like Microsoft and Apple are surrounded by romantic images of college dropouts tinkering away in garage workshops. This story is one of independence, of genius allowed to run free and inventions flourishing in the open market. Of course, the government is conspicuously absent here; as Bill Gates has said, "the amazing thing is that all this happened without any government involvement."

The PC legend may be compelling, but like all legends, it has more to do with fiction than fact. While the role of individual innovators can hardly be understated, the active involvement of the federal government – especially the military – 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.

From the beginnings of the computer industry, federal and military agencies promoted vital basic research into computing hardware and deployed early computers throughout the government. As 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." 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 Atmosphere Research, and the U.S. Weather Bureau commissioned their own supercomputers soon after. 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.

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. The defense establishment took computing seriously. 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 the 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 Palo Alto Research Center (PARC), the famous computer research center, 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.

No less important, however, were the innumerable programmers, system designers, and computer theorists who cut their teeth and honed their skills 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, and later scattered to run startup firms like Apple, Microsoft, and Adobe.

Popular myths about the rise of the PC make little mention of the government, but 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

The ubiquitous World Wide Web now enables instantaneous communications connecting the far corners of the world. While former Vice President Al Gore **didn't** ***invent it, the United States government*** **was** ***responsible for the core innovations and key technologies that become known as the Internet.***

These days, the Internet seems like an indispensable aspect of daily life. The ubiquitous World Wide Web is taken for granted by most Americans and most people pay little attention to its origin. Commercialized relatively recently, this remarkable network of computers has transformed the world. But where did the Internet come from? While former Vice President Al Gore didn't invent the Internet, it *was* the United States government that was responsible for the core innovations that became known as the Internet, and it was the U.S. military that funded the demonstration of key technologies crucial to its development.

The origins of the Internet lie in the 1950s space race and the national defense concerns surrounding this race to control the skies. 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 into 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 their communications systems. 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, if the Soviet Union were to attack one of the SAGE sites, the military could potentially be rendered deaf and dumb, unable to regroup and respond. ARPA needed to create a more flexible communications network that was sophisticated enough to survive an attack upon a central location.

To meet this challenge, ARPA knew that it had to appeal to the top minds in the country, and it did so by seeking out and funding important research at top American universities. ARPA targeted individuals in the private sector who could help them create a communications network of multiple computer systems. J.C.R Licklider, a professor at MIT, was hired in 1962 as a 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, so that humans could devote more of their time to the 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 neighboring 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 turned down the offer. The company had been doing well 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 their business. So ARPA instead employed the small, Cambridge, MA based firm Bolt, Beranek and Newman to create the computers and the communications network that would support it.

The company completed the basic elements of an Internet system in nine months, and the beginnings of "ARPANET" took shape. The first ARPANET connection was successfully demonstrated in October 1969 when an AT&T telephone connection was used to connect two computers, one located at the University of California, Los Angeles, the other at the Stanford Research Institute. By 1971, 15 sites had been linked. In 1972, the Internet was demonstrated at the International Conference on Computer Communication, where skeptics were converted 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 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, 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: 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, and forged links between university researchers, federal laboratories, and private sector partners in working toward specific technology targets. Less than a decade later, and building on innovations developed through the program, General Electric unveiled its GE H System Turbine, which effectively reduced carbon dioxide emissions and broke the existing temperature barrier for gas turbines - setting, in the process, a new world record for turbine efficiency. The H System relies upon a number of innovative heat resistant parts developed through the DOE program and drew upon ATS financial support in its research and development processes. 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.

For more information see:
http://fossil.energy.gov/programs/powersystems/turbines/turbines_successes.html
http://fossil.energy.gov/programs/powersystems/publications/Brochures/Advancedturbinesystems.pdf
http://www.gepower.com/about/press/en/2007_press/091007.htm

Atoms for Peace: Nuclear Power

The massive cooling tower of a nuclear power plant built by the Tennessee Valley Authority in Tennessee. 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.

Years of frantic research and development in atomic science culminated in 1945 with the nuclear bombing of Hiroshima and Nagasaki. In the aftermath of the devastating bombings, nuclear energy could easily have been considered a scourge, a wholly destructive force irrevocably unleashed upon the world. Yet a few short years later, President Eisenhower stood before the United Nations and delivered his famed "Atoms for Peace" speech, outlining his vision of a future where nuclear fission was a force for good and a source of abundant energy.

