Biological Innovation: Benefits of Federal Investments in Biology

American Institute of Biological Sciences

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“Biological Innovation: Benefits of Federal Investments in Biology”
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"As never before, advances in biological sciences hold tremendous promise for surmounting many of the major challenges confronting the United States and the world. Historically, major advances in science have provided solutions to economic and social challenges... Scientific efforts based on meeting societal needs have laid the foundation for countless new products, industries, even entire economic sectors that were unimagined when the work began."

Dr. Thomas Connelly, Chief Innovation Officer for Dupont
Dr. Phillip Sharp, professor at the Massachusetts Institute of Technology and Nobel laureate

For centuries, scientific innovation has led to major improvements in our quality of life. From the discovery of the lifesaving properties of penicillin to sequencing the human genome, our ability to improve people's health, food security, and environment is constantly improving. Such advances are the result of significant efforts by biologists to better our understanding of life in all of its diverse forms.

Expanding our knowledge of cells, tissues, organisms, and ecosystems is not just an academic exercise. Biological research is essential to our national interests. Food security, public health, biosecurity, and natural resources management all rely heavily on biological knowledge.

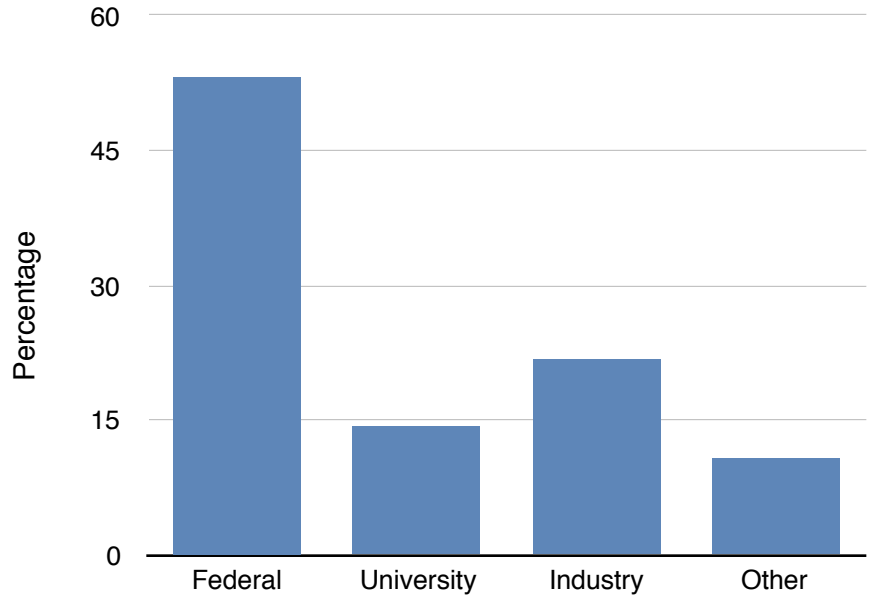
Economic growth is also fueled by such research. **Over the past 50 years, roughly half of the economic growth at private businesses has been due to advances in knowledge resulting from research and development.**[1]

Science has also been a fertile ground for job creation. Since 1960, **growth in U.S. employment in science and engineering has outpaced growth in total employment, increasing by an average rate of 3 percent per year.**[2] Scientifically skilled workers were also half as likely to be unemployed as the rest of the U.S. workforce during the recent recession.[3]

In addition, research provides training opportunities for the next generation of skilled workers. Research experience builds analytical skills that students can apply in future careers in science or other fields.

Although the broad spectrum of scientific activities yields dividends, basic research is the most powerful economic engine. The innovation pipeline is comprised of multiple stages of research and development. Basic research expands our knowledge and understanding of fundamental aspects of matter, living organisms, and our planet. Although basic research is not conducted with a specific commercial outcome in mind, it is the basis of applied research and ultimately the development of new technologies and products. This is demonstrated by the fact that in the last decade, **80,000 U.S. patents were based on the results of basic research originally sponsored by the National Science Foundation.**[4]

Sources of Basic Research Funding in the U.S.[5]



The federal government is the main supporter of basic research in the United States, providing more than half of funding, with additional support coming from academic institutions and private industry.[5] Given the unpredictable nature of early exploratory research, industry invests twice as much on applied versus basic research.[6] Myriad as the benefits of basic research often are, it falls largely in the purview of public institutions to ensure that those benefits are realized.

