Section 4
Campus Research

Research Support

MIT has historically viewed teaching and research as inseparable parts of its academic mission. Therefore, the Institute recognizes its obligation to encourage faculty to pursue research activities that hold the greatest promise for intellectual advancement. MIT maintains one of the most vigorous programs of research of any university and conducts basic and applied research principally at two Massachusetts locations, the MIT campus in Cambridge and MIT Lincoln Laboratory, a federally funded research and development center in Lexington.

MIT pioneered the federal/university research relationship, starting in World War II. Initially called upon by the federal government to serve the national war effort, that relationship has continued into the present day, helping MIT fulfill its original mission of serving the nation and the world.

Research Expenditures (MIT FY2015)

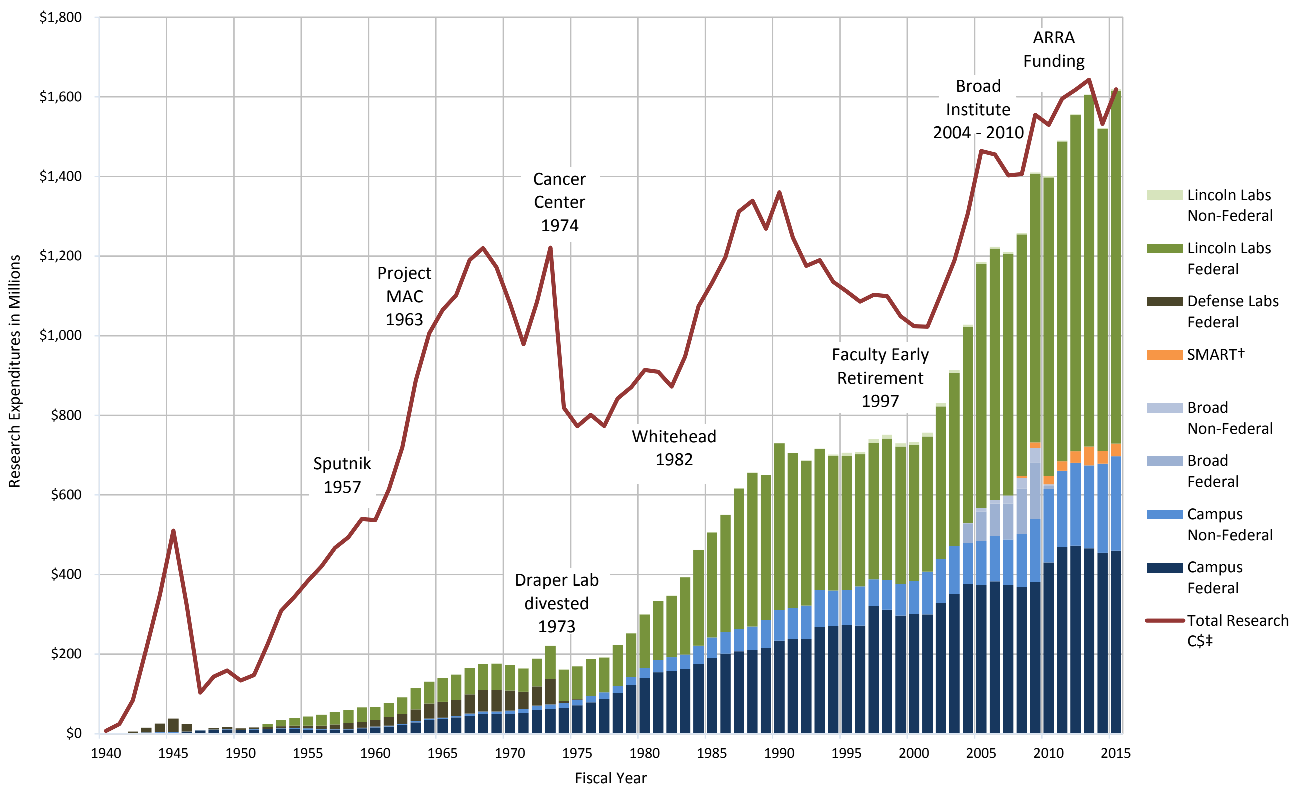
Cambridge Campus	$696.9 million
Lincoln Laboratory*	$890.2 million
SMART*	$31.9 million
Total	**$1,619.0 million**

*Totals do not include research performed by campus laboratories for Lincoln Laboratory and Singapore-MIT Alliance for Research and Technology (SMART).

All federal research on campus is awarded competitively based on the scientific and technical merit of the proposals. In FY2015, there were 2,723 active awards and 396 members of research consortiums.

Research activities range from individual projects to large-scale, collaborative, and sometimes international endeavors. Peer-reviewed research accomplishments form a basis for reviewing the qualifications of prospective faculty appointees and for evaluations related to promotion and tenure decisions.

MIT Research Expenditures
1940–2015



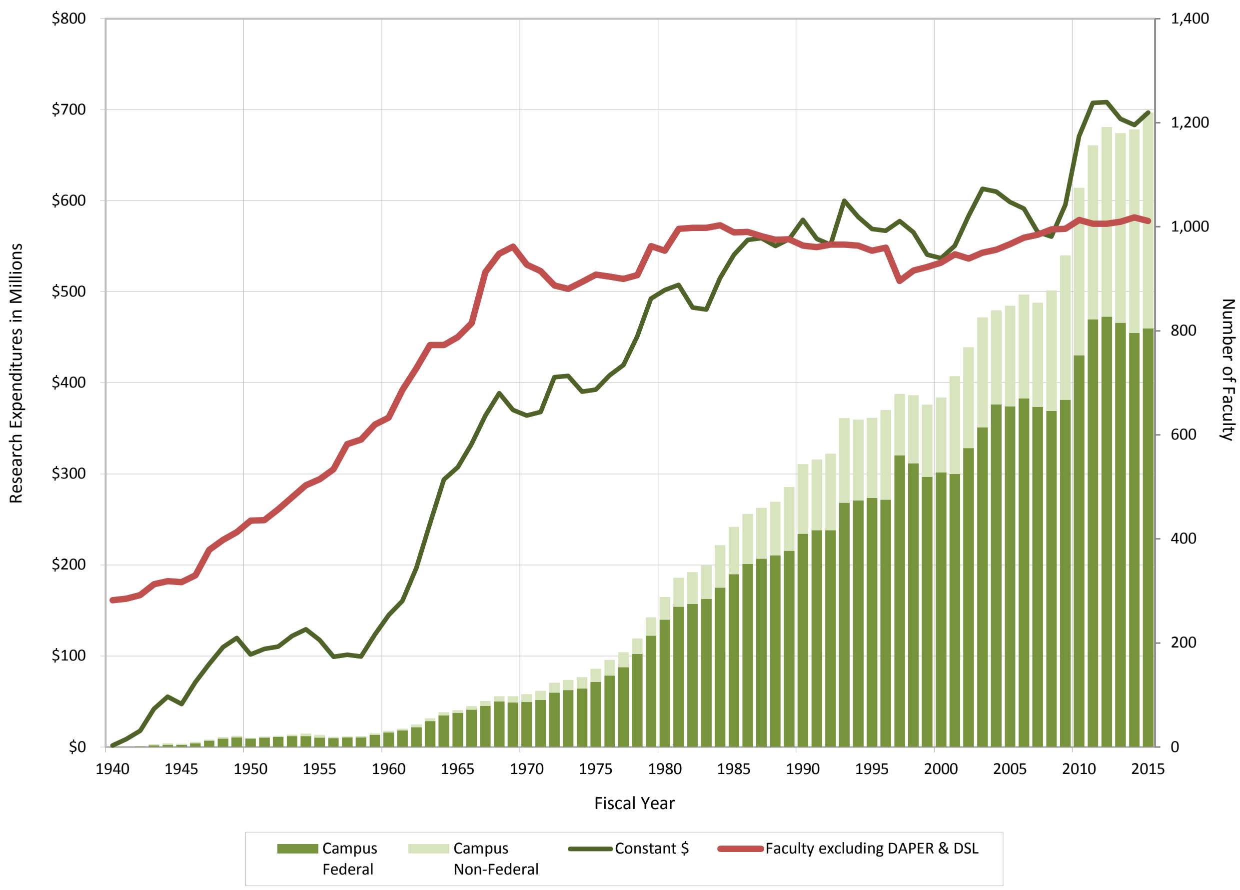
†SMART: Singapore-MIT Alliance for Research and Technology
‡Total Research constant dollars are calculated using the Consumer Price Index for all Urban Consumers weighted with fiscal year 2015 equaling 100.