Today, Eisenhower's speech seems overly optimistic. Atomic energy has failed to live up to the wild expectations of that era, and its spread has not been without problems. Nuclear power continues to face significant risks related to operational safety, waste disposal, proliferation of nuclear weapons, and increasing cost. However, nuclear plants have also successfully supplied massive amounts of carbon-free, reliable energy for decades, and nuclear power is the only significant new energy source pioneered and widely deployed in the latter half of the 20th century. Nuclear energy has not met the wild expectations of Eisenhower and its other early supporters, nor has it become the debacle imagined by its critics in the environmental and nonproliferation communities.

Leaving such debate behind, however, it is important to note the development of nuclear energy represents an indisputable technological feat. This feat was primarily accomplished by the federal government, ensuring that a piece of Eisenhower's vision would be realized. Through publicly funded research, demonstration, and deployment, nuclear energy has become a key source of emissions-free American energy.

America's nuclear power industry has its origins in the Manhattan Project, the famous World War II atomic research project. In 1941, President Roosevelt, aware of Germany's ongoing efforts to develop nuclear weapons, authorized an all-out effort to control nuclear fission and incorporate it into armaments. The federal initiative was quick to bear fruit. In December 1942, an Armybacked research team achieved controlled nuclear fission in a University of Chicago squash court. It was the first such demonstration in the world's history.

From 1942 to 1945, the U.S. 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, as well as research centers at several American universities, and funded labs and production facilities from coast to coast. This massive government effort paid off within three years, with the detonation of the first nuclear bomb at a New Mexico test site in July 1945.

Yet America’s investments in nuclear technology were far from over. Eisenhower’s Atoms for Peace address in 1953 and the 1954 Atomic Energy Act (AEA) committed the US to develop peaceful uses of 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 Pressurized Water Reactor, developed at Oak Ridge National Laboratory and currently in use throughout the world.

Furthermore, realizing 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 by 1973. Today, these plants generate nearly 20% 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. 435 nuclear plants are currently in operation worldwide – all based on technologies invented, developed, and deployed through government-supported initiatives.

To be sure, the world's experience with nuclear energy has been mixed. The Chernobyl disaster and the partial meltdown at Pennsylvania’s Three Mile Island loom large, proliferation of fissile materials remains a danger, and the costs of new nuclear power plants are high. Perhaps most importantly, long-term solutions for the storage and disposal of nuclear waste are sorely lacking. But despite its problems, 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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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 electricity 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.

For more information see:
http://www.nanosolar.com
http://www.darpa.mil/sbir/pdf_files/Nanosolar_09_05_07.pdf
http://www.nanosolar.com/pr10.htm

Myth and Reality: Synthetic Fuels

Oil drums await shipment. In 1980, the U.S. government launched the Synthetic Fuels Corporation to develop alternative fuels from coal and oil shale. This failed endeavor is often cited as evidence against the meddling of government in technology deployment. The truth, as usual, is more complicated, and the story of the Synthetic Fuels Corporation offers many lessons for future public efforts to develop new energy technologies.

When the topic of federal energy investment arises, those of a certain age may recall the last large-scale publicly funded push for alternative energy – the Synthetic Fuels Corporation (SFC). Established in 1980, the SFC was Congress' attempt to develop significant alternative domestic fuel production in light of the Arab oil embargoes of 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 conventional wisdom of the failure of government involvement in synfuels is overly reductive. The many pitfalls of the SFC provide clear lessons for future public efforts to develop energy technologies.

The chief lesson of the U.S. synfuels experience is that an investment regime must be sufficiently independent from the vagaries of the market. The SFC was created as a reaction to the rising price of oil, and its fortune was economically and politically tied to oil prices throughout its short existence. The SFC explicitly aimed to produce fuels that could compete with gasoline in the marketplace in the near term, based on models that projected continuously rising gasoline prices and a comparatively modest price for synfuel production. In turn, rigid production quotas and targets were established based on these projections. Over the next few years, however, the price of oil declined substantially, ensuring that SFC-developed synfuels would never become price competitive and that demand would never expand to drive increased production – and lower production costs – dooming the initiative. By relying on short-term market trends to support its product, rather than consistent, government-supported demand, the SFC was set up for failure.

However, the same market trends that undermined the success of the SFC—the price of oil—were the very political impetus for its creation. Political attitudes towards the Corporation fluctuated with oil prices, and as prices fell so did the apparent utility of supporting the corporation. And, despite the partial independence of the SFC from the federal government, decision-making was still subject to considerable political influence. Congress interfered substantially in the selection and management of R&D projects and deployment schemes. For example, fuel cell development projects were allocated to all fifty states, rather than to those with the greatest deployment potential or research base.

