Chapter 5.

Academic Research and Development

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Highlights

Spending for Academic R&D

In 2014, U.S. academic institutions spent $63.7 billion on research and development in all S&E fields.

- When adjusted for inflation, spending decreased by 1% between 2013 and 2014.
- As in prior years and dating back over four decades, academic R&D spending was concentrated in a relatively small number of public and private research-intensive institutions, which conduct a large share of the nation's basic research.
- Although the federal government provided well over half of academic R&D funds in 2014 (58%), its share has declined in recent years.
- By contrast, universities' share of academic R&D spending has grown in recent years and reached its highest level ever in 2014 (22%).

Six agencies provided over 92% of federal support for academic R&D in S&E in 2014.

- In declining order of funding, the major federal agencies that support academic R&D are the Department of Health and Human Services (HHS), the National Science Foundation, the Department of Defense, the Department of Energy, the National Aeronautics and Space Administration, and the Department of Agriculture.
- HHS (mainly through the National Institutes of Health) provides the bulk of total federal funds for academic R&D in S&E (55% in 2014).

Funding sources differed in importance for public and private institutions in 2014, as in prior years.

- Public universities relied more heavily on state and local government funds than their private counterparts (8% versus 2%) and more heavily on their own funds (25% versus 18%).
- Private universities relied more heavily than public universities on the federal government (66% versus 54%).
- Business funding and nonprofit funding were broadly similar for both types of institutions: 6% from business, and 8%–9% from nonprofits and other sources.

Over the last quarter century, the distribution of academic R&D expenditures has shifted in favor of life sciences and away from physical sciences. However, over the last decade, engineering R&D has grown faster than R&D in life sciences.

- Life sciences received the largest share (59%) of funding in academic S&E R&D in 2014, followed by engineering (17%).
- Over the last 20 years, life sciences was the only broad S&E field to experience a sizable increase in share—5 percentage points—of total academic R&D in S&E.
- Within life sciences, the fields of medical sciences and biological sciences have grown more rapidly than agricultural sciences.
- Within engineering, bioengineering has grown faster than the other engineering fields, although from a lower base.

- The other broad fields of science—computer sciences, environmental sciences, mathematical sciences, physical sciences, psychology, and social sciences—each received between 1% and 7% of total funding in academic S&E R&D in 2014.

Research collaboration involving multiple institutions and fields mirrors recent trends in overall academic R&D.

- Funds continue to flow among institutions in the form of pass-through arrangements made to support collaborative research activities. Although growth in pass-through funds historically has exceeded growth in overall academic R&D spending, pass-through funds in 2014 declined slightly (1%) from 2013 levels after adjusting for inflation, similar to overall academic R&D.
- With some vacillations, growth has been registered during most of the past decade in sciences that cannot be classified within one field but that instead span or integrate multiple disciplines. In 2014, approximately $1 billion was spent on such "other sciences."

Infrastructure for Academic R&D

Research space at academic institutions has continued to grow annually since the 1980s, although the pace of growth has slowed in the last few years.

- Total research space at universities and colleges was 4.7% greater at the end of 2013 than it was in 2011.
- Research space for the biological and biomedical sciences accounted for 27% of all S&E research space in 2013, making it the largest of all the major fields.
- In 2013, 81% of research space was reported as being in either superior or satisfactory condition by academic institutions, while 4% needed replacement, and the rest required renovation.
- The bulk of capital costs for laboratory and research facilities continues to be borne by the universities themselves, typically above 60% of the total. State and local governments typically support more than a quarter of the costs, while the federal government has consistently provided well below 10% of such funds.

In 2014, about $2 billion was spent for academic research equipment (i.e., movable items such as computers or microscopes), a decrease of 11% from 2013 after adjusting for inflation.

- Equipment spending as a share of total academic R&D expenditures reached a three-decade low of 3.1% in 2014.
- Three S&E fields accounted for 87% of equipment expenditures in 2014: life sciences (37%), engineering (33%), and physical sciences (17%).
- In 2014, the federal share of support for all academic research equipment funding fell below 50% for the first time since data collection began in 1981. The 2014 federal support share of 45.1% was 10 percentage points lower than the 2013 share of 55.5%.

Cyberinfrastructure

High-speed networking infrastructure, high-performance computing, and related technologies and services have become integral components of academic research.

- These resources are difficult to quantify due to rapid developments in technology.

- Valid measurements of academic R&D cyberinfrastructure are not yet available despite the central role that cyberinfrastructure now plays in many fields of S&E research.

Doctoral Scientists and Engineers in Academia

The academic workforce with research doctorates in science, engineering, and health (SEH, hereafter referred to as S&E) numbered just under 370,000 in 2013, the latest year for which data are available.

- The U.S.-trained portion of this workforce numbered about 309,000, and the foreign-trained portion numbered about 59,000.
- Growth from 2010 to 2013 in the U.S.-trained doctoral academic workforce (6%) was similar to growth in the doctoral workforce employed by businesses (4%); by contrast, the doctoral workforce employed by federal, state, or local governments remained stable from 2010 to 2013.
- The share of all U.S.-trained S&E doctorate holders employed in academia dropped from 55% in 1973 to 42% in 2013.

Full-time faculty positions for S&E doctorate holders have been in steady decline for four decades, offset by a rise in other types of full- and part-time positions.

- The percentage of S&E doctorate holders employed in academia who held full-time faculty positions declined from about 90% in the early 1970s to about 70% in 2013.
- Compared to 1997, a smaller share of the doctoral academic workforce had achieved tenure in 2013. In 1997, tenured positions accounted for an estimated 53% of doctoral academic employment; this decreased to 47% in 2013. Tenure-track positions as a share of doctoral academic employment, however, held steady.

The demographic profile of the U.S.-trained academic doctoral workforce has shifted substantially over time.

- The number of women in academia grew substantially between 1997 and 2013, from about 60,000 to 114,000. In 2013, women constituted 37% of academically employed doctorate holders, up from 25% in 1997. Women as a share of full-time senior doctoral faculty also increased substantially.
- In 2013, underrepresented minorities (blacks, Hispanics, and American Indians or Alaska Natives) constituted 8.8% of total U.S.-trained academic doctoral employment and 8.3% of full-time faculty positions, up from about 2% in 1973 and 7%–8% of these positions in 2003.
- More than one-quarter (27%) of U.S.-trained doctorate holders in academia were foreign born, contrasted with about 12% in 1973.
- About one-half of all U.S.-trained postdoctorates (postdocs) were born outside of the United States.
- The U.S.-trained doctoral academic workforce has aged substantially over the past two decades. In 2013, 24% of those in full-time faculty positions were between 60 and 75 years of age, compared with 11% in 1995.

Since 1993, there has been an increase in the share of full-time faculty who identify research as their primary work activity, and there has been a decrease in the share of full-time faculty who identify teaching as their primary activity.

- Slightly more than one-third (36%) of full-time faculty identified research as their primary work activity in 2013, up slightly from 33% in 1993.

- In 2013, 31% of recently degreed doctoral faculty identified research as their primary work activity.
- The share of full-time faculty who identified teaching as their primary activity declined from 53% in 1993 to 46% in 2013.

A substantial pool of academic researchers exists outside the ranks of tenure-track faculty.

- Approximately 43,000 S&E doctorate holders were employed in academic postdoc positions in 2013.
- In 2013, 42% of U.S.-trained doctorate holders less than 4 years beyond the doctorate held academic postdoc positions, exceeding the share (29%) employed in full-time faculty positions. Among those 4–7 years beyond their doctorates, 17% held postdoc positions.
- Almost 115,000 graduate research assistants conducted research in academia in 2013, underscoring the tight link between advanced education and direct cutting-edge research training.
- Other S&E doctorate holders engaged in academic R&D include research associates and adjunct faculty.

The share of U.S.-trained academic doctorate holders receiving federal support declined somewhat since the early 1990s.

- In 2013, about 44% of doctorate holders received federal support, compared with 49% of their peers during the late 1980s and very early 1990s.
- Among full-time faculty, recent doctorate recipients were less likely to receive federal support than their more established colleagues.
- Federal support has become less available to doctorate holders in nonfaculty positions, declining from about 60% in 1973 to about 43% in 2013.