The Institute provides the faculty with the infrastructure and support necessary to conduct research, much of it through contracts, grants, and other arrangements with government, industry, and foundations. The Office of Sponsored Programs provides central support related to the administration of sponsored research programs, and it assists faculty, other principal investigators, and their local administrators in managing and identifying resources for individual sponsored projects. In addition, a Research Council—which is chaired by the Vice President for Research and composed of the heads of all major research laboratories and centers that report to the Vice President for Research—addresses research policy and administration issues.

The Resource Development Office is available to work with faculty to generate proposals for foundation or other private support.

The Institute sees profound merit in a policy of open research and free interchange of information among scholars. At the same time, MIT is committed to acting responsibly and ethically in all its research activities. As a result, MIT has policies related to the suitability of research projects, research conduct, sources of support, use of human subjects, sponsored programs, relations with intelligence agencies, the acquisition of art and artifacts, the disposition of equipment, and collaborations with research-oriented industrial organizations. These policies are spelled out on the Policies and Procedures website and on the Office of Sponsored Programs website.

Campus Research Expenditures and Faculty Excluding Broad and Defense Labs 1940–2015



DAPER: Department of Athletics, Physical Education and Recreation
DSL: Division of Student Life

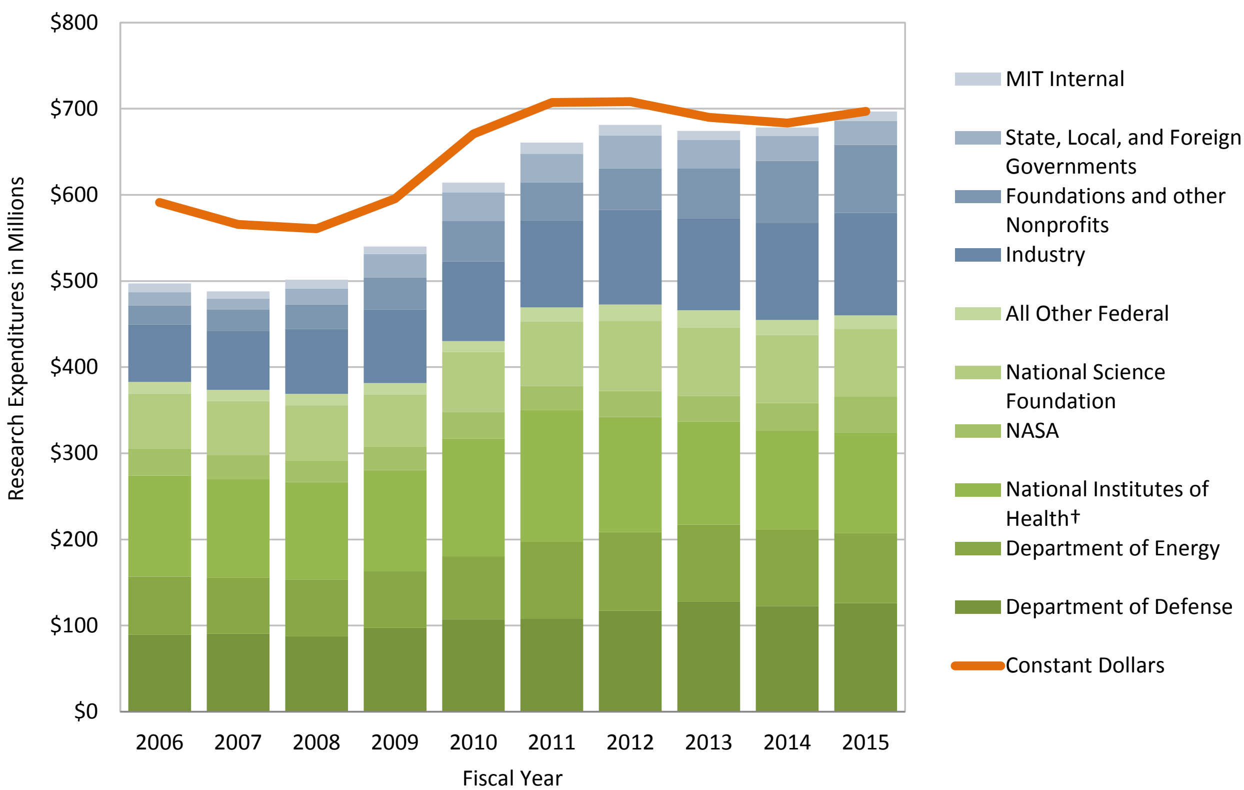
Campus Research Sponsors

The tables and charts for campus research expenditures below, and on the following pages, show the amount MIT expended by fiscal year (July 1–June 30). These figures do not include expenditures for MIT Lincoln Laboratory. Information for Lincoln Laboratory begins on page 79. Expenditures funded by industrial sponsors are shown on page 99 in the MIT and Industry section. Federal research expenditures include all primary contracts and grants, including sub-awards from other organizations where the federal government is the original funding source.

Campus Research Expenditures (in U.S. Dollars)
Fiscal Years 2006–2015

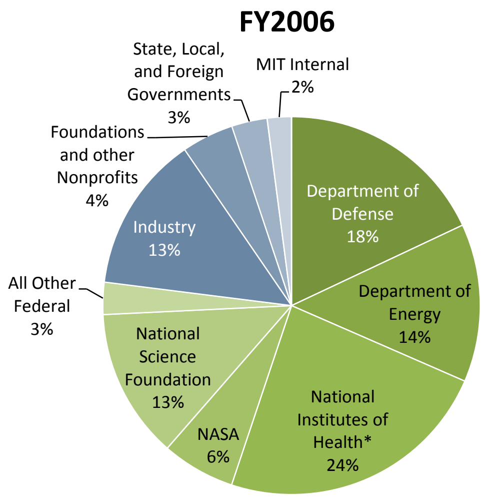
	2006	2007	2008	2009	2010
Federal	382,784,774	373,603,371	369,008,780	381,459,466	430,154,479
Non-federal	114,361,780	114,389,201	132,487,316	158,595,887	184,216,417
Total	**497,146,554**	**487,992,571**	**501,496,096**	**540,055,353**	**614,370,896**
Constant dollars*	591,295,439	565,776,227	560,656,987	595,451,903	670,897,854

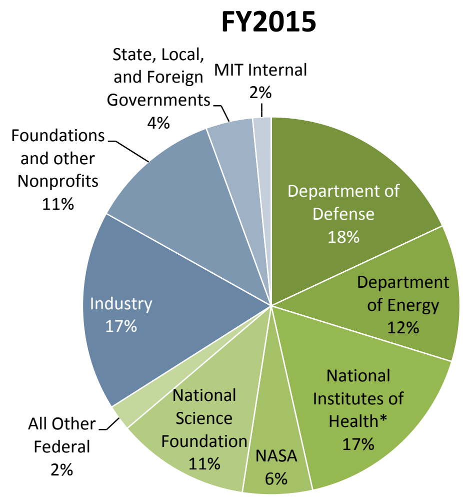
	2011	2012	2013	2014	2015
Federal	469,520,579	472,582,743	465,946,679	454,938,599	459,979,141
Non-federal	191,304,692	208,496,567	208,401,668	223,473,071	236,912,028
Total	**660,825,271**	**681,079,310**	**674,348,348**	**678,411,670**	**696,891,169**
Constant dollars*	707,421,238	708,349,648	689,867,045	683,350,357	696,891,169



*Constant dollars are calculated using the Consumer Price Index for All Urban Consumers weighted with the fiscal year 2015 equaling 100.
†National Institutes of Health data includes expenditures from other Department of Health and Human Services agencies which account for less than 1% of expenditures per year.