Government support of basic biological research is money well spent. Public investments in research yield a positive rate of return economically. For example, each dollar spent on agricultural research returns about $10 worth of economic benefits.[7]

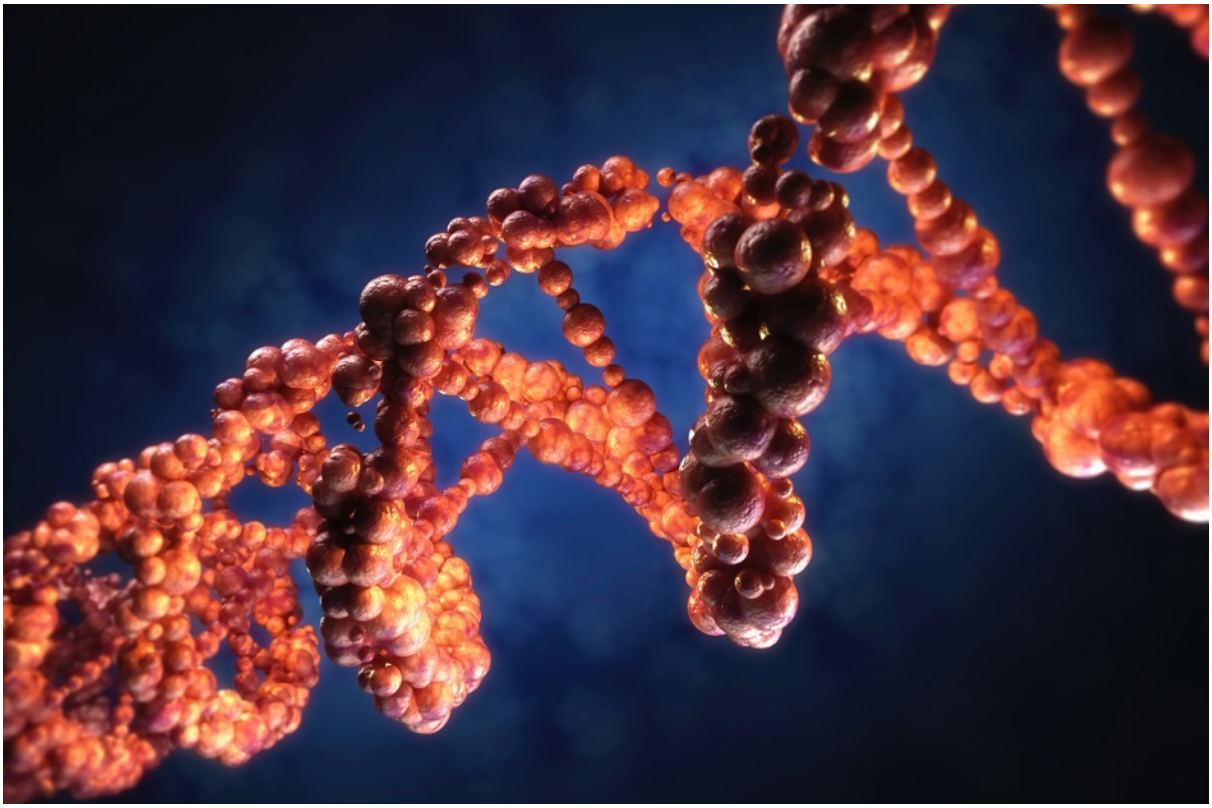
China and other nations recognize the value of supporting science. They are investing aggressively in research and development in order to enhance innovation capacities. The United States cannot afford to do otherwise.

Sustained federal support for scientific research, particularly basic research, is key to maintaining American global competitiveness and economic health. Basic research precedes and informs nearly all new applications and development. It is an essential foundation for innovation.

For the U.S. to remain a global leader in science and technology, support for biological research must be a sustained, annual investment. Swings in funding levels have negative repercussions on scientific output. Without sustained funding, researchers limit or abort projects that have been years in the making. Reliable funding is also required to train new scientists and skilled workers.

This report features a few of the diverse ways that federal funding in the biological sciences has profited the nation. Although these examples are representative of the types of innovations resulting from federally supported research, numerous other examples could be highlighted.

Human Genome Project Transforms the 21st Century



The Human Genome Project is arguably one of the most successful investments the federal government has ever made in the biological sciences. The far-reaching and diverse benefits of sequencing the human genome could not have been easily predicted when the Department of Energy and the National Institutes of Heath first funded the project in 1988. The initiative was incredibly ambitious, with a goal of sequencing human DNA and identifying and mapping all of the genes that are responsible for human traits.

Over the course of 12 years, researchers worked to sequence all of our genes – collectively known as the genome. Scientists developed powerful new machines to sequence DNA, and to process the digital genetic code that was generated. As a result, the cost and time for sequencing an entire genome rapidly declined to a tiny fraction of the initial cost and can now be completed within days.

The knowledge gained and new technologies developed during the course of the Human Genome Project subsequently spurred billions of dollars in economic growth and the creation of countless new jobs.

Economic returns from the Human Genome Project far outweigh the government's investment in it. According to a report by Battelle Technology, federal investments

totaled just over $12 billion.[8] This value includes both initial investment through the completion of the project in 2003 and subsequent support for Human Genome Project-related research. In return, between 1988 and 2012, human genome sequencing and associated research and industrial activity is estimated to have generated an economic output of almost $800 billion. This is a return of $65 dollars for every dollar initially invested by the government. The project also resulted in the creation of new companies that generate $6 billion in tax revenue annually. Additionally, more than 4 million job-years of employment were created.

Beyond the economic benefits, successfully completing the Human Genome Project required the development of genomics and analytic technologies that have spread to other scientific fields. These technologies have spurred the growth of the genomics industry and further empowered scientific discovery and commercial innovation.

> "From human healthcare to veterinary medicine, from industrial biotechnology to high productivity agriculture, the knowledge, tools and technologies supported through the sequencing of the human genome form a foundation of advanced economic and social progress for the United States and humankind."
>
> *Excerpt from "Economic Impact of the Human Genome Project"*

Transformational changes in medicine are underway as a consequence of new medical and biological knowledge derived from human genome sequencing. Before the Human Genome Project, researchers knew the genetic basis of about 60 disorders. Now we understand the cause of at least 5,000.[9] With ongoing advancements, it is not a stretch to say that doctors may soon be able to design targeted drug treatments specific to an individual's cancer, based on their DNA.

Impacts of the Human Genome Project from 1988 to 2010

$796 billion in U.S. economic output

$244 billion in personal income for Americans

3.8 million job-years of employment

Plants as Inspiration for Adhesives, Sunscreen

The natural world is a limitless source of inspiration. Often referred to as 'biomimickry,' scientists explore the properties of living creatures to develop next-generation materials inspired by nature, but used for industry.

Dr. Mingjun Zhang, Dr. Scott Lenaghan, and colleagues at the University of Tennessee's Knoxville campus study biology at the nanoscale—a million times smaller than the period at the end of this sentence—to find and mimic useful biological properties.

Some of their research involves plants. Sundew is a carnivorous plant that catches insect prey on hair-like tendrils that secrete a powerful adhesive liquid. The adhesive is so elastic it can stretch to one million times its normal size. The researchers have identified several prospective medical uses for this natural adhesive, including healing wounds, regenerating damaged tissues, coating replacement body parts, and improving synthetic adhesives.

In medical operations, "you need something cells can recognize and attach to," Lenaghan said. The sundew adhesive is sticky, making it able to tightly grip cells. In addition, it is safely biodegradable, comprised of sugars and amino acids. It is flexible enough to form a scaffold that will bend and stretch as cells and tissues on it grow. With the help of National Science Foundation funding, the lab's experiments have shown that nanoparticles in sundew's adhesive show high compatibility for attaching human cells. Development of the adhesive is ongoing and very promising.

In working with another plant species, English ivy, the lab discovered nanoparticles that scatter light, providing a new, safer alternative to metal-based nanoparticles currently used in sunscreen. Several cosmetic companies have already inquired about that line of research and its applications.

The lab has also found inspiration from nanoparticles in fungi that have the potential to stimulate the immune system and fight cancer. They are also studying and mimicking the propulsion mechanics of Whirligig beetles, which are considered to have the most efficient thrust-generating apparatuses in the natural world. Based on findings from the latter research, the lab is designing swimming and diving robots for the Office of Naval Research.

Long-Term Ecological Research Results in Cost Effective Forest Management

Dead wood in forests has traditionally been considered a wasted resource and a hazard in our nation's parks and national forests. In the Pacific Northwest National Forests, millions of dollars were being spent to remove and manage dead wood. However, researchers at a H.J. Andrews Experimental Forest – one of a network of 26 Long Term Ecological Research (LTER) sites supported by the National Science Foundation – discovered new and cost-saving information about the ecological role of dead wood in the northwestern U.S.

H.J. Andrews scientists found that dead wood served a wide range of functions: it was a food source and habitat for many terrestrial and aquatic species, a seedbed for plants, and a source of water, energy, carbon, and nutrients. Dead wood was also important in controlling stream structure and function. As a result of their work, many stream habitat restoration efforts now focus on the reintroduction and maintenance of large pieces of dead wood in streams to create desirable habitat for aquatic species, including economically important fish species such as salmon.

The research done at H.J. Andrews impacted more than just the restoration and scientific communities; it strongly influenced forest management practices in 10 million hectares of federal forest in Washington, Oregon, and California, as well as forest management throughout the nation. In Pacific Northwest National Forests tens of millions of dollars per year have been saved by leaving unmerchantable dead wood in place instead of removing it. These savings would not have been realized without the scientific contributions of the LTER Network, which has been around since the 1980s and includes sites in deserts, estuaries, lakes, oceans, coral reefs, prairies, forests, alpine and Arctic tundra, urban areas, and production agriculture.

Research programs that span continents and persist over decades are rare, but incredibly valuable. They are uniquely positioned to provide key insights into natural resource management, biodiversity conservation, ecology, and environmental change.

Nicholas Locatelli

Improving Public Health Through Biological Collections

Scientific collections are a vital component of our nation's research infrastructure. Biological collections are maintained in museums, universities, and other research centers. They are public repositories of knowledge, preserving everything from whole organisms to DNA libraries and cell lines. These specimens and associated data drive cutting edge research on human health, natural resource management, environmental remediation, and other significant challenges facing society.

One area where biological collections have been useful is in tracking the history and transmission of infectious disease, information that is used to prevent and contain future outbreaks. For example, the influenza pandemic of 1918 killed over 20 million people worldwide, and more than half a million people in the U.S. It was among the most devastating disease epidemics in modern history, yet little was known about the origins of the disease, information that could prevent a similar outbreak in the future. Using tissue collections at the Smithsonian Institution, modern day researchers were able to determine the 1918 virus was not transmitted from birds to people, as had previously been suspected. Other scientific collections have since been used to trace the evolutionary history of the virus and provide guidance for future vaccine development.

Scientific collections have been integral in solving another medical mystery. In 1993, a deadly disease appeared in the southwestern United States. The agent was hantavirus, but its origin was unknown. Using biological collections at Texas Tech University and University of New Mexico, researchers discovered that certain rodents naturally carried the disease. When rodents became much more abundant following an El Niño weather event in 1992, the animals spread into human environments. This brought more rodents into contact with people and increased the transmission of hantavirus. With the vector known, new cases of hantavirus were largely prevented by reducing transmission opportunities.

The influenza and hantavirus studies were funded by the Centers for Disease Control and Prevention, the National Institutes of Health, and the National Science Foundation. They were also made possible through cooperation from the U.S. Fish and Wildlife Service, the Long Term Ecological Research Program, and the U.S. National Park Service.

Engineering Crops for Better Yields in Extreme Weather

Biologists are using an ever expanding toolkit to improve agricultural output despite environmental change. Shifting weather patterns, unpredictable extreme weather events, and new pests and diseases are placing additional pressure on food systems both in the U.S. and globally.

Scientists forecast continued increases in average air temperatures, causing concerns about impacts on staple crops that feed the majority of the world's population. More than 4.5 billion people worldwide acquire at least 30 percent of their daily calories from corn, rice, or wheat.[10] These crops have fed humanity for millennia, however, adverse environmental conditions could detract from future yields and jeopardize our ability to provide adequate calories for some.


Carrie Thurber

"Man has been growing [wheat, rice, and maize] for thousands of years, but we've only had the tools to try to understand what really makes them grow for a relatively short amount of time."

Dr. L. Curtis Hannah

Researchers are working to develop crop varieties that will produce high yields even under adverse weather conditions. University of Florida professor Dr. L. Curtis Hannah and collaborators successfully developed a heat-stable version of the enzyme responsible for synthesizing starch, and incorporated it into the genome of three staple crops: corn, wheat, and rice. The National Science Foundation and the U.S. Department of Agriculture supported this research.

The experiments resulted in significant increases in crop yields when air temperatures exceeded 91°F. In experiments, yields increased by 20 to 60 percent, depending on the crop. These are dramatic results, as traditional breeding programs typically only produce a 1 percent increase in yield per year.

Dr. Hannah's research hints at the potential to further increase crop yield. In his experiments, plants produced higher numbers of seeds when grown in high temperatures. This is a promising target for further research. "We're going to keep looking at different combinations that will give us better and better yields," Hannah said. "Meanwhile, by watching what happens when we make these changes, we learn more and more about what makes these plants tick."

Biocontrols Combat Invasive Asian Carp in U.S. Waterways

Invasive species are ecologically devastating, and can be very expensive to combat. They are almost impossible to eradicate once established, and controlling them is a constant expense. Their impacts can be seen across economic sectors, from forestry to agriculture to fisheries.

Invasive Asian carp represent a major threat to the already vulnerable Great Lakes ecosystem. The spread of Asian carp in the Mississippi River Basin places the Great Lakes at risk for infestation.

Carp can severely damage aquatic ecosystems and outcompete native fish species. This has commercial implications, because native fish are worth more as a commodity. The silver variety of Asian carp also poses a safety hazard. They are easily startled by boat motors and can leap up to 10 feet out of the water, causing injury to people.

In light of the threat posed by Asian carp, scientists have been racing to develop new ways to kill and repel these damaging fish. Developing and testing controls for Asian carp is increasingly urgent to prevent the establishment of breeding populations in the lakes, if and when carp arrive.

The U.S. Geological Survey is supporting and coordinating such efforts. Research has focused on ways to kill, stun, or herd the fish, as well as improving our ability to detect them. Examples of controls include nanoparticles imbued with poison that affects only Asian carp, physical and sound barriers, and genetic manipulation to induce sterility. Special scents, called pheromones, can also be deployed to lure carp into traps or away from barriers in waterways.

Methods of control developed for Asian carp can potentially serve as a model for management of other difficult aquatic invasive species such as zebra and quagga mussels. Invasive mussels continue to cause severe problems in the Great Lakes ecosystems, including eliminating native mussel species and negatively altering food webs and nutrient dynamics.

In very few other sectors of the economy is biological knowledge so urgently needed as when preventing and controlling invasive species.

Ecosystem Services in Urban Environments

Ecosystem services are a vital but often overlooked set of benefits that the environment provides to society. They include the "goods" that nature provides (food, water, fiber, and energy), as well as soil fertility, air and water quality, pest control, recreation, and aesthetics. Healthy systems deliver these services free of charge.

Although ecosystem services are most often associated with natural areas, areas more impacted by humans can still provide benefits. Researchers at the National Science Foundation-funded Central Arizona-Phoenix Long Term Ecological Research site discovered that thoughtfully engineered aquatic systems in urban areas can in fact provide ecosystem services.

At the urban site, scientists studied different systems for water delivery, stormwater removal, and wastewater processing, and determined the systems and conditions that can have environmental benefits. For example, concrete stormwater spillways do not provide any public benefits beyond the flood control for which they were originally designed.

Conversely, locating a park in the flood plain along a waterway has benefits. In addition to recreational value and capacity to absorb or convey floods, these retention basin parks are also efficient at removing contaminants from floodwater.

The Central Arizona-Phoenix studies are important because they showed that not all engineered aquatic ecosystems provide the same set of benefits. This research could help urban planners and policymakers design water systems for urban settings that optimize ecosystem services.

Pamela Geddes

Fungi As Basis for Innovation and Patents

Basic research about the appearance, physiology, and behavior of organisms has long been a foundation for many avenues of applied research.

Dr. Gary Strobel of Montana State University focuses much of his research on fungi. These organisms frequently live in cooperation with plants. They produce complex and often useful organic molecules, including compounds that attack viruses, bacteria, and other fungi.

The Strobel lab has unearthed numerous compounds previously unknown to science. In the 1980's, they discovered bacteria that secrete antifungal agents that combat Dutch elm disease, which has devastated elm trees across the U.S. This innovation has been licensed to Eli Lilly for use in treating fungal infections in people.

In Honduras, Strobel discovered a fungus that produces gases capable of asphyxiating insects. The biopesticide technology kills agricultural pests without using synthetic chemicals. It was licensed to AgraQuest.

Strobel was also associated with isolating and characterizing another fungus, *Muscodor albus*, which excretes volatile antibiotics. Numerous patents now cover its associated uses for decontaminating waste and soil, and disinfecting fruit, seeds, and buildings.

Many other novel biologically active compounds useful in both medicine and agriculture have been isolated and chemically characterized by Strobel's lab. As his research demonstrates, new sources of inspiration for medications continue to be found in unlikely places.

Strobel's work is associated with over 30 patent applications,[11] and has resulted in numerous publications. Government support for the Strobel lab has come from the National Science Foundation, U.S. Department of Agriculture, National Institutes of Health, National Aeronautics and Space Administration, and the U.S. Forest Service.

U.S. Department of Agriculture

Biological Control of the Soybean Aphid

The invasive insect *Aphis glycines* is presently the greatest threat to soybean production in the United States. This Asian insect has spread rapidly through the Midwest since its detection in the U.S. in 2000, and costs growers $30 to $50 million per year in reduced soybean yield.[12] Farmers responded with a twenty-fold increase in insecticide use, resulting in the spraying of millions of acres of soybeans that formerly went untreated. This additional pesticide use comes at a cost of $10 per acre.[12]

Around the same time that *A. glycines* was invading, researchers at Kellogg Botanical Station, part of the National Science Foundation-funded Long Term Ecological Research Network, were conducting long-term studies of ladybird beetles. They found that the insects were important predators of native aphids that damage wheat, poplar, and other crops. They also detected the arrival of *Harmonia axyridis*, an Asian species of ladybird beetle, in the U.S.

Their research showed that ladybird beetles could keep the invading soybean aphids below "economic thresholds"—levels that would otherwise justify pesticide spraying. In fact, Kellogg Botanical Station scientists showed that ladybird predation provided a biocontrol equivalent to $13 to $79 per acre in reduced pesticide use and averted crop loss.[13] Across four states (Iowa, Michigan, Minnesota, and Wisconsin), the value of natural biological control of aphids was estimated at $239 million per year.[13]

Researchers at Kellogg Botanical Station also found that biological control was greater where the surrounding landscape was more varied in land use. Diverse landscapes have many different types of crop and non-crop habitats, as well as a wide range of living organisms. For example, the increased presence of corn within one mile of a soybean field tended to reduce the effectiveness of Asian ladybird beetle biological control, because corn is a less favorable habitat for ladybird beetles and other insect predators. Consequently, a 19 percent increase in corn acreage from 2006 to 2007 (in response to grain ethanol demand) reduced the supply of beneficial predators to control soybean pests. This loss was valued at $58 million in 2008 for the four states studied.[14]

Economic Benefits of Tracking Animals

Animal migrations are among the most fascinating spectacles on Earth, sometimes involving species crossing entire continents. In addition to their pageantry, understanding migrations can have important practical implications. A prime example is the impact of bird migrations on aviation.

In the period from 1995 to 2010, the U.S. Air Force reported almost 65,000 collisions between birds and planes, resulting in a cost of more than $527 million.[15] Moreover, such strikes are a hazard to aircraft and personnel. Birds are similarly a known problem in commercial and recreational aviation. Predicting when and where to expect migrating birds is considered of utmost importance.

Due to a powerful new tool, it may now be possible to predict the paths of migrating birds. The system, Env-DATA, was developed by Dr. Gil Bohrer from The Ohio State University with funding from the NASA Earth Science Division. Released in 2013, the system can link animal movement data with information from global environmental datasets on weather, land use, satellite imagery, and more. Env-DATA authors illustrated its use by determining how Galapagos albatross migration patterns responded to wind, ocean productivity, and chlorophyll concentration—a measure of tiny algae in the water.

With Env-DATA it becomes feasible to link bird migration patterns to environmental conditions, and potentially to predict how that movement will change under different conditions. Such predictive power would be a boon to aviation.

Federally Supported Research Gives Rise to Biotechnology Companies

Several federal programs support the transfer of technology from academic and non-profit research institutions to private businesses. The National Science Foundation's Innovation Corps fosters entrepreneurship by researchers and assists with the commercialization of new discoveries. The National Institutes of Health created a spinoff program for biomedical research innovations. The Department of Energy and other agencies assist grantees with tech transfer through small business programs.

Federal support is an important reason why licensing activity and start-up formation are strong. **In fiscal year 2014, over 900 new companies formed to further develop academic discoveries that had been reported by universities and research institutes.**[16] A notable 700 of those companies were based in the institute's home state.

Measured across time, the number of new companies formed based on academic research findings is staggering. About 4,700 such start-up companies are currently in operation in the United States.[16] These range from newly formed entities to titans of industry. Notably, Google cofounders Larry Page and Sergey Brin both benefited from National Science

Foundation funding while in graduate school.[17]

Genentech is one of a small sampling of the many companies founded as a direct result of federally funded biological research. Genentech capitalized on recombinant DNA technology developed by Dr. Herbert Boyer and Dr. Stanley Cohen, respectively at University of California, San Francisco and Stanford University. Boyer and Cohen received support from the National Science Foundation and National Institutes of Health for their research. The company develops and manufactures pharmaceuticals to treat a variety of medical conditions. Genentech's annual revenues exceed $13 billion and it employs more than 11,000 people.

Another company founded upon federally funded research is Chromatin. The business was enabled by Dr. Daphne Preuss' pioneering research into chromosomes at the University of Chicago, which was originally supported by the National Science Foundation. The company's patented mini-chromosome technologies enable the development of new varieties of sorghum, a crop that is used for animal feed and to generate bioenergy.

Allylix was founded by two scientists whose 12 years of National Science Foundation-funded research yielded new methods for producing plant products called terpenes. Terpenes are plant products that have enormous potential commercial value in flavor and fragrance, insect repellent, and pharmaceutical industries, among others. The researchers developed proprietary technology to generate terpenes at low cost while working at the University of Kentucky's College of Agriculture and the Salk Institute for Biological Studies. Since its founding, Allylix has been issued 62 patents.

ArmaGen Technologies was founded in 2004 using technology developed by Dr. William Pardridge and his research team at the University of California, Los Angeles. With the help of funding from the National Institutes of Health and the Department of Defense, the Pardridge team developed "molecular Trojan horses" that deliver various drugs and gene therapies to the brain. ArmaGen Technologies products help treat Alzheimer's disease, Parkinson's disease, strokes, and brain cancer. The company raised $17 million from investors in 2012.

Looking Ahead

"The United States has invested wisely to make us the world leader in life science discovery by promoting and supporting the curiosity and creativity of individual scientists. It is crucial that this investment continues and expands."

Dr. Keith Yamamoto, former chair of the National Academy of Sciences' Board on Life Sciences and professor at University of California, San Francisco

"In addressing the future quality of life in America one cannot help but notice warnings of what appears to be an impending Perfect Storm… What, then, must America do? There is but one answer: We must compete… we must significantly increase our federal investment in research."

Norman Augustine, former Chairman and CEO of the Lockheed Martin Corporation, former Chair of the National Academy of Engineering

Federally funded biological research generates results. From preventing the spread of invasive species to improving the treatment of disease to creating new products, biological research fuels advancement across diverse sectors of the U.S. economy.

Federal investment is especially critical for basic research. Basic research serves as the foundation for scientific innovation and applied research.

Unfortunately, federal funding for biological research has stagnated in recent years. **In constant FY 2015 dollars, federal investments in the life sciences declined by 14.3 percent from 2003 to 2013.**[18]

Declining funding is forestalling innovations as promising research goes unfunded in the near term. Grant programs have become so competitive that **less than one in five research proposals are funded** by the National Science Foundation, National Institutes of Health, or U.S. Department of Agriculture's Agriculture and Food Research Initiative.[19]

A lack of federal funding is also hindering the careers of the next generation of researchers. **The proportion of science and engineering graduate students receiving federal support is lower now than it was in any year since 1998.**[20]

Without sustained investments in basic research, the United States will lose its global leadership in science. We must boldly act to prevent further damage to our scientific enterprise.

Footnotes

1. Dr. Fred Block, research professor at the University of California, Davis. March 2012 presentation.
2. Total employment grew by an average of 2 percent per year from 1960-2013. *Science and Engineering Indicators 2016*, National Science Foundation.
3. In February 2013, unemployment was 3.8 percent for the science and engineering workforce versus 8.1 percent for the entire U.S. workforce. *Science and Engineering Indicators 2016*, National Science Foundation.
4. Data for 2000-2009. R&D Dashboard, http://rd-dashboard.nitrd.gov/
5. National Science Foundation, http://www.nsf.gov/statistics/infbrief/nsf12310/
6. In 2013, businesses spent $21.2 billion on basic research as compared to $46.3 billion on applied research. *Science and Engineering Indicators 2016*, National Science Foundation.
7. *Economic Returns to Public Agricultural Research*, Economic Research Service, 2007.
8. *Economic Impact of the Human Genome Project*, Battle Technology Partnership Practice, 2011.
9. Young, S. *A decade of advances since the Human Genome Project*. April 12, 2013. MIT Technology Review. http://www.technologyreview.com/view/513666/a-decade-of-advances-since-the-human-genome-project/
10. von Braun, J., S. Fan, R. Meinzen-Dick, M.W. Rosegrant, and A. Nin Pratt. *International agricultural research for food security, poverty reduction, and the environment - What to expect from scaling up CGIAR investments and "best bet" programs*. 2008. Washington, DC: International Food Policy Research Institute.
11. A list of the patents awarded to the Strobel lab is available at http://plantsciences.montana.edu/facultyorstaff/faculty/strobel/patents.html.
12. Long Term Ecological Research Network. http://www.lternet.edu/research/keyfindings/diverse-landscapes-curtail-crop-pests
13. Costamagna, A.C., and D.A. Landis. *Predators exert top-down control of soybean aphid across a gradient of agricultural management systems*. 2006. Ecological Applications 16: 1619-1628.
14. Landis, D.A., M.M. Gardiner, W. van der Werf, and S.M. Swinton. *Increasing corn for biofuel production reduces biocontrol services in agricultural landscapes*. 2008. Proceedings of the National Academy of Sciences 105: 20552-20557.
15. Cowsert, D. *Migrating birds increase risk to aircraft*. 5 October 2011. Air Force Reserve Command – News. http://www.afrc.af.mil/news/story.asp?id=123274698
16. Association of University Technology Managers Licensing Activity Survey FY 2014
17. National Science Foundation, https://www.nsf.gov/discoveries/disc_summ.jsp?cntn_id=100660
18. Analysis by the American Association for the Advancement of Science, based on data from the National Science Foundation.
19. In FY 2014, the funding rate was 18 percent for the National Institutes of Health, 11 percent for the Agriculture and Food Research Initiative, and less than 10 percent for several divisions within the Directorate for Biological Sciences at the National Science Foundation.
20. *Science and Engineering Indicators 2016*, National Science Foundation.