Outputs of S&E Research: Publications and Patents

U.S. researchers accounted for just under one-fifth of the global output volume of peer-reviewed S&E articles; academic researchers contributed about three-quarters of the U.S. total. Like U.S. output, the number of EU and Japanese publications have continued to grow.

- But the developing world's growing capacity for scientific and technical activities is manifest in rapidly increasing output of peer-reviewed S&E publications. The balance of global articles—2.2 million in 2013--is shifting towards authors from the developing world. The United States and China have reached approximate parity in their respective shares of the world's total S&E publications in 2013, at 18.8% and 18.2%, respectively. Between 2003 and 2013, the U.S. share declined from 26.8%, and China's share almost tripled from 6.4%. China's growth rate was the fastest among the top 15 producers of S&E publications.
- Japan, the country with the third-largest share of S&E publications in 2013, experienced a decline from 7.8% to 4.7% over the period. Shares of Germany and the United Kingdom, fourth and fifth largest producers, declined from 6.0% to 4.6% and 6.2% to 4.4%, respectively.
- After a decade of 13.6% average annual growth, India is the sixth-largest producer of S&E articles, with a 4.2% share of world S&E publication output in 2013. South Korea reached 2.7%, Brazil 2.2%.
- Iran, a developing nation with a much smaller publication base in 2003, grew to a 1.5% global share by 2013, becoming the 16th-largest producer of S&E publications.
- When viewed as one region, the share for the EU declined, from 33.0% in 2003 to 27.5% in 2013.

Biological and medical sciences dominate research output in the United States, Japan, and the EU. Engineering dominates in China.

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- Of the major producers of S&E publications, the United States has the highest concentration of publications in medical sciences.
- The United States has 46% and the EU has 40% of their publications in two fields, biological and medical sciences. Japan has 39% of its publications in those fields.
- China has 38% of its publications in engineering and 21% in biological and medical sciences.
- Of these major producers, India has the highest concentration of publications in biological sciences and the second-highest concentration in engineering.

S&E research publications are increasingly collaborative as well as increasingly international in authorship.

- More than 60% of global S&E publications had multiple authors in 2013, compared with less than half of such publications in 2000.
- Internationally coauthored publications correspondingly grew from 13.2% to 19.2% of all coauthored publications over the same period.
- International collaboration grew between 2000 and 2013 in all fields of science, with the highest percentage of international collaboration in astronomy and geosciences and the lowest percentage in engineering and social sciences.
- In the United States, 33% of publications were coauthored with institutions in other countries in 2013, compared with 19% in 2000.
- Among the major producers of S&E publications, the United Kingdom had the highest international collaboration rate in 2013, at 51%.

The impact of S&E publications has also become more global. U.S. S&E publications increasingly cite S&E publications from foreign authors and also increasingly receive citations from foreign-authored publications.

- Between 1996 and 2012, U.S. authors increased their citations to international S&E publications from 43% to 55% more than would otherwise have been expected, based on the number of U.S. S&E publications.
- The average impact of U.S. publications—a measure of citations received relative to the number of S&E articles published—was 43% higher than would otherwise have been expected in 2012.
- The average impact of S&E publications from China and India is increasing rapidly, though it is still below what would be expected, based on the number of publications.
- In 2012, publications with U.S. authors were almost twice as likely to be among the world's top 1% most-cited publications as would be expected, based on the volume of U.S. publications.
- By this measure, S&E publications from the Netherlands and Sweden are more than twice as likely to be among the top 1% of highly cited articles; S&E publications from Switzerland, almost three times as likely.
- Publications with Chinese authors are still less likely to be in the top 1% cited but are increasing their presence.

U.S. academic patents have been on a rising trend since 2008.

- Patents granted by the U.S. Patent and Trademark Office to U.S. academic institutions reached 5,990 in 2014, accounting for 4% of the patents issued to U.S. owners.
- The largest technology category for U.S. academic patents in 2014 was pharmaceuticals, which made up 16% of patents to academic institutions.

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- Pharmaceutical patents exceeded biotechnology patents in 2012. Biotechnology is now the second-largest category (13%) of university patents.
- The top 201 U.S. patenting universities and university systems were granted 99% of the total patents granted to U.S. universities between 1996 and 2014.

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Introduction

Chapter Overview

U.S. academic institutions play a critical role in the nation's S&E enterprise by providing advanced education and training students in research practices in the areas of science, engineering, and mathematics. The nation's universities together conduct over half of the nation's basic research, thus creating new knowledge and contributing to innovation. This model, widely admired, draws large numbers of foreign students and researchers to the U.S. research enterprise who contribute to its vitality and robustness. This chapter analyzes trends in funding sources and spending levels for academic research and development and illustrates patterns of spending. It discusses academic research facilities and equipment and examines academic research personnel. The chapter concludes with an analysis of selected results of this work in the form of journal articles and citations to these articles, along with patent-based measures.

Chapter Organization

The first section of this chapter examines trends in spending on academic R&D. It discusses funding sources and spending patterns by institution types and fields. The section highlights the continuing role of federal funding for academic R&D, even as the federal share of total spending in recent years has continued to decline, while the share paid for by universities themselves has increased.

The chapter's second section analyzes trends in infrastructure by field for academic R&D, including research facilities and research equipment. In addition, this section also comments on the role of academic research cyberinfrastructure such as high-performance computing (HPC), networking, and storage resources.

The academic workforce of scientists and engineers has changed substantially over the past decades, and the third section examines these trends, including changing demographics and types of positions held. The section further analyzes the degree of participation in academic research of full-time faculty, postdoctorates (postdocs), and graduate research assistants and focuses on recipients of federal research funds, particularly early career researchers.

The fourth and final section of this chapter analyzes trends in two types of research outputs: S&E publications, which are largely (but not exclusively) produced by the academic sector, and patents issued to U.S. universities. This section first compares the volume of S&E publications for selected regions, countries, and economies, focusing (when appropriate) on patterns and trends in publications by U.S. academic researchers. Trends in coauthored publications, both across U.S. sectors and internationally, are indicators of increasing collaboration in S&E research. Trends in production of influential publications, as measured by the frequency with which publications are cited, are examined, with emphasis on international comparisons. The analysis of U.S. academic patenting activities examines patents, licenses, and income from these as forms of academic R&D output. Patent citations to the S&E literature are also examined, with emphasis on citations in awarded patents for clean energy and related technologies.

Expenditures and Funding for Academic R&D

Academic R&D is a key component of the overall U.S. R&D enterprise.[i] Academic scientists and engineers conduct the bulk of the nation's basic research and, importantly, train young researchers in the process. (For an overview of the sources of data used, see sidebar, Data on the Financial and Infrastructure Resources for Academic R&D).

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[i] The academic R&D totals presented here exclude expenditures at the federally funded research and development centers (FFRDCs) associated with universities. Those expenditures are tallied separately and discussed in chapter 4. Nevertheless, the FFRDCs and other national laboratories (including federal intramural laboratories) play an important role in academic research and education, providing research opportunities for students and faculty at academic institutions, often by providing highly specialized, shared research facilities.

Data on the Financial and Infrastructure Resources for Academic R&D

Financial data on academic R&D are drawn from the National Science Foundation's Survey of Research and Development Expenditures at Universities and Colleges (1972–2009) and its successor, the Higher Education Research and Development Survey (HERD; 2010 onward). Trend analysis is possible because both surveys capture comparable information on R&D expenditures by sources of funds and field. HERD offers a more comprehensive treatment of R&D (including non-S&E fields), an expanded group of surveyed institutions, and greater detail about the sources of funding for R&D expenditures by field (Britt 2010). The latest survey is available at http://nsf.gov/statistics/srvyherd/surveys/srvyherd_2014.pdf.

HERD data are in current-year dollars and reported on an academic-year basis. For example, FY 2014 covers July 2013–June 2014 for most institutions and is referred to in this chapter as 2014. HERD data spanning more than 1 year are generally presented in inflation-adjusted constant 2009 dollars using gross domestic product implicit price deflators.