Campus Research Expenditures by Primary Sponsor





Campus Research Expenditures by Primary Sponsor

Primary Sponsor	FY2015 (In U.S. Dollars)	Percent of Campus Total
Department of Defense	125,853,521	18
Department of Energy	81,528,299	12
National Institutes of Health*	116,469,457	17
NASA	41,739,692	6
National Science Foundation	78,952,919	11
All other federal	15,435,252	2
Total Federal	**459,979,141**	**66**
Industry	119,238,077	17
Foundations and other nonprofit	78,666,639	11
State, local, and foreign governments	27,951,041	4
MIT internal	11,056,271	2
Total Non-Federal	**236,912,028**	**34**
Campus Total	**696,891,169**	**100**

*National Institutes of Health data includes expenditures from other Department of Health and Human Services agencies which account for less than 1% of expenditures per year.

Department of Defense

Selected Projects

A bipedal robot with human reflexes

On the MIT campus, a two-legged robot named HERMES is wreaking controlled havoc: punching through drywall, and kicking over trash buckets. Its actions, however, are not its own. Just a few feet away, PhD student Joao Ramos stands on a platform, wearing an exoskeleton of wires and motors. Ramos' every move is translated instantly to HERMES, much like a puppeteer controlling his marionette. As Ramos mimes punching through a wall, the robot does the same. When the robot's fist hits the wall, Ramos feels a jolt at his waist. By reflex, he leans back against the jolt, causing the robot to rock back, effectively balancing the robot against the force of its punch.

The exercises are meant to demonstrate the robot's unique balance-feedback interface. Without this interface, while the robot may successfully punch through a wall, it would also fall headlong into that wall. The interface allows a human to remotely feel the robot's shifting weight, and quickly adjust the robot's balance by shifting his own weight. As a result, the robot can carry out momentum-driven tasks—like punching through walls—while maintaining its balance.

Ramos and his colleagues, including PhD student Albert Wang and Professor Sangbae Kim, will present a paper on the interface at the IEEE/RSJ International Conference on Intelligent Robots and Systems.

http://newsoffice.mit.edu/2015/bipedal-robot-with-human-reflexes-0811

A new look at superfluidity

MIT physicists have created a superfluid gas, the so-called Bose-Einstein condensate, for the first time in an extremely high magnetic field. The magnetic field is a synthetic magnetic field, generated using laser beams, and is 100 times stronger than that of the world's strongest magnets. Within this magnetic field, the researchers could keep a gas superfluid for a tenth of a second—just long enough for the team to observe it. The team, led by Wolfgang Ketterle, took pictures of the distribution of atoms to capture the shape of the superfluid. Those images also reveal the structure of the magnetic field—something that's been known, but never directly visualized until now.

A superfluid is a phase of matter that only certain liquids or gases can assume, if they are cooled to extremely low temperatures. Superfluids are thought to flow endlessly, without losing energy, similar to electrons in a superconductor. Observing the behavior of superfluids may help scientists improve the quality of superconducting magnets and sensors, and develop energy-efficient methods for transporting electricity.

http://newsoffice.mit.edu/2015/new-look-at-superfluidity-0810

Solving mysteries of conductivity in polymers

Materials known as conjugated polymers have been seen as very promising candidates for electronics applications, including photodiodes, and thermoelectric devices. But they've faced one major obstacle: Nobody has been able to explain just how electrical conduction worked in these materials, or to predict how they would behave when used in such devices.

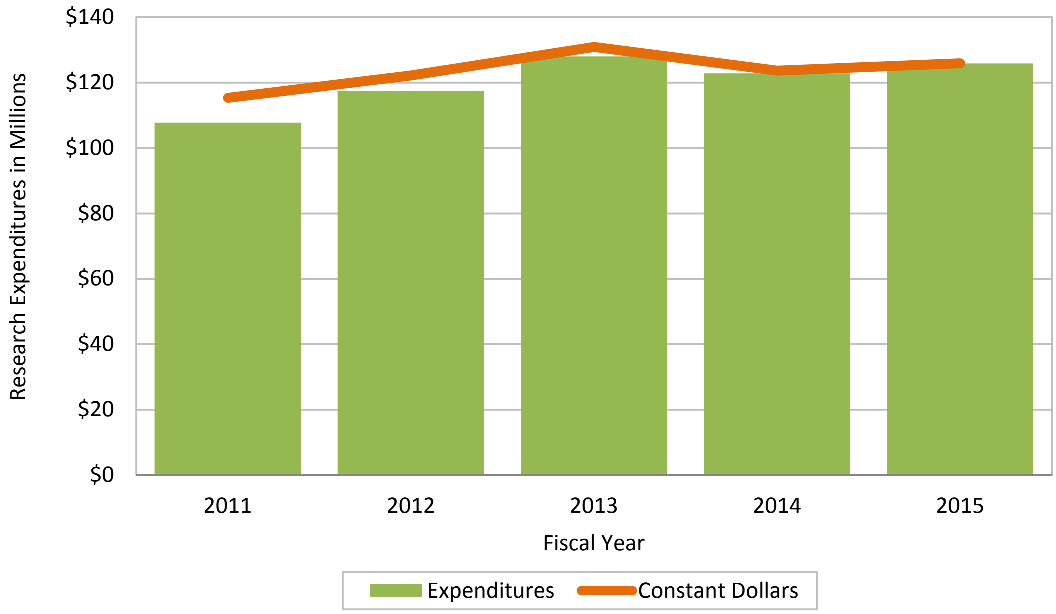
Conjugated polymers fall somewhere between crystalline and amorphous materials—and that's caused some of the difficulty in explaining how they work, says Asli Ugur, an MIT postdoc and research team member. Crystals have a perfectly regular arrangement of atoms and molecules, while amorphous materials have a completely random arrangement. Conjugate polymers have characteristics of both. Researchers at MIT and Brookhaven National Laboratory have explained how electrical charge carriers move in these compounds, potentially opening up further research on such applications.

The research team also included Professor Karen Gleason, Associate Professor Kripa Varanasi, postdoc Ferhat Katmis and graduate student Mingda Li, and Brookhaven National Laboratory research scientists Lijun Wu and Yimei Zhu.

http://newsoffice.mit.edu/2015/solving-mysteries-conductivity-polymers-0714

Department of Defense Campus Research Expenditures (in U.S. Dollars)
Fiscal Years 2011–2015

	2011	2012	2013	2014	2015
Campus research	107,753,196	117,457,789	127,966,747	122,761,059	125,853,521
Constant dollars*	115,351,066	122,160,785	130,911,630	123,654,733	125,853,521



*Constant dollars are calculated using the Consumer Price Index for All Urban Consumers weighted with the fiscal year 2015 equaling 100.

Leading Departments, Laboratories, and Centers Receiving Support in Fiscal Year 2015
(Shown in descending order of expenditures)

Research Laboratory of Electronics
Computer Science and Artificial Intelligence Laboratory
Institute for Soldier Nanotechnologies
Biological Engineering
Mechanical Engineering
Sociotechnical Systems Research Center
Laboratory for Information and Decision Systems
Chemistry
Aeronautics and Astronautics
Microsystems Technology Laboratories

In fall 2014, the Department of Defense funded the primary appointments of graduate students with 291 research assistantships and 89 fellowships.

Twenty-eight current faculty and staff have received the Office of Naval Research Young Investigator Program Award.