To make matters worse, the SFC was extremely inflexible, as it was built around a progressively expanding series of production targets. The mandate to fulfill these targets – even in the face of unfavorable market conditions, and regardless of technological progress or other variables – constrained research efforts and short-term planning. A maze of regulation hindered the implementation of many projects.

However, despite its clear shortcomings, there is another side to the synfuels story, one ignored by those who raise the specter of the SFC to admonish proposals for government involvement in energy technology development. In fact, the U.S. synfuels experiment did make major technological contributions, both planned and unexpected. The SFC did succeed 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. The fact that the price of oil collapsed in the late 1980s and 1990s should not discredit the technological achievements of the SFC project. In addition, North Dakota's Great Plains chemical plant, built with government funds in the early 1980's, was a key demonstration of both coal gasification technology and large-scale carbon capture and storage – both technologies that are now the subject of great interest as concerns about climate change mount.

While producing synthetic liquid fuels from coal may no longer be in the national interest, due to its potentially large contribution to global warming pollution, we cannot ignore the significant technological developments made by the SFC in both coal liquefaction and carbon capture and storage – technologies which, not incidentally, have seen little advancement in the twenty plus years since the dissolution of the SFC.

Furthermore, the SFC's mistakes need not be repeated in a contemporary investment regime. Rather than embracing monolithic production targets, a new energy initiative should focus on a diverse suite of policies that together are relatively robust to short- and medium-term market fluctuations. New technology development programs should be given a flexible mandate to drive down production prices through the most effective means available, including basic and applied research, flexible, indirect incentives to the private sector, and direct public procurement programs. In addition, any new initiative should be rooted in truly independent structures, in the tradition of existing, semi-autonomous agencies such as DARPA or the Federal Reserve Bank, and should delegate substantial discretion to “street-level” researchers and program directors. Decisions at all levels should be made on the basis of scientific and practical merit rather than political expediency.

The story of America's synfuels experiment illustrates both the need for smart technology development policy and the perils of reducing historic precedent to politically expedient myth. With the right structures and strategies in place, government involvement can indeed spur the development of new technologies critical to the national interest.

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International Examples

Inheriting the Wind: Danish Wind Power

Wind turbines, like those deployed across Denmark. Since 1979, the Danish government, through intelligent, sustained public investment, has mobilized the nation in the development of next-generation wind energy. Today, a third of all wind turbines produced in the world are made by Danish firms, and wind power provides twenty percent of the nation's electricity.

At the mouth of Copenhagen harbor, twenty giant wind turbines, arranged in a graceful arc, turn in the coastal breeze. This is Middelgrunden, Denmark's first cooperative wind farm and a symbol of that tiny country's impressive wind energy industry. Middelgrunden's turbines, installed in the late 1990s, were designed by Danish engineers, built and installed by Danish technicians, and generate enough electricity to power 40,000 Danish homes. Perhaps most impressively, the project is owned by over 8,500 cooperative members who share the profits of clean energy generation.

Middelgrunden is a result of Denmark's long and successful collaboration between private industry, individual citizens and, most importantly, strong government support. Since 1979, the Danish government, through intelligent, sustained investment, has mobilized the nation in the development of next-generation wind energy, and the results have been impressive. Today, Danish firms account for one third of the global wind power market and have driven the creation of a booming multi-billion dollar industry. In Denmark alone, 6,300 wind turbines pump energy into the regional grid today, providing roughly twenty percent of the nation's electricity. Wind power accounts for some 25,000 Danish jobs, and in 2007, the industry exported 4.7 billion euros worth of energy technology. Without a doubt, government involvement in the wind sector enabled this Danish success story.

Denmark unlocked the energy and capital of its private citizens through strong, consistent market incentives. From 1979 to 1989, the Danish government covered 30 percent of wind investment costs, and later implemented loan guarantees for large turbine export projects. It also guaranteed the domestic wind market by mandating that utilities purchase all generated wind energy at a consistent, above-market price. These market guarantees and subsidies, along with significant tax breaks for wind-generated electricity, promoted rapid deployment and technological innovation, as firms competed to capture the profits to be made from wind energy with the most efficient and cost-effective technologies. Financial incentives also drew ordinary citizens into the wind energy economy, including the members of Middelgrunden and other wind cooperatives, who were attracted by income from shares in wind cooperatives, made tax-free by the Danish government.