The data on research facility infrastructure come from the Survey of Science and Engineering Research Facilities. The facilities survey includes all universities and colleges in HERD with $1 million or more in R&D expenditures. These surveys are completed by university and college administrators under the direction of the institutional presidents. The latest survey is available at http://nsf.gov/statistics/srvyfacilities/surveys/srvyfacilities_2013.pdf.

Data on federal obligations for academic R&D are reported in chapter 4; that chapter also provides data on the academic sector's share of the nation's overall R&D.

National Academic R&D Expenditures in All Fields

Expenditures by U.S. colleges and universities on R&D in all fields totaled $67.3 billion in 2014.[i] This total includes spending by 895 degree-granting institutions that spent at least $150,000 in R&D in 2014. Furthermore, it includes spending of $3.4 billion in non-S&E fields, which constituted 5% of total academic R&D (Table 5-1). In this chapter, the discussion focuses on the highest-spending institutions, that is, 634 institutions that reported at least $1 million in R&D. Together, these schools accounted for over 99% ($67.2 billion) of academic R&D spending in

2014 (Table 5-2) . Where possible, this chapter will focus on these institutions' R&D spending in the various fields of S&E. However, certain Higher Education Research and Development Survey (HERD) data are not separated by field. Such data include institutions' estimates of spending for basic research, applied research, and development; American Recovery and Reinvestment Act of 2009 (ARRA)-funded R&D; data on R&D funds that universities and colleges pass through to other institutions (or receive from others); and detail on institutionally financed R&D.

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[i] In this chapter, the terms *universities and colleges, schools, higher education,* and *academic institutions* are used interchangeably.

Table 5-1 **R&D expenditures in non-S&E fields at universities and colleges: FY 2014**

(Millions of current dollars)

Field	Total expenditures	Federal expenditures
All non-S&E fields	3,412	1,127
Business and management	483	78
Communication, journalism, and library science	167	54
Education	1,242	661
Humanities	399	76
Law	148	24
Social work	225	106
Visual and performing arts	96	9
Other non-S&E fields	652	119

NOTE: Detail may not add to total because some respondents reporting non-S&E R&D expenditures did not break out total and federal funds by non-S&E fields.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey, 2014.

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Table 5-2 Higher education R&D expenditures, by source, character of work, and institution type: FYs 2010–14

(Thousands of dollars)

	All sources				Federal sources			
Fiscal year and institution type	Total	Basic research	Applied research	Development	Total	Basic research	Applied research	Development
2010								
All institutions	61,253,743	40,282,242	15,726,093	5,245,408	37,475,234	25,432,529	9,393,753	2,648,952
Public	41,231,333	27,065,641	10,637,171	3,528,521	23,349,370	15,829,220	5,723,934	1,796,216
Private	20,022,410	13,216,601	5,088,922	1,716,887	14,125,864	9,603,309	3,669,819	852,736
2011								
All institutions	65,276,179	42,378,148	17,217,069	5,680,962	40,767,871	27,165,672	10,666,679	2,935,520
Public	43,915,002	28,680,207	11,585,251	3,649,544	25,385,046	17,015,546	6,571,448	1,798,052
Private	21,361,177	13,697,941	5,631,818	2,031,418	15,382,825	10,150,126	4,095,231	1,137,468
2012								
All institutions	65,729,338	41,821,911	17,902,343	6,005,084	40,139,567	26,156,548	10,846,437	3,136,582
Public	44,162,988	28,454,204	11,992,691	3,716,093	25,107,091	16,565,923	6,689,969	1,851,199
Private	21,566,350	13,367,707	5,909,652	2,288,991	15,032,476	9,590,625	4,156,468	1,285,383
2013								
All institutions	67,014,807	43,108,628	17,614,033	6,292,146	39,444,861	25,831,607	10,534,555	3,078,699

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	All sources				Federal sources			
Fiscal year and institution type	Total	Basic research	Applied research	Development	Total	Basic research	Applied research	Development
Public	44,851,358	28,855,083	11,929,504	4,066,771	24,687,550	16,194,093	6,653,441	1,840,016
Private	22,163,449	14,253,545	5,684,529	2,225,375	14,757,311	9,637,514	3,881,114	1,238,683
2014								
All institutions	67,154,642	42,952,394	17,835,521	6,366,727	37,922,314	24,813,130	10,091,346	3,017,838
Public	44,657,466	28,499,463	11,850,721	4,307,282	23,493,609	15,325,514	6,195,221	1,972,874
Private	22,497,176	14,452,931	5,984,800	2,059,445	14,428,705	9,487,616	3,896,125	1,044,964

NOTE: Data include S&E and non-S&E R&D expenditures.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey.

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Academic R&D spending is primarily for basic research—in 2014, 64% was spent on basic research, 27% was spent on applied research, and 9% was spent on development (Table 5-2),[ii] percentages largely unchanged from 2013. Of federal expenditures for academic R&D, basic research (65%), applied research (27%), and development (8%) accounted for very similar proportions. The estimated percentage of spending on basic research is somewhat less than institutions had reported throughout the late 1990s and the 2000–09 decade (Appendix Table 5-1). Improvements to the survey question in 2010 likely affected how universities reported these shares.[iii]

ARRA provided an important source of federal funds during the economic downturn and recovery. Most of these funds ($9.3 billion) were spent from 2010 to 2012. After adjusting for inflation, federal spending for academic R&D would have increased by an average annual rate of 2.3% from 2009 to 2012 if ARRA had not been enacted; with ARRA funds, these expenditures instead increased by an average annual rate of 4.5%.[iv]

By 2014, universities and colleges had spent the last of the funds provided by ARRA. In total, ARRA provided $11.3 billion over the 5-year period from 2010 to 2014 (Table 5-3).

[ii] For a more complete discussion of these concepts, see the chapter 4 "Glossary." Chapter 4 provides further detail on federal obligations for academic R&D, by character of work.

[iii] Starting in 2010, the Higher Education Research and Development Survey asked institutions to categorize their R&D expenditures as *basic research,* as *applied research,* or as *development*; prior surveys had asked how much total S&E R&D the institution performed and requested an estimate of the percentage of their R&D expenditures devoted to basic research. By only mentioning basic research, the survey question may have caused some respondents to classify a greater proportion of their activities in this category. The 2010 question provided definitions and examples of the three R&D categories to aid institutions in making more accurate assignments. In debriefing interviews, institutional representatives cited the changes in the survey question as the most important factor affecting their somewhat lower estimates of the amount of basic research that institutions performed. The explicit inclusion of clinical trials and research training grants and the addition of non-S&E R&D may also have contributed.

[iv] From 2004 to 2008, prior to the enactment of the American Recovery and Reinvestment Act of 2009, federal academic R&D expenditures were relatively flat; they increased by an annual average rate of only 0.2% after adjusting for inflation. Because non-S&E R&D spending totals were collected only from institutions with S&E R&D and NSF did not attempt to estimate for nonresponse on the non-S&E expenditures survey question, national academic R&D spending totals for these years are lower-bound estimates.

Table 5-3 Federally financed higher education R&D expenditures funded by the American Recovery and Reinvestment Act of 2009, by Carnegie classification and institution type: FYs 2010–14

(Thousands of dollars)

	2010		2011		2012		2013		2014	
Type of institution	All federal R&D expenditures	ARRA	All federal R&D expenditures	ARRA	All federal R&D expenditures	ARRA	All federal R&D expenditures	ARRA	All federal R&D expenditures	ARRA
All institutions	37,475,234	2,684,122	40,767,871	4,173,439	40,139,567	2,435,743	39,444,861	1,468,553	37,922,314	540,590
Very high research	27,641,468	1,980,718	30,047,688	3,113,463	29,863,632	1,803,555	29,683,589	1,123,691	28,620,941	409,936
High research and doctoral research	4,167,348	235,252	4,539,476	398,189	4,487,141	286,484	4,217,978	190,238	4,034,382	69,575
Special focus	3,729,808	317,961	3,994,149	484,460	3,684,878	235,661	3,588,788	95,425	3,297,676	28,142
Other	1,936,610	150,191	2,186,558	177,327	2,103,916	110,043	1,954,506	59,199	1,969,315	32,937
Public	23,349,370	1,609,011	25,385,046	2,547,741	25,107,091	1,600,919	24,687,550	925,392	23,493,609	377,338
Private	14,125,864	1,075,111	15,382,825	1,625,698	15,032,476	834,824	14,757,311	543,161	14,428,705	163,252

NOTES: ARRA = American Recovery and Reinvestment Act of 2009.