Department of Energy

Selected Projects

A small, modular, efficient fusion plant

Advances in magnet technology have enabled researchers to propose a new design for a practical compact tokamak fusion reactor—that might be realized in as little as a decade, they say. The era of practical fusion power, which could offer a nearly inexhaustible energy resource, may be coming near.

Using these new commercially available superconductors, rare-earth barium copper oxide (REBCO) superconducting tapes, to produce high-magnetic field coils "just ripples through the whole design," says Dennis Whyte, a professor of Nuclear Science and Engineering and director of MIT's Plasma Science and Fusion Center. "It changes the whole thing."

The stronger magnetic field makes it possible to produce the required magnetic confinement of the superhot plasma—that is, the working material of a fusion reaction—but in a much smaller device than those previously envisioned. The reduction in size makes the whole system less expensive and faster to build, and also allows for some ingenious new features in the power plant design. The proposed reactor, using a tokamak (donut-shaped) geometry that is widely studied, is described in a paper in the journal *Fusion Engineering and Design*, co-authored by Whyte, PhD candidate Brandon Sorbom, and 11 others at MIT. The paper started as a design class taught by Whyte and became a student-led project after the class ended.

http://news.mit.edu/2015/small-modular-efficient-fusion-plant-0810

MIT awarded Dept. of Energy grant to create and deploy energy-saving travel information and incentives system

The U.S. Department of Energy's Advanced Research Projects Agency-Energy (ARPA-E) has announced that MIT researchers, along with colleagues from the University of Massachusetts (UMass), received a $3,990,128 grant to design, build, and trial a new system to incentivize people to adapt their travel choices to conserve energy.

Professor Moshe Ben-Akiva and Assistant Professor Jessika Trancik will lead the project, involving a diverse team from several MIT departments. The MIT team will work with UMass Associate Professor Song Gao and colleagues. The innovative initiative is one of five proposals funded as part of ARPA-E's newest program, the Traveler Response Architecture using Novel Signaling for Network Efficiency in Transportation (TRANSNET).

The grant will be used to develop and test a Mobility Electronic Market for Optimized Travel (MeMOT). It will use real and simulated personal travel data to reward people to shift their routes, departure times, modes of travel, and vehicles based on live information they receive from MeMOT. Incentives will include points awarded based on energy savings that can be redeemed both in real-time and in the future for travel-related and other benefits at local participating vendors.

http://news.mit.edu/2015/mit-awarded-department-energy-grant-travel-information-incentives-system-0806

New manufacturing approach slices lithium-ion battery cost in half

An advanced manufacturing approach for lithium-ion batteries, developed by researchers at MIT and at a spinoff company called 24M, promises to significantly slash the cost of the most widely used type of rechargeable batteries while also improving their performance and making them easier to recycle.

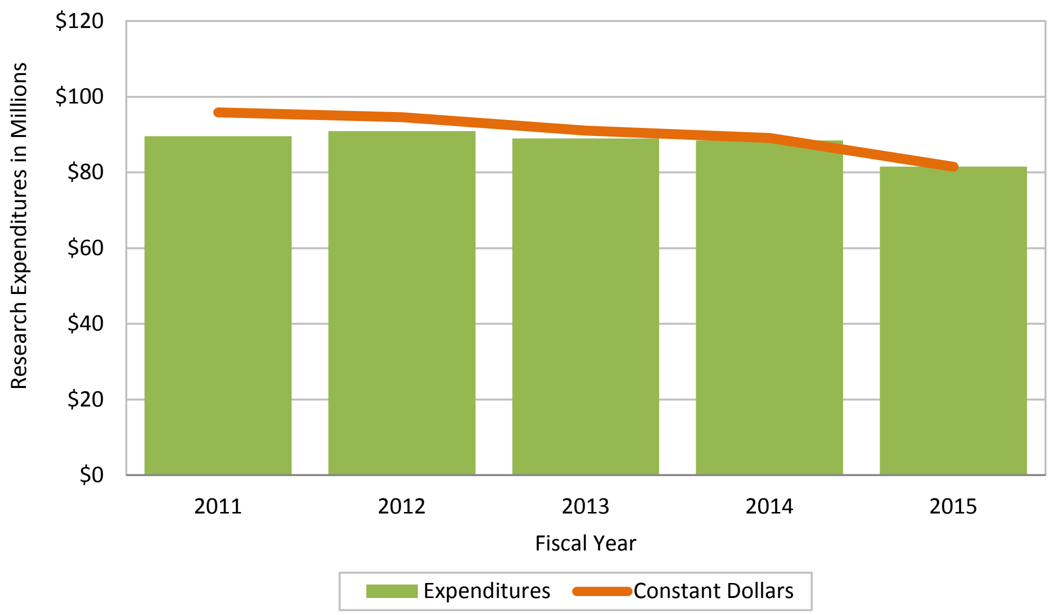
"We've reinvented the process," says Yet-Ming Chiang, professor and a co-founder of 24M. The existing process for manufacturing lithium-ion batteries, he says, has hardly changed in the two decades since the technology was invented, and is inefficient, with more steps and components than are really needed.

The new process is based on a concept developed five years ago by Chiang and colleagues including Professor W. Craig Carter. The new battery design is a hybrid between flow batteries and conventional solid ones: In this version, while the electrode material does not flow, it is composed of a similar semisolid, colloidal suspension of particles. Chiang and Carter refer to this as a "semisolid battery."

http://news.mit.edu/2015/manufacturing-lithium-ion-battery-half-cost-0623

Department of Energy Campus Research Expenditures (in U.S. Dollars)
Fiscal Years 2011–2015

	2011	2012	2013	2014	2015
Campus research	89,562,126	90,940,035	88,987,983	88,450,656	81,528,299
Constant dollars*	95,877,311	94,581,264	91,035,853	89,094,557	81,528,299



*Constant dollars are calculated using the Consumer Price Index for All Urban Consumers weighted with the fiscal year 2015 equaling 100.

Leading Departments, Laboratories, and Centers Receiving Support in Fiscal Year 2015
(Shown in descending order of expenditures)

Plasma Science and Fusion Center
Laboratory for Nuclear Science
Mechanical Engineering
Chemical Engineering
Nuclear Science and Engineering
Research Laboratory of Electronics
Materials Science and Engineering
Materials Processing Center
Nuclear Reactor Laboratory
Chemistry

In fall 2014, the Department of Energy funded the primary appointments of graduate students with 191 research assistantships and 22 fellowships.

Twenty-five current faculty have received the Department of Energy Outstanding Junior Investigator award or Early Career Research Program Award.

National Institutes of Health

Selected Projects

Uncovering a dynamic cortex

Researchers at MIT have proven that the brain's cortex doesn't process specific tasks in highly specialized modules—showing that the cortex is, in fact, quite dynamic when sharing information.

Previous studies of the brain have depicted the cortex as a patchwork of function-specific regions. In a paper published in *Science*, researchers from the Picower Institute for Learning and Memory at MIT show that, indeed, multiple cortical regions work together simultaneously to process sensorimotor information—sensory input coupled with related actions—despite their predetermined specialized roles.

The researchers used cutting-edge techniques to record neural activity simultaneously, for the first time, across six cortical regions during a task in which the color or motion of dots had to be identified. These regions, ranging from the front to back of the brain, were thought to each specialize in specific sensory or executive functions. Yet the researchers found significant encoding for all information across all regions—but at varying degrees of strength and timing.

These findings, Professor Earl Miller says, could lead to improved treatments for brain disease, attention deficit hyperactivity disorder, stroke, and trauma.

The paper's lead author is Markus Siegel, a principal investigator at the University of Tübingen, and a co-author is Timothy Buschman, an assistant professor at Princeton University. Miller is senior author.

http://news.mit.edu/2015/multiple-cortical-regions-process-information-0618

Quick test for Ebola

When diagnosing a case of Ebola, time is of the essence. However, existing diagnostic tests take at least a day or two to yield results, preventing health care workers from quickly determining whether a patient needs immediate treatment and isolation.

A new test from MIT researchers could change that: The device, a simple paper strip similar to a pregnancy test, can rapidly diagnose Ebola, as well as other viral hemorrhagic fevers such as yellow fever and dengue fever.

The new device relies on lateral flow technology, which is used in pregnancy tests and has recently been exploited for diagnosing strep throat and other bacterial infections. Unlike most existing paper diagnostics, which test for only one disease, the new MIT strips are color-coded so they can be used to distinguish among several diseases.

Kimberly Hamad-Schifferli and Lee Gehrke are the senior authors of a paper describing the new device in the journal *Lab on a Chip*. The paper's lead author is postdoc Chun-Wan Yen, and other authors are graduate student Helena de Puig, postdoc Justina Tam, instructor Jose Gomez-Marquez, and visiting scientist Irene Bosch.

http://newsoffice.mit.edu/2015/ten-minute-ebola-test-0224

MIT researchers design tailored tissue adhesives

After undergoing surgery to remove diseased sections of the colon, up to 30 percent of patients experience leakage from their sutures, which can cause life-threatening complications. Many efforts are under way to create new tissue glues that can help seal surgical incisions and prevent such complications; now, a new study from MIT reveals that the effectiveness of such glues hinges on the state of the tissue in which they are being used.

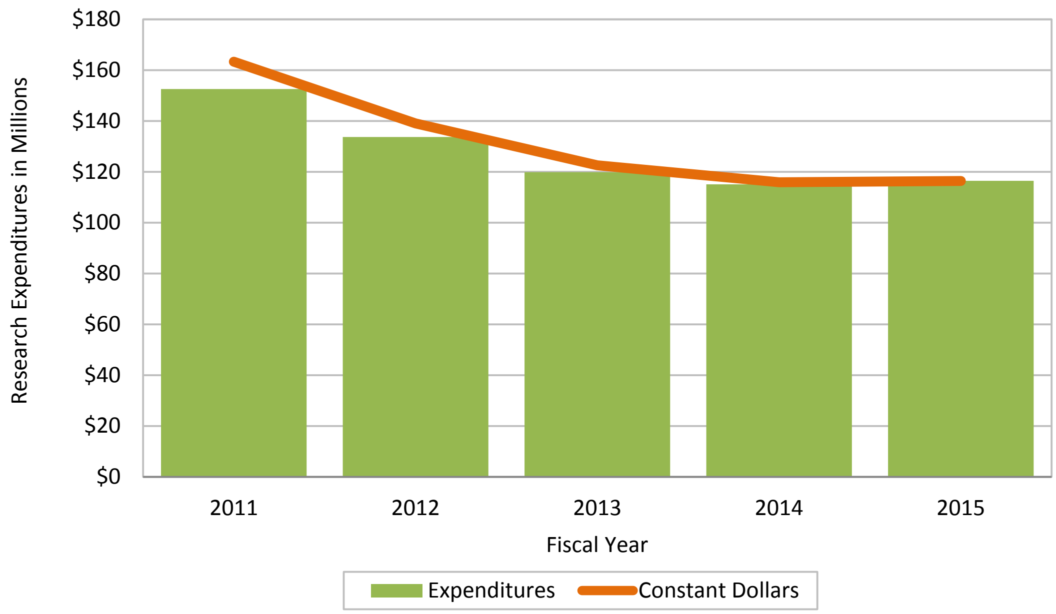
The researchers found that a sealant they had previously developed worked much differently in cancerous colon tissue than in colon tissue inflamed with colitis. The tissue glue works through a system where molecules in the adhesive interact with chemical structures found in abundance in structural tissue known as collagen. When enough of the molecules and collagen bind to each other, the adhesive forms a tight seal. This system is disrupted in colitic tissue because the inflammation breaks down collagen. However, cancerous tissue tends to have excess collagen.

Using this data, the researchers created a model to help them alter the composition of the material depending on the circumstances. The researchers can tune it to perform best in different types and states of tissue.

http://newsoffice.mit.edu/2015/tailored-tissue-adhesives-0128

National Institutes of Health Campus Research Expenditures (in U.S. Dollars)*
Fiscal Years 2011–2015

	2011	2012	2013	2014	2015
Campus research	152,664,013	133,687,332	119,908,451	115,074,564	116,469,457
Constant dollars†	163,428,625	139,040,157	122,667,889	115,912,281	116,469,457



*National Institutes of Health data includes expenditures from other Department of Health and Human Services agencies which account for less than 1% of expenditures per year.
†Constant dollars are calculated using the Consumer Price Index for All Urban Consumers weighted with the fiscal year 2015 equaling 100.

Leading Departments, Laboratories, and Centers Receiving Support in Fiscal Year 2015
(Shown in descending order of expenditures)

Koch Institute for Integrative Cancer Research
Biology
Biological Engineering
Picower Institute for Learning and Memory
Chemistry
McGovern Institute for Brain Research
Computer Science and Artificial Intelligence Laboratory
Center for Environmental Health Sciences
Research Laboratory of Electronics
Institute for Medical Engineering and Science

In fall 2014, the National Institutes of Health and other Department of Health and Human Services programs funded the primary appointments of graduate students with 167 research assistantships and 32 fellowships.

Ten current faculty or staff have received the NIH Director's Pioneer Award. The recipients are Edward Boyden, Emery Brown, Arup Chakraborty, James Collins, Hidde Ploegh, Aviv Regev, Leona Samson, Alice Ting, Mehmet Yanik, and Feng Zhang.

NASA

Selected Projects

Working out in artificial gravity

Astronauts on the International Space Station (ISS) have a number of exercise options, including a mechanical bicycle bolted to the floor, a weightlifting machine strapped to the wall, and a strap-down treadmill. They spend a significant portion of each day working out to ward off the long-term effects of weightlessness, but many still suffer bone loss, muscle atrophy, and issues with balance and their cardiovascular systems.

To counteract such debilitating effects, research groups around the world are investigating artificial gravity—the notion that astronauts, exposed to strong centrifugal forces, may experience the effects of gravity, even in space. Engineers have been building and testing human centrifuges—spinning platforms that, at high speeds, generate G-forces strong enough to mimic gravity.

Now engineers at MIT have built a compact human centrifuge with an exercise component: a cycle ergometer that a person can pedal as the centrifuge spins. The centrifuge was sized to just fit inside a module of the ISS. After testing the setup on healthy participants, the team found the combination of exercise and artificial gravity could significantly lessen the effects of extended weightlessness in space—more so than exercise alone.

Professor Laurence Young says artificial gravity would be a huge benefit for astronauts, particularly those embarking on long-duration space missions, such as a journey to Mars. The risks, he says, are uncertain, but potentially significant. He and his colleagues, former graduate students Ana Diaz and Chris Trigg, have published results from their experiments in the journal *Acta Astronautica*.

http://newsoffice.mit.edu/2015/exercise-artificial-gravity-space-0702

A second minor planet may possess Saturn-like rings

There are only five bodies in our solar system that are known to bear rings. The planet Saturn; to a lesser extent, rings of gas and dust also encircle Jupiter, Uranus, and Neptune. The fifth member of this haloed group is Chariklo, one of a class of minor planets called centaurs: small, rocky bodies that possess qualities of both asteroids and comets.

Scientists only recently detected Chariklo's ring system—a surprising finding, as it had been thought that centaurs are relatively dormant. Scientists at MIT and elsewhere have detected a possible ring system around a second centaur, Chiron.

The group observed a stellar occultation in which Chiron passed in front of a bright star. The researchers analyzed the star's light emissions, and the momentary shadow created by Chiron, and identified optical features that suggest the centaur may possess a circulating disk of debris. The team believes the features may signify a ring system.

Amanda Bosh, Jessica Ruprecht, Michael Person, and Amanda Gulbis have published their results in the journal *Icarus*.

http://newsoffice.mit.edu/2015/planet-chiron-saturn-like-rings-0317

A twist on planetary origins

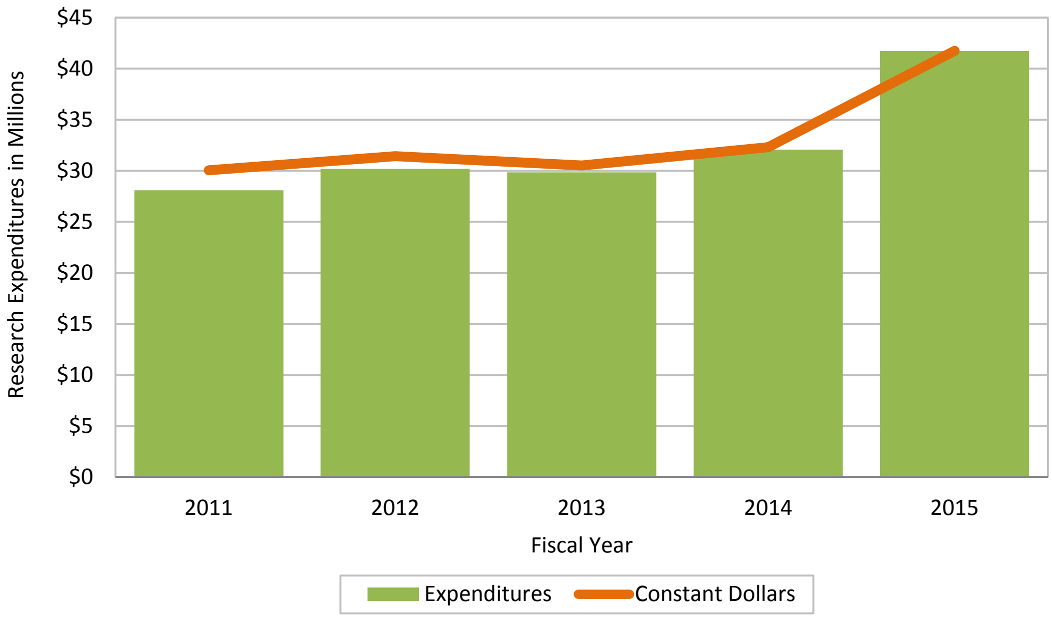
Meteors that have crashed to Earth have long been regarded as relics of the early solar system. These craggy chunks of metal and rock are studded with chondrules—tiny, glassy, spherical grains that were once molten droplets. Scientists have thought that chondrules represent early kernels of terrestrial planets: As the solar system started to coalesce, these molten droplets collided with bits of gas and dust to form larger planetary precursors.

Researchers at MIT and Purdue University have found that chondrules may have played less of a fundamental role. Based on computer simulations, the group concludes that chondrules were not building blocks, but rather byproducts of a violent and messy planetary process. Postdoc Brandon Johnson says the findings revise one of the earliest chapters of the solar system. Johnson and his colleagues, including Maria Zuber, have published their results in the journal *Nature*.

http://newsoffice.mit.edu/2015/meteorites-byproducts-of-planetary-formation-0114

NASA Campus Research Expenditures (in U.S. Dollars)
Fiscal Years 2011–2015

	2011	2012	2013	2014	2015
Campus research	28,079,693	30,203,575	29,834,713	32,062,601	41,739,692
Constant dollars*	30,059,642	31,412,923	30,521,295	32,296,010	41,739,692



*Constant dollars are calculated using the Consumer Price Index for All Urban Consumers weighted with the fiscal year 2015 equaling 100.

Leading Departments, Laboratories, and Centers Receiving Support in Fiscal Year 2015
(Shown in descending order of expenditures)

Kavli Institute for Astrophysics and Space Research
Earth, Atmospheric and Planetary Sciences
Aeronautics and Astronautics
Haystack Observatory
Center for Global Change Science
Media Laboratory
Civil and Environmental Engineering
Research Laboratory of Electronics
Laboratory for Manufacturing and Productivity
Microsystems Technology Laboratories

In fall 2014, NASA funded the primary appointments of graduate students with 53 research assistantships and 24 fellowships.

National Science Foundation

Selected Projects

Unusual magnetic behavior observed at a material interface

An exotic kind of magnetic behavior, driven by the mere proximity of two materials, has been analyzed by a team of researchers using a technique called spin-polarized neutron reflectometry. They say the new finding could be used to probe a variety of exotic physical phenomena, and could ultimately be used to produce key components of future quantum computers.

The phenomenon occurs at the boundary between a ferromagnet and a topological insulator, which blocks electricity from flowing through all of its bulk but whose surface is, by contrast, a very good electrical conductor. In the new work, a layer of topological insulator material is bonded to a ferromagnetic layer. Where the two materials meet, an effect takes place called proximity-driven magnetic order, producing a localized and controllable magnetic pattern at the interface.

One of the new findings of this research is that the magnetism induced by the proximity of the two materials is not just at the surface, but actually extends into the interior of the topological insulator material. Possible applications of the new findings include the creation of spintronics, transistors based on the spin of particles rather than their charge. These are expected to have low energy dissipation if based on topological insulators, and are a very active area of research.

The research is described in a paper in the journal *Physical Review Letters*, written by doctoral student Mingda Li, postdoc Cui-Zu Chang, professor Ju Li, senior scientist Jagadeesh Moodera, and seven others. The work included researchers at the National Institute of Standards and Technology, Brookhaven National Laboratory, Northeastern University, and Boston College.

http://newsoffice.mit.edu/2015/unusual-magnetic-behavior-quantum-computers-0818

Giving robots a more nimble grasp

Engineers at MIT have now hit upon a way to impart more dexterity to simple robotic grippers: using the environment as a helping hand. The team, led by assistant professor Alberto Rodriguez, and graduate student Nikhil Chavan-Dafle, has developed a model that predicts the force with which a robotic gripper needs to push against various fixtures in the environment in order to adjust its grasp on an object. For instance, if a robotic gripper aims to pick up a pencil at its midpoint, but instead grabs hold of the eraser end, Rodriguez's model enables a robot to loosen its grip slightly, and push the pencil against a nearby wall, just enough to slide the robot's gripper closer to the pencil's midpoint.

With Rodriguez's new approach, robots in manufacturing, disaster response, and other gripper-based applications may interact with the environment, in a cost-effective way, to perform more complex maneuvers.

http://newsoffice.mit.edu/2015/giving-robots-more-nimble-grasp-0804

Predicting the shape of river deltas

The Mississippi River delta is a rich ecosystem of barrier islands, estuaries, and wetlands that's home to a diverse mix of wildlife—as well as more than 2 million people. Over the past few decades, the shape of the delta has changed significantly, as ocean waves have carved away at the coastline, and marshes lacking new river sediment have submerged habitats.

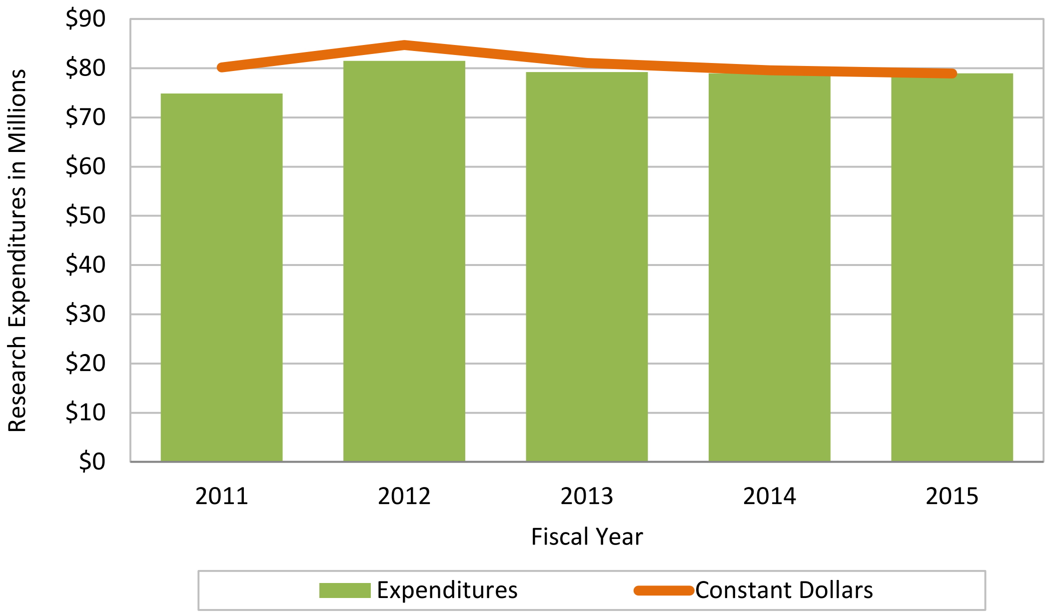
To keep flooding at bay, engineers have erected dams and levees along the river. However, it's unclear how such measures will affect the shape of the delta, and affect its communities, over time. Now researchers from MIT and the Woods Hole Oceanographic Institution (WHOI) have devised a simple way to predict a river delta's shape, given two competing factors: how fast a river forces sediment into the ocean, and ocean waves' strength in pushing that sediment back along the coast. The new metric may help engineers determine how the shape of deltas around the world may shift in response to engineered structures such as dams and levees, and environmental changes, such as hurricane activity and sea-level rise.

Jaap Nienhuis, a graduate student in the MIT-WHOI Joint Program in Marine Geology and Geophysics, and Andrew Ashton and Liviu Giosan of WHOI, report their results in the journal *Geology*.

http://newsoffice.mit.edu/2015/predicting-shape-river-deltas-0722

National Science Foundation Campus Research Expenditures (in U.S. Dollars)
Fiscal Years 2011–2015

	2011	2012	2013	2014	2015
Campus research	74,859,339	81,487,208	79,255,278	78,978,705	78,952,919
Constant dollars*	80,137,804	84,749,947	81,079,170	79,553,652	78,952,919



*Constant dollars are calculated using the Consumer Price Index for All Urban Consumers weighted with the fiscal year 2015 equaling 100.

Leading Departments, Laboratories, and Centers Receiving Support in Fiscal Year 2015
(Shown in descending order of expenditures)

Computer Science and Artificial
Intelligence Laboratory
Research Laboratory of Electronics
Earth, Atmospheric and Planetary Sciences
Biological Engineering
McGovern Institute for Brain Research
Kavli Institute for Astrophysics and Space Research
Haystack Observatory
Mathematics
Chemistry
Media Laboratory

In fall 2014, the National Science Foundation funded the primary appointments of graduate students with 287 research assistantships and 199 fellowships.

The National Science Foundation has awarded Faculty Early Career Development (CAREER) Awards to 155 current faculty and staff members.

Other Federal Agencies

Selected Projects

Can rain clean the atmosphere?

As a raindrop falls through the atmosphere, it can attract tens to hundreds of tiny aerosol particles to its surface before hitting the ground. The process by which droplets and aerosols attract is coagulation, a natural phenomenon that can act to clear the air of pollutants like soot and organic particles.

Atmospheric chemists at MIT have now determined just how effective rain is in cleaning the atmosphere. Given the altitude of a cloud, the size of its droplets, and the diameter and concentration of aerosols, the team can predict the likelihood that a raindrop will sweep a particle out of the atmosphere.

The researchers carried out experiments in the group's MIT Collection Efficiency Chamber—a 3-foot-tall glass chamber that generates single droplets of rain at a controlled rate and size. As droplets fell through the chamber, researchers pumped in aerosol particles, and measured the rate at which droplets and aerosols merged, or coagulated. In general, they found that the smaller the droplet, the more likely it was to attract a particle. Conditions of low relative humidity also seemed to encourage coagulation.

Dan Cziczo, an associate professor, says the new results, published in the journal *Atmospheric Chemistry and Physics*, represent the most accurate values of coagulation to date. These values, he says, may be extrapolated to predict rain's potential to clear a range of particles in various environmental conditions.

The paper's co-authors are postdoc Karin Ardon-Dryer and former postdoc Yi-Wen Huang. This research was funded, in part, by the National Oceanic and Atmospheric Administration.

http://news.mit.edu/2015/rain-drops-attract-aerosols-clean-air-0828

Measuring climate change action

Reducing global greenhouse gas emissions could have big benefits in the U.S., according to a report released by the U.S. Environmental Protection Agency (EPA), including thousands of avoided deaths from extreme heat, billions of dollars in saved infrastructure expenses, and prevented destruction of natural resources and ecosystems.

The report, "Climate Change in the United States: Benefits of Global Action", relies on research developed at the MIT Joint Program on the Science and Policy of Global Change to estimate the effects of climate change on 22 sectors in six areas: health, infrastructure, electricity, water resources, agriculture and forestry, and ecosystems.

The MIT researchers developed two suites of future climate scenarios, socioeconomic scenarios, and technological assumptions that serve as the foundation of the EPA report's findings. In the first scenario, no new constraints were placed on greenhouse gas emissions. In the second, global warming was limited to 2 degrees Celsius through global climate action.

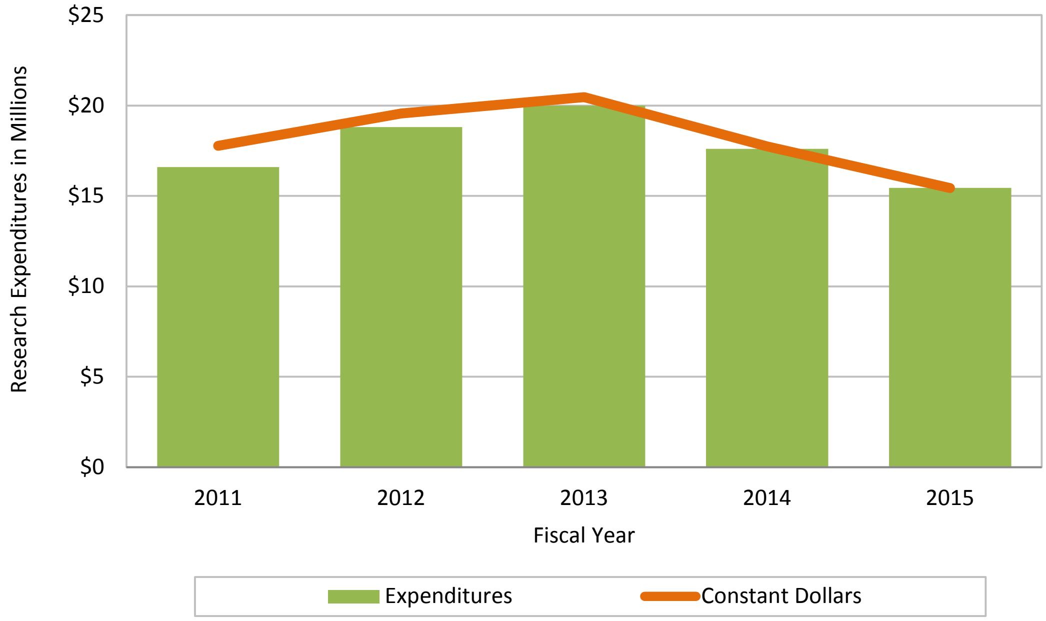
Research groups across the country then built on the scenarios developed at MIT to study how different sectors in the U.S. would fare under each future scenarios. The groups studied a diverse range of impacts of climate change according to their own areas of expertise, ranging from lost wages due to extreme temperatures, to damage to bridges from heavy river flows, among others. The MIT team also contributed heavily to the section of the report focusing on water resources. The report concludes that mitigating greenhouse gas emissions can reduce the risk of both damaging floods and droughts, and prevent future water management issues.

The report is part of the ongoing Climate Impacts and Risk Analysis (CIRA) program, an EPA-led collaborative modeling effort among teams in the federal government, MIT, the Pacific Northwest National Laboratory, the National Renewable Energy Laboratory, and several consulting firms. The report summarizes more than 35 studies that were individually peer reviewed in scientific journals.

http://newsoffice.mit.edu/2015/measuring-climate-change-action-epa-report-0622

Other Federal Agencies Campus Research Expenditures (in U.S. Dollars)
Fiscal Years 2011–2015

	2011	2012	2013	2014	2015
Campus research	16,602,212	18,806,804	19,993,508	17,611,014	15,435,252
Constant dollars*	17,772,863	19,559,826	20,453,616	17,739,219	15,435,252



*Constant dollars are calculated using the Consumer Price Index for All Urban Consumers weighted with the fiscal year 2015 equaling 100.

A few of the leading other federal agencies providing funding are: the Department of Commerce, the Department of Transportation, the Federal Aviation Administration, the Intelligence Advanced Research Projects Activity, and the Environmental Protection Agency.

Leading Departments, Laboratories, and Centers Receiving Support in Fiscal Year 2015
(Shown in descending order of expenditures)

Center for Transportation and Logistics
Aeronautics and Astronautics
Computer Science and Artificial
Intelligence Laboratory
Sea Grant College Program
Civil and Environmental Engineering
Urban Studies and Planning
Mechanical Engineering
Center for Global Change Science
Materials Processing Center
Sociotechnical Systems Research Center

In fall 2014, other federal agencies funded the primary appointments of graduate students with 50 research assistantships and 1 fellowship.

Nonprofit Organizations
Selected Projects

New material opens possibilities for super-long-acting pills

Medical devices designed to reside in the stomach have a variety of applications, including prolonged drug delivery, electronic monitoring, and weight-loss intervention. However, these devices, often created with nondegradable elastic polymers, bear an inherent risk of intestinal obstruction as a result of accidental fracture or migration. As such, they are usually designed to remain in the stomach for a limited time.

Researchers at MIT's Koch Institute for Integrative Cancer Research and Massachusetts General Hospital (MGH) have created a polymer gel that overcomes this safety concern and could allow for the development of long-acting devices that reside in the stomach, that can release drugs over a number of days, weeks, or potentially months following a single administration. This polymer is pH-responsive: It is stable in the acidic stomach environment but dissolves in the small intestine's near-neutral pH, allowing for safe passage through the remainder of the gastrointestinal (GI) tract. The material is also elastic, allowing for the compression and folding of devices into easily ingestible capsules—meaning this polymer can be used to create safe devices designed for extremely prolonged residence in the stomach.

Koch Institute research affiliate Giovanni Traverso, also a gastroenterologist at MGH and an instructor at Harvard Medical School, and Robert Langer, the David H. Koch Institute Professor at MIT and a member of the Koch Institute, are the senior authors of a paper in *Nature Materials* that describes the application of this new polymer gel for creating gastric devices. Shiyi Zhang, a postdoc at the Koch Institute, is the paper's lead author. The paper's other authors include Andrew Bellinger, Dean Glettig, Ross Barman, Young-Ah Lee, Cody Cleveland, Veronica Montgomery, and Li Gu from MIT; Jiahua Zhu from Oak Ridge National Laboratory; and Landon Nash and Duncan Maitland from Texas A&M University.

http://newsoffice.mit.edu/2015/polymer-gel-swallowable-devices-drug-delivery-0727

Ocean acidification may cause dramatic changes to phytoplankton

Oceans have absorbed up to 30 percent of human-made carbon dioxide around the world, storing dissolved carbon for hundreds of years. Since pre-industrial times, the pH of the oceans has dropped from an average of 8.2 to 8.1 today. Projections of climate change estimate that by the year 2100, this number will drop further, to around 7.8—significantly lower than any levels seen in open ocean marine communities today.

A team of researchers from MIT, the University of Alabama at Birmingham, and elsewhere has found that such increased ocean acidification will dramatically affect global populations of phytoplankton—microorganisms on the ocean surface that make up the base of the marine food chain.

In a study published in the journal *Nature Climate Change*, the researchers report that increased ocean acidification by 2100 will spur a range of responses in phytoplankton: Some species will die out, while others will flourish, changing the balance of plankton species around the world.

The researchers also compared phytoplankton's response to other projected drivers of climate change, such as warming temperatures and lower nutrient supplies. Based on global simulations, however, they found the most dramatic effects stemmed from ocean acidification.

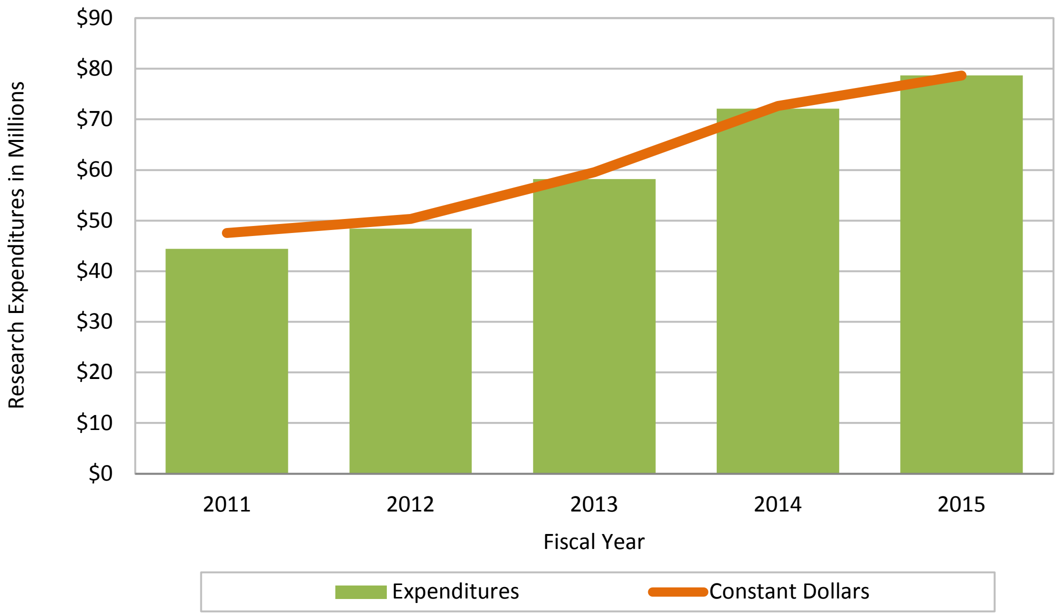
Stephanie Dutkiewicz, a principal research scientist in MIT's Center for Global Change Science, says that while scientists have suspected ocean acidification might affect marine populations, the group's results suggest a much larger upheaval of phytoplankton—and therefore probably the species that feed on them —than previously estimated. Dutkiewicz says shifting competition at the plankton level may have big ramifications further up in the food chain.

Dutkiewicz, is the paper's lead author. The paper's co-authors include associate professor Mick Follows.

http://newsoffice.mit.edu/2015/ocean-acidification-phytoplankton-0720

Nonprofit Organizations Campus Research Expenditures (in U.S. Dollars)
Fiscal Years 2011–2015

	2011	2012	2013	2014	2015
Campus research	44,436,470	48,373,460	58,226,616	72,117,488	78,666,639
Constant dollars*	47,569,765	50,310,328	59,566,578	72,642,488	78,666,639



*Constant dollars are calculated using the Consumer Price Index for All Urban Consumers weighted with the fiscal year 2015 equaling 100.

Leading Departments, Laboratories, and Centers
Receiving Support in Fiscal Year 2015
(Shown in descending order of expenditures)

Koch Institute for Integrative Cancer Research
Masdar
Computer Science and Artificial
Intelligence Laboratory
Economics
Civil and Environmental Engineering
Research Laboratory of Electronics
Mechanical Engineering
McGovern Institute for Brain Research
Biological Engineering
Materials Processing Center