The government also provided strong research support for the wind industry. Middelgrunden's turbines, and innumerable others, follow the guidelines set by the government's Risø research center, a global leader in wind energy technology. Risø introduced innovative standards for wind turbines and pioneered a host of technologies relating to the exploration and exploitation of wind resources. Together with the "learning by doing" benefits of mass deployment, these advances have allowed wind turbines to become more durable, more efficient, and dramatically cheaper, and helped private firms in Denmark and abroad move from small turbines to today's multi-megawatt giants – helping Denmark's firms capture a sizable share of global wind energy markets in the process.

Danish citizens and government regulators have been vital in turbine development. Close links between researchers and regulators ensure that government technology standards are well attuned to the latest technology. And earlier in the industry's history, Danish wind turbine owners provided vital feedback on the reliability and productivity of early machines, boosting confidence in Danish firms and stimulating demand. Today, ordinary Danes like the builders, shareholders and customers of Middelgrunden are a driving force behind the wind energy economy, both politically and economically. In fact, over 80 percent of Denmark's turbines are owned by more than 150,000 Danish families organized in cooperatives.

The thriving firms, research centers, cooperatives, and turbine owners of the Danish wind industry are proof that strong, smart government investment in young technologies can lead to big results. Denmark's wind energy success is a model for governments around the world.

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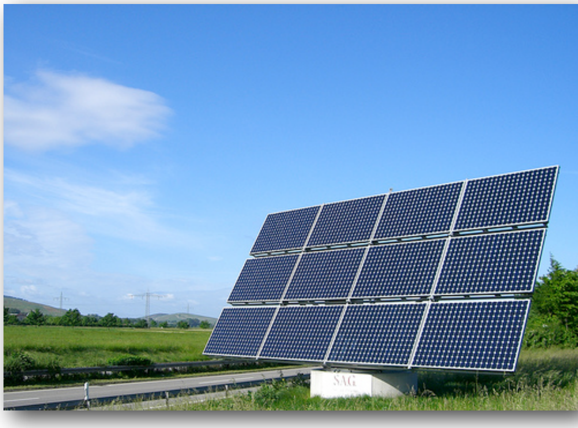
Soaking Up the Sun: Solar Power in Germany and Japan



A solar array installed along a highway near Freiburg, Germany. Japan and Germany, two somewhat unlikely nations, are now world leaders in solar energy installations and are home to booming domestic solar industries. The secret of their success: sustained public investments in both the development and deployment of solar energy technology. Each nation took a distinct path, and lessons can be learned from both.

Two distinct paths led two very different nations—Germany and Japan—to become global leaders in the production and installation of solar photovoltaic technology. Motivated variously by concerns over security, health, climate change and high energy prices, these nations are now home to robust and growing solar industries and solar panels can be found on hundreds of thousands of rooftops across these nations. However, differences in the public policies employed by each nation led to different results: Germany's solar industry is still dependent on subsidized power production costs, while Japan's investments to drive down the costs of solar energy have successfully created a domestic industry that has been independent of federal subsidies since 2005.

In the 1970s, Germans were faced with soaring energy prices. Successive oil crises had sent price shocks throughout Europe, while heightening energy security concerns. In the next two decades, increasing pollution and the Chernobyl nuclear disaster made the environment a central concern for the German public. Thus, it was no surprise when, in 1998, Germany's Green Party won enough votes to form a coalition with the Social Democratic Party and gain control of parliament. Meanwhile, global warming presented a moral imperative that demanded international cooperation. Under the resulting Kyoto Protocol, Germany committed to a 21% reduction in emissions from 1990 levels by 2012.

All this marked the beginning of a massive government investment in renewable energy deployment, particularly solar photovoltaics. To surmount the myriad challenges to emissions reductions, the government invested in a new industry that would establish Germany as a global leader in clean energy technology.

The German solar photovoltaic (PV) industry began with the passage of the "1000 roofs program" in 1991, in which the government gave subsidies to individuals to cover the cost of installing a PV rooftop system. The aims of the program were to gain experience with solar installations, make new housing compatible with renewable electricity generation needs, and stimulate consumer usage of solar power. By the mid 1990s, 2,000 grid-connected PV systems had been installed on the Germany's rooftops.