Data include S&E and non-S&E federal expenditures. Data starting with FY 2012 include only those institutions with $1 million or more in total R&D expenditures. Institutions reporting less than $1 million in total R&D expenditures completed a shorter version of the survey form, and that form did not request information on ARRA-funded expenditures.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2015) of the Higher Education Research and Development Survey.

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National Academic R&D Spending in S&E Fields

In 2014, universities and colleges spent $63.7 billion on R&D in S&E fields, an increase of only 0.6% over the prior year (Appendix Table 5-2).[i] After adjusting for inflation, spending declined by about the same amount (0.8%), with changes ranging from a reduction of 8% in the relatively small field of computer sciences to an increase of 1% in engineering. Spending in environmental sciences and social sciences increased by less than one-half of 1% each while spending in life sciences and psychology dipped by about the same percentage. Spending in mathematical sciences and physical sciences dropped by between 2% and 3% each.

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[i] The academic R&D reported here includes separately budgeted R&D and related recovered indirect costs and also institutional estimates of unrecovered indirect costs associated with externally funded R&D projects, including committed cost sharing. *Indirect costs* are general expenses that cannot be associated with specific research projects but pay for things that are used collectively by many research projects at an academic institution. Two major components of indirect costs exist: (1) *facilities-related costs,* such as the construction, maintenance, and operation of facilities used for research; and (2) *administrative costs,* including expenses associated with financial management, institutional review boards, and environment, health, and safety management. Some indirect costs are recovered as a result of indirect-cost proposals that universities submit based on their actual costs from the previous year.

Sources of Support for Academic R&D in S&E

Academic R&D relies on funding support from a variety of sources, including the federal government, universities' and colleges' own institutional funds, state and local government, business, and other organizations (Appendix Table 5-3). The federal government has consistently provided the majority of funding for academic R&D in S&E, generally around 60% or more, although the share has been less in recent years.[i] Institutional funds contribute a sizeable share of funding (22% in 2014), while state and local governments, businesses, and nonprofit organizations each provide about 6% of R&D funds.[ii]

Federal Support

The federal government allocates R&D funding to academia primarily through competitive review processes, and overall support reflects the combined result of numerous discrete funding decisions made by the R&D-supporting federal agencies. Varying agency missions, priorities, and objectives affect the level of funds that universities and colleges receive as well as how they are spent. ARRA was an important source of federal expenditures for academic R&D during the economic downturn and recovery from 2010 through 2012 and continued to contribute to such spending, although in smaller amounts, in 2013 and 2014.

Excluding ARRA funds, there has been a gradual decline since 2005 in the proportion of R&D paid for with federal funds (from just under 64% to under 60%). Taking a longer perspective, the federal share, at 69%, was highest in 1973 (Figure 5-1). It then declined fairly steadily throughout the remainder of the 1970s and the 1980s. During the 1990s, the federal share, with some vacillations, remained at or just under 60%. However, during the first half of the 2000–09 decade, the federal share gradually increased to 64%, coinciding with rapid increases in the budget of the National Institutes of Health (NIH), a major academic R&D funding agency discussed below. The federal share fell during the latter part of the 2000–09 decade but rose in 2010 and 2011 with the infusion of ARRA funds.

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In 2014, as the last of the ARRA funds were being spent, the federal government provided $36.8 billion (58%) of the $63.7 billion total, a reduction of almost $1.5 billion from 2013 (Figure 5-2).

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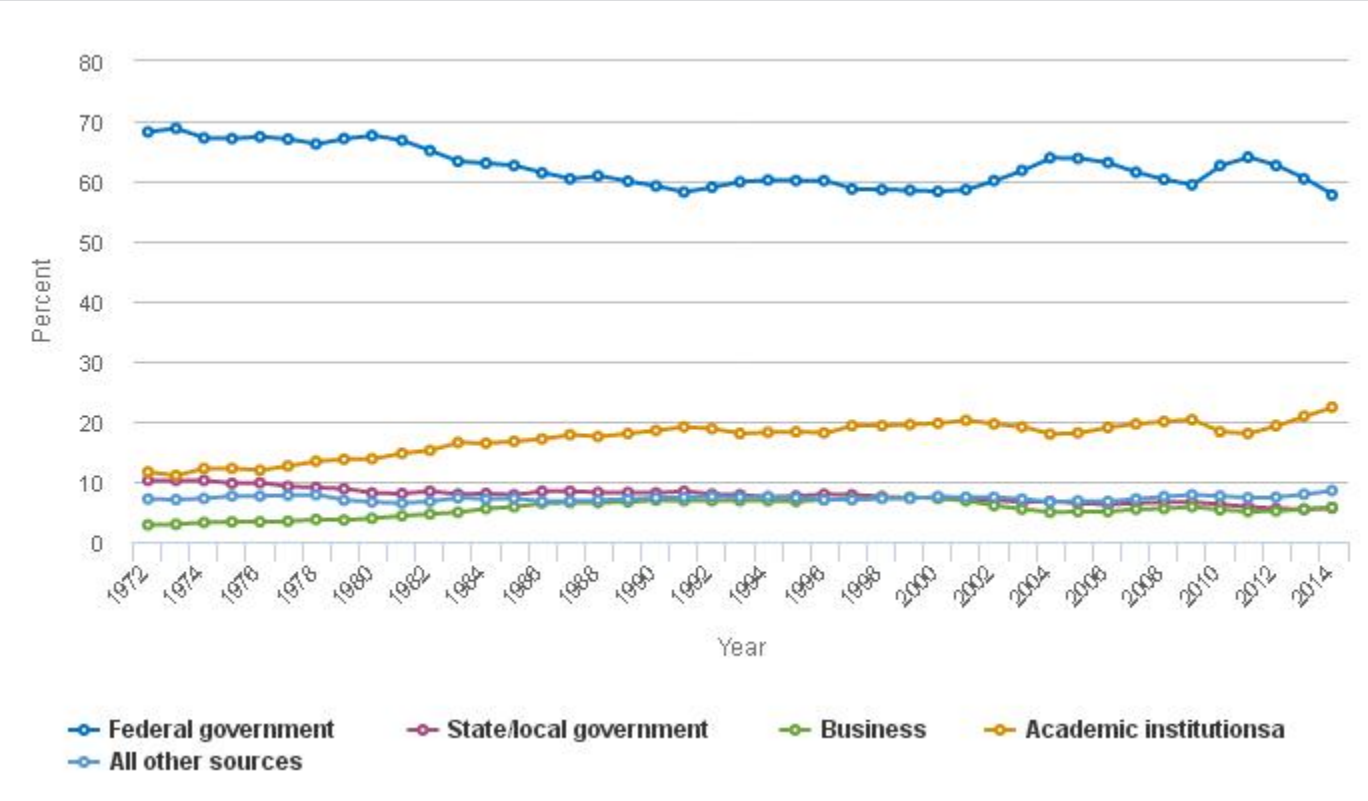
[i] The federal government funds a much smaller proportion of R&D in non-S&E fields (33% in 2014).

[ii] See (NRC 2012) for a report exploring ways to strengthen the partnership between government, universities, and industry in support of national goals.

Figure 5-1

Academic S&E R&D expenditures, by source of funding: FYs 1972–2014



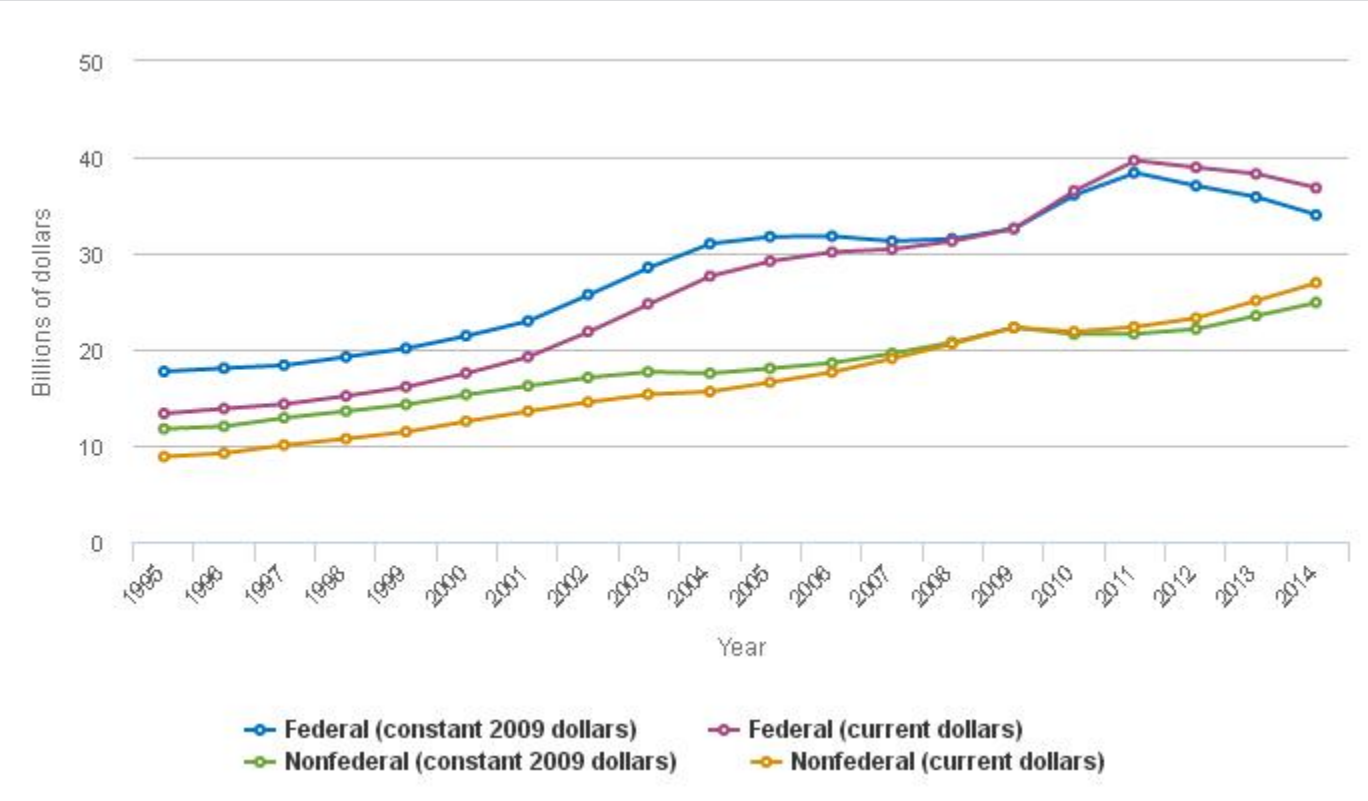
[a] Academic institutions' funds exclude research funds spent from multipurpose accounts.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey.

Science and Engineering Indicators 2016

Figure 5-2

Federal and nonfederal funding of academic S&E R&D expenditures: FYs 1995–2014



NOTES: Gross domestic product deflators come from the U.S. Bureau of Economic Analysis and are available at http://www.bea.gov/national/, accessed 18 February 2015. See appendix table 4-1.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey. See appendix table 5-1.

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Top Federal Agency Supporters

Six agencies are responsible for the vast majority of annual federal expenditures for academic R&D in S&E fields: the Department of Health and Human Services (HHS), in particular, NIH; the National Science Foundation (NSF); the Department of Defense (DOD); the Department of Energy (DOE); the National Aeronautics and Space Administration (NASA); and the Department of Agriculture (USDA). In 2014, these six agencies were the source of over 92% of the estimated $36.8 billion federal expenditures (Appendix Table 5-4; Chapter 4 provides data on these agencies' obligations for academic R&D).[iii]

Among these six agencies, HHS is by far the largest funder, the source of 55% of total federal expenditures in 2014. NSF and DOD were the next-largest funders, each providing about 13%; DOE, NASA, and USDA provided smaller shares of between 3% and 5%. For at least the last decade, the relative ranking of the top six funding agencies in terms of R&D expenditures in S&E fields has remained quite stable, with DOD experiencing the greatest gains in share (from 9% in 2005 to 13% in 2014) (Table 5-4).

[iii] Statistics on R&D performance can differ depending on whether the reporting is by R&D performers—in this case, academic institutions—or R&D funders. Reasons for this difference are discussed in the chapter 4 sidebar, "Tracking R&D Expenditures: Disparities in the Data Reported by Performers and Sources of Funding."

Table 5-4 **Top six federal agencies' shares of federally funded academic S&E R&D expenditures: FYs 2005–14**

(Percent)

Agency	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Department of Health and Human Services	55.8	56.7	56.1	56.0	55.4	57.3	57.4	55.6	54.8	54.5
National Science Foundation	12.1	11.9	11.7	12.1	12.1	12.5	12.5	13.0	13.5	13.3
Department of Defense	8.9	9.2	9.1	9.8	10.4	12.1	12.0	12.4	13.0	13.2
Department of Energy	3.6	3.7	3.7	3.6	3.8	4.2	4.7	5.0	4.9	4.9
National Aeronautics and Space Administration	3.9	3.5	3.5	3.4	3.4	4.0	3.6	3.4	3.4	3.6
Department of Agriculture	2.8	2.9	3.0	2.9	2.8	2.6	2.5	2.8	2.8	2.8

NOTE: The Department of Health and Human Services includes primarily the National Institutes of Health.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2015) of the Higher Education Research and Development Survey.

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Federal support for academic R&D historically has been concentrated at the nation's most research-intensive higher education institutions. Recognizing that human talent is widespread, federal government agencies have long supported a program to develop academic research capability in states that are less competitive in obtaining federal research grants. An overview of the program and recent statistics on its activities are presented in the sidebar, Experimental Program to Stimulate Competitive Research.

Experimental Program to Stimulate Competitive Research

The Experimental Program to Stimulate Competitive Research (EPSCoR) is a long-standing multiagency federal program that seeks to increase the geographical dispersion of federal support for academic R&D. It is based on the premise that universities and their S&E faculty and students are resources that can influence a state's development in the 21st century just as agricultural, industrial, and natural resources did in the 20th century.

EPSCoR is rooted in the history of the National Science Foundation (NSF) and of federal support for R&D. In 1978, Congress, concerned about undue concentration of federal R&D funds, authorized NSF to initiate EPSCoR, which was targeted at states that received lesser amounts of federal R&D funds but demonstrated a commitment to develop sustainable, competitive research capabilities anchored in their research universities. The ultimate aim was to move EPSCoR researchers and institutions into the mainstream of federal and private-sector R&D support.

The experience of the NSF EPSCoR program during the 1980s prompted Congress to authorize the creation of EPSCoR and EPSCoR-like programs in six other federal agencies: the Departments of Energy, Defense

(DOD), and Agriculture; the National Aeronautics and Space Administration; the National Institutes of Health; and the Environmental Protection Agency (EPA). Two of these, EPA and DOD, discontinued issuing EPSCoR program solicitations in FY 2006 and FY 2010, respectively.

In FY 2014, the five remaining agencies spent a total of $488.6 million on EPSCoR and EPSCoR-like programs, up from $288.9 million in 2002 (Table 5-A).

Table 5-A **EPSCoR and EPSCoR-like program budgets, by agency: FYs 2002–14**

(Millions of dollars)

Agency	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
All agencies	288.9	358.0	353.3	367.4	367.1	363.1	418.9	437.2	460.1	436.0	483.4	461.0	488.6
DOD	15.7	15.7	8.4	11.4	11.5	9.5	17.0	14.1	0.0	0.0	0.0	0.0	0.0
DOE	7.7	11.7	7.7	7.6	7.3	7.3	14.7	16.8	21.6	8.5	8.5	8.4	10.0
EPA	2.5	2.5	2.5	2.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
NASA	10.0	10.0	10.0	12.0	12.5	12.8	15.5	20.0	25.0	25.0	18.0	18.0	18.0
NIH	160.0	210.0	214.0	222.0	220.0	218.0	223.6	224.3	228.8	226.5	276.5	261.6	273.3
NSF	79.3	88.8	93.7	93.4	97.8	101.5	120.0	133.0	147.1	146.8	150.9	147.6	158.2
USDA	13.7	19.3	17.0	18.6	18.0	14.0	28.1	29.0	37.6	29.2	29.5	25.4	29.1

DOD = Department of Defense; DOE = Department of Energy; EPA = Environmental Protection Agency; EPSCoR = Experimental Program to Stimulate Competitive Research; NASA = National Aeronautics and Space Administration; NIH = National Institutes of Health; NSF = National Science Foundation; USDA = U.S. Department of Agriculture.

NOTES: EPA and DOD discontinued issuing separate EPSCoR program solicitations in FY 2006 and FY 2010, respectively. USDA's reported budget in FY 2012 includes $6.8 million in unobligated funds. NASA made minor revisions to prior-year data in 2014.

SOURCE: Data are provided by agency EPSCoR representatives and are collected by the NSF Office of Integrative Activities, Office of EPSCoR, January 2015.

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Institutional Support for Academic R&D

Notwithstanding the continuing dominant federal role in academic R&D funding in S&E fields, nonfederal funding sources have grown steadily over the past 20 years (Figure 5-2). Adjusted for inflation, annual growth in nonfederal funding for academic R&D averaged 4% from 1995 to 2014. The largest source of this funding comes from higher education institutions themselves. In 2014, institutional funds combined to be the second-largest source of funding for academic R&D, accounting for 22% of the total ($14.3 billion) (Appendix Table 5-3). This share grew rapidly from only 11% in 1973 to around 18% by 1990 (Figure 5-1). With some vacillations,

universities' and colleges' share of R&D spending increased more slowly during the decades of 1990–99 and 2000–09. With the infusion of federal ARRA funds, the institutional share dipped slightly in 2010 and 2011 but has since climbed to 22%, its highest-ever share (Figure 5-1; Appendix Table 5-3).

In addition to internal funding from general revenues, institutionally financed R&D includes unrecovered indirect costs and committed cost sharing (discussed in greater detail below, where differences between public and private research institutions are highlighted).[iv]

Institutionally financed research includes both organized research projects fully supported with internal funding and all other separately accounted-for institutional funds for research. This category does not include funds spent on research that are not separately accounted for, such as estimates of faculty time budgeted for instruction that is spent on research. Funds for institutionally financed R&D may also derive from general-purpose state or local government appropriations; general-purpose awards from industry, foundations, or other outside sources; endowment income; and gifts. Universities may also use income from patents and licenses or revenue from patient care to support R&D.[v] (See this chapter's section Academic Patenting, Commercialization of U.S. Academic Patents, for a discussion of patent and licensing income.)

Other Sources of Funding

- **State and local government funds.** State and local governments provided 5.6% ($3.6 billion) of academic R&D funding in S&E fields in 2014, with public institutions receiving a higher share and their private counterparts a lower share (Figure 5-1; Appendix Table 5-3). The state and local government funding share has declined from a peak of 10% in the early 1970s to below 6% in recent years. However, these figures are likely to understate the actual contribution of state and local governments, particularly for public institutions, because they reflect only funds that these governments directly target to academic R&D activities.[vi] They exclude any general-purpose, state government, or local government appropriations that academic institutions designate and use to fund separately accounted-for research or to pay for unrecovered indirect costs; such funds are categorized as institutional funds. (See the State Data Tool for some indicators of academic R&D by state, and see chapter 2 section Trends in Higher Education Expenditures and Revenues for a discussion of trends in higher education spending and revenues.)
- **Nonprofit funds.** Nonprofit organizations provided 5.7% ($3.6 billion) of academic R&D funding in S&E fields in 2014, about the same share as that provided by state and local governments (Appendix Table 5-5). A large share of nonprofit funding (over 70%) is directed toward R&D in life sciences—in particular, medical sciences. Nonprofit organizations provided approximately $2.5 billion in each year from 2010 to 2014 for R&D in life sciences, with about $1.5 billion in each year directed toward medical sciences.
- **Business funds.** Businesses provided 5.7% ($3.6 billion) of academic R&D funding in S&E fields in 2014, about the same amount as provided by nonprofit organizations and by state and local governments (Figure 5-1; Appendix Table 5-5).
- **Other funds.** In 2014, all other sources of support, such as foreign-government funding or gifts designated for research, accounted for 2.8% ($1.8 billion) of academic R&D funding in S&E fields (Appendix Table 5-5).

[iv] *Unrecovered indirect costs* are calculated as the difference between an institution's negotiated indirect cost rate on a sponsored project and the amount that it recovers from the sponsor. *Committed cost sharing* is the sum of the institutional contributions required by the sponsor for specific projects (*mandatory cost sharing*) and the institutional resources made available to a specific project at the discretion of the grantee institution (*voluntary cost sharing*).

[v] Various challenges exist with measuring institutionally financed research. For numerous universities, including some with very high research activity, their accounting systems or administrative practices do not enable them to separate the R&D component of multipurpose accounts. Because HERD measures only spending that is fully budgeted as R&D, for these institutions, reported institutional funds are less than the full amount of academic R&D their schools fund.

[vi] Federal grants, contracts, and awards from other sources that are passed through state and local governments to academic institutions are credited to the original provider of the funds.

Academic R&D Expenditures, by S&E Field

Academic R&D spending has long been concentrated in the life sciences, which have received more than half of all academic R&D expenditures for more than three decades. The remainder is distributed across seven broad fields, including computer sciences, environmental sciences, mathematical sciences, physical sciences, psychology, social sciences, and engineering (Appendix Table 5-5). Over the past decade, engineering grew fastest, at an annual average rate of about 4%, after adjusting for inflation, followed by life sciences, computer sciences, and psychology, each at about 2% annually. The mathematical, environmental, physical, and social sciences grew more slowly, at about 1% annually. In one indication that research spanning more than one field of S&E remains vital, there has also been notable growth in sciences that are not classified within a particular field. For all fields of S&E, constant average annual growth rates were lower in recent years (from 2005 to 2014) than earlier (from 1995 to 2004) (Table 5-5).

Table 5-5 **Growth of academic R&D expenditures, by S&E field: FYs 1995–2014**

(Percent)

	Constant average growth rate	
S&E field	1995–2004	2005–14
Computer sciences	6.3	1.7
Environmental sciences	3.7	0.9
Life sciences	6.7	1.7
Mathematical sciences	3.5	1.4
Physical sciences	3.2	0.6
Psychology	6.6	1.8
Social sciences	3.7	1.2
Engineering	4.7	3.7

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2015) of the Higher Education Research and Development Survey.
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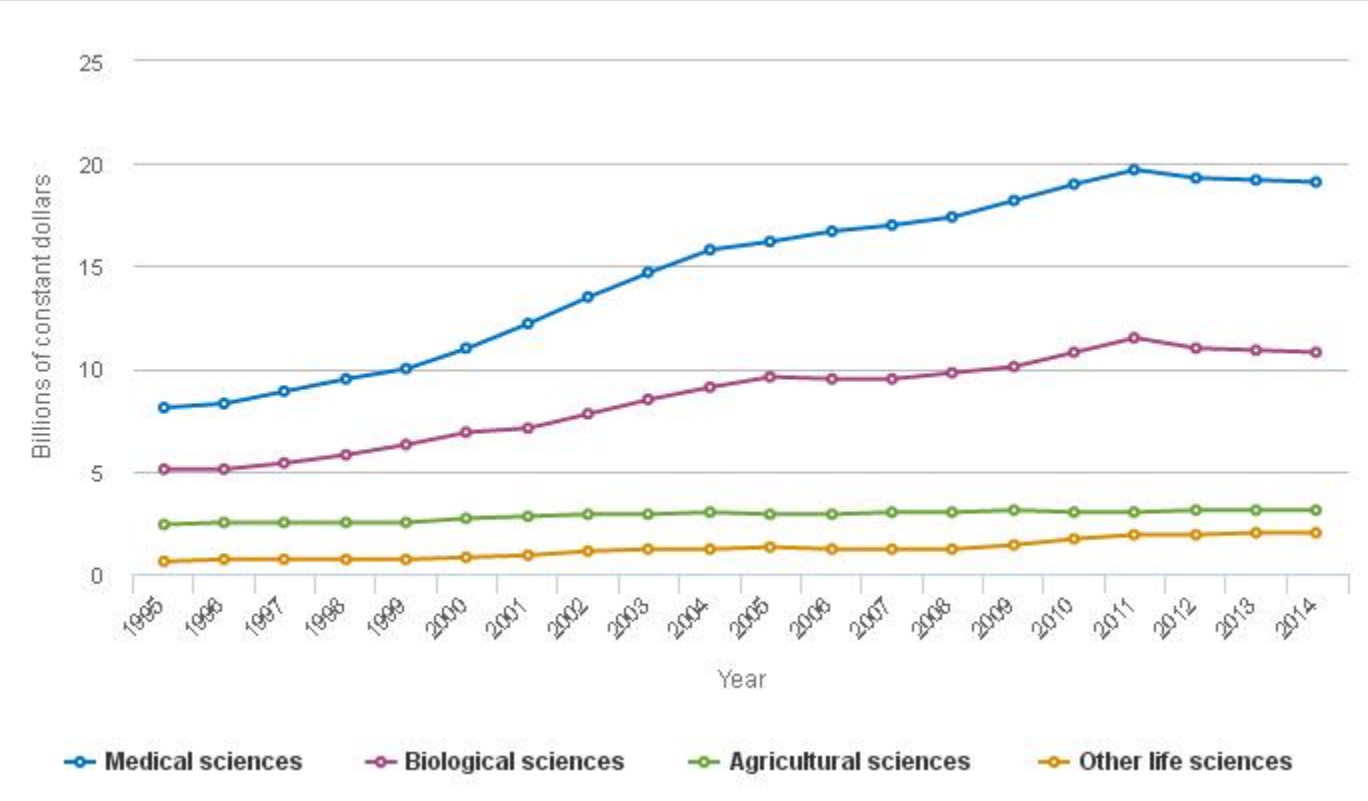
In 2014, academic R&D in life sciences accounted for 59% of total academic spending in all fields of S&E and a slightly smaller share (56%) of federally supported academic R&D that year. Within life sciences, medical sciences accounted for over one-half of this field's spending (and 32% of total academic R&D), while biological sciences

constituted just under one-third of spending in the life sciences (and 18% of total academic R&D). The remainder was spread between agricultural sciences (5% of total academic R&D) and other life sciences—life sciences R&D that could not be classified into one of the subfields. Academic R&D expenditures in medical sciences almost doubled from 1995 to 2004 and then grew more slowly from 2005 to 2013, declining slightly from 2011 to 2014. The sizeable increase from 1995 to 2004 resulted, in part, from a near-doubling of NIH's budget from 1998 to 2003. Similarly, academic R&D expenditures in biological sciences increased by about 80% from 1995 to 2004 and by much less (13%) from 2005 to 2014 after adjusting for inflation; there was also a decline in spending from 2011 to 2014. Spending changes over the two decades were somewhat less dramatic within the smaller life sciences field of agricultural sciences (Figure 5-3).

Figure 5-3

Academic R&D expenditures, by life sciences field: FYs 1995–2014



NOTES: Gross domestic product deflators come from the U.S. Bureau of Economic Analysis and are available at http://www.bea.gov/national/, accessed 18 February 2015. See appendix table 4-1.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey.

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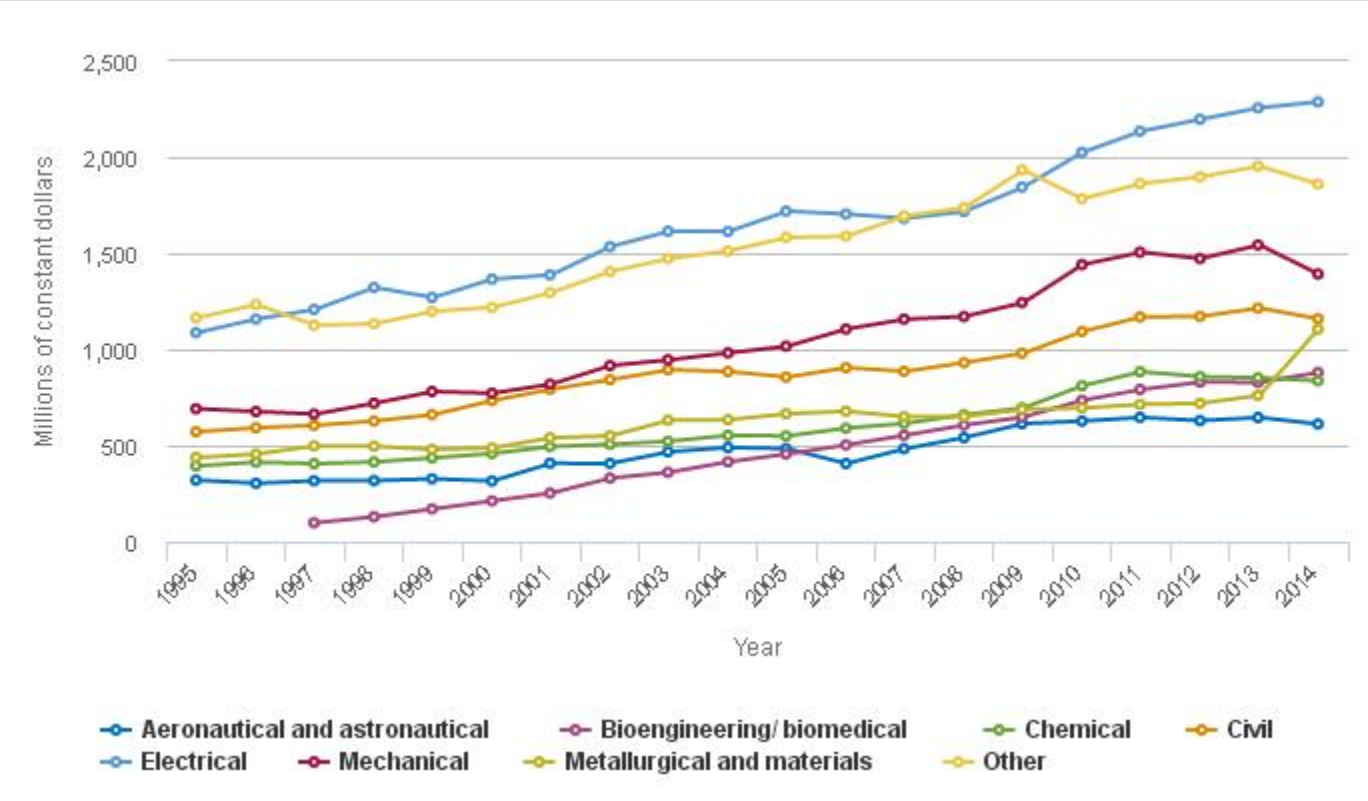
Engineering R&D—constituting 17% of academic R&D spending in S&E fields in 2014—has generally seen robust growth over the past decade, particularly over the period from 2008 to 2011. Bioengineering/biomedical engineering exceeded the rapid growth of the medical sciences, increasing by almost 800% from a small base in 1997—the first year for which spending data are available. Spending essentially doubled from 1995 to 2014 in each of the other subfields of engineering after adjusting for inflation (Figure 5-4).

Figure 5-4

Academic R&D expenditures, by engineering field: FYs 1995–2014



NA = not available.

NOTES: Data were not available for all fields for all years. Gross domestic product deflators come from the U.S. Bureau of Economic Analysis and are available at http://www.bea.gov/national/, accessed 18 February 2015. See appendix table 4-1.

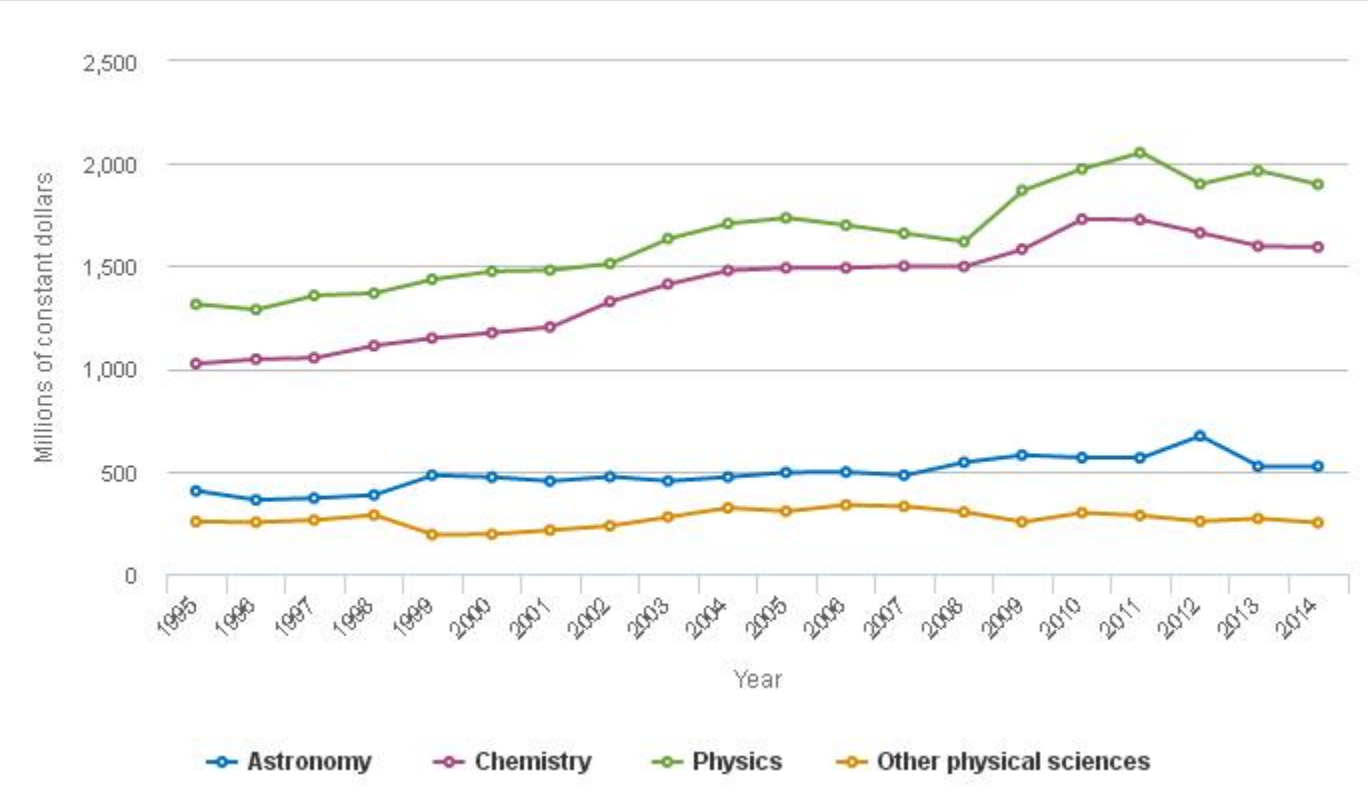
SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey.

Science and Engineering Indicators 2016

Physical sciences—consisting primarily of astronomy, chemistry, and physics—experienced slower-than-average growth in recent decades in academic R&D spending. In 2014, academic R&D spending in physical sciences accounted for 7% of total spending in S&E fields. In 1995, by contrast, inflation-adjusted spending in physical sciences, at $3 billion, constituted over 10% of total academic R&D spending in S&E fields that year. As with life sciences, constant average growth was quite a bit lower from 2005 to 2014 (1%) than it was over the decade prior to 2004 (3%) (Figure 5-5).

Figure 5-5

Academic R&D expenditures, by physical sciences field: FYs 1995–2014



NOTES: Gross domestic product deflators come from the U.S. Bureau of Economic Analysis and are available at http://www.bea.gov/national/, accessed 18 February 2015. See appendix table 4-1.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey.

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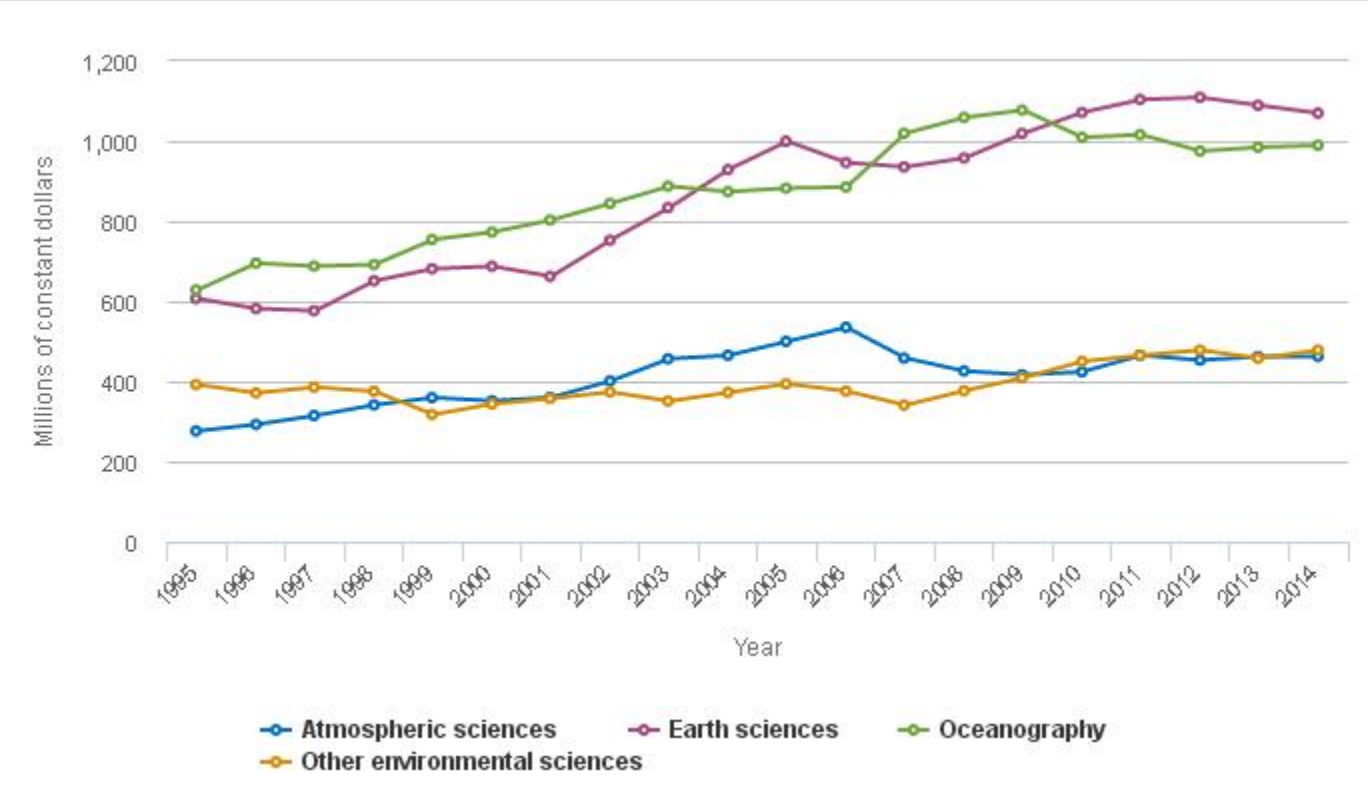
Environmental sciences, which include atmospheric and earth sciences as well as oceanography and other environmental sciences, showed the same dual-growth pattern as the other fields: about 4% from 1995 to 2004 and 1% thereafter (Figure 5-6). In 2014, environmental sciences constituted about 5% of academic R&D in S&E fields.

Figure 5-6

Academic R&D expenditures, by environmental sciences field: FYs 1995–2014



NOTES: Gross domestic product deflators come from the U.S. Bureau of Economic Analysis and are available at http://www.bea.gov/national/, accessed 18 February 2015. See appendix table 4-1.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey.

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