This successful initiative soon expanded into the 100,000 roofs program to drive further expansion of the industry. The program aimed to drive down the price of solar PV and invited private entities to participate. Each participant was given a loan of 6,230 euros per kilowatt (peak) for PV systems with an output less than five megawatts and 3,115 euros per kilowatt if the output was higher. The program ended after 2004, with the successful installation of 100,000 grid-connected rooftop solar systems. By its end, Germany's solar PV industry had moved beyond niche markets to become capable of mass manufacture.

The German government also supported the nascent solar industry and the solar roofs programs by establishing a policy known as a feed-in tariff. The feed-in tariff guarantees a higher-than-market price for electricity generated by solar PV which is fixed for 20 years beyond the installation date, providing investment certainty for firms and individuals. The tariff, a component of the country's renewable energy law, has been a part Germany's energy policy since 1991 and continues to this day.

In 2000, with the demonstrated success of the 100,000 roofs program, the new government increased the feed-in tariff rates for solar PV. Part of the updated tariff, however, was a 5% decrease each year in reimbursement for newly installed systems, providing a clear incentive for the solar industry to develop more cost effective panels.

Meanwhile, in Japan, the Ministry of Economy, Trade and Industry (METI) in 1993 embarked on the New Sunshine Project, an effort to create a Japanese solar photovoltaic industry and a domestic market for solar power. Through a series of publicly funded and coordinated research, development, demonstration and deployment ventures, Japan has taken great strides in manufacturing and driving down the costs of reliable photovoltaics.

A combination of public concern for global warming as well as the high price of energy in Japan —the country imports nearly 85 percent of its coal—have made a national priority of solar PV. Various initiatives and projects focused on growing Japan's solar industry and capacity have come out of METI, including the aforementioned New Sunshine Project, as well as the "5-Year Plan for Photovoltaic Power Generation Technology Research and Development," and the "Residential PV System Dissemination Program."

METIs coordinated effort to grow both industrial capacity and consumer demand has been incredibly effective, installing rooftop PV systems on nearly half a million homes, while driving down the costs of solar power. In 1994, installing a rooftop PV system on a residential home cost $60,000 (in 2007 dollars). By 2005, installations costs had dropped to $20,000, making solar photovoltaics competitive with domestic electricity rates in Japan. Soon after, Japan ended federal subsidies for rooftop systems. In addition, Japan is now home to several of the world's top solar companies.

Their success can be attributed to Japan's embrace of coordinated public investment in each stage of the solar technology innovation pipeline, including not just funding for research and development, but also demonstration and early-stage deployment efforts. These efforts to support the demonstration and early-stage deployment of solar photovoltaics ensured a market for the emerging technology; without these policies photovoltaics would have faltered before reaching costs that were competitive with market electricity rates.

As a result of strategic public investments, Germany's solar PV industry is booming. Germany is the world's leader in solar PV installation and manufacturing and German firms make up 46% of the global market, generating over 10,000 jobs for the German workforce. However, the feed-in tariff has been at the core of the industry's success and continues to be a key driver of solar installations in Germany. Japan, on the other hand, has successfully implemented a suite of policies that have made solar photovoltaics competitive with domestic electricity rates and has stopped subsidizing solar. While METI still plays a robust role in research and development of next generation photovoltaic technologies, the Japanese solar industry is still growing and the government now seems on track to reach the its goal of bringing solar power to 30 percent of Japan's rooftops without further direct subsidies for deployment.

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Spotlight: New Efficient Appliances

Through its Buildings Energy Program, the Department of Energy (DOE) has supported a host of energy efficient technologies. In one such endeavor, a DOE supported collaboration between private firms and the Oak Ridge National Laboratory generated a new, more reliable generation of heat pump water heaters for residential use that far outstrip the efficiency of electrical water heaters. By improving the lifespan of the Heat Pump Water Heaters and reducing the need for specialized repair when the unit breaks down, the DOE collaboration has helped to lower cost barriers and reduced the need for specialized maintenance, thus fostering their broader adoption in the market. As political scientist Linda Weiss has written: "Other successful federally sponsored demonstrations have led to the introduction of a high-efficiency refrigerator-freezer, to improved solid state lighting ballasts, to advanced oil burners, and to an advanced motorcompressor for refrigeration."

For more information see:
http://www1.eere.energy.gov/buildings/technologies.html
Linda Weiss, "Crossing the Divide: From Military-Industrial to the Development-Procurement Complex." Working Paper #3, *Project on Innovation*, Institute for Governmental Affairs, UC Davis (1 December 2008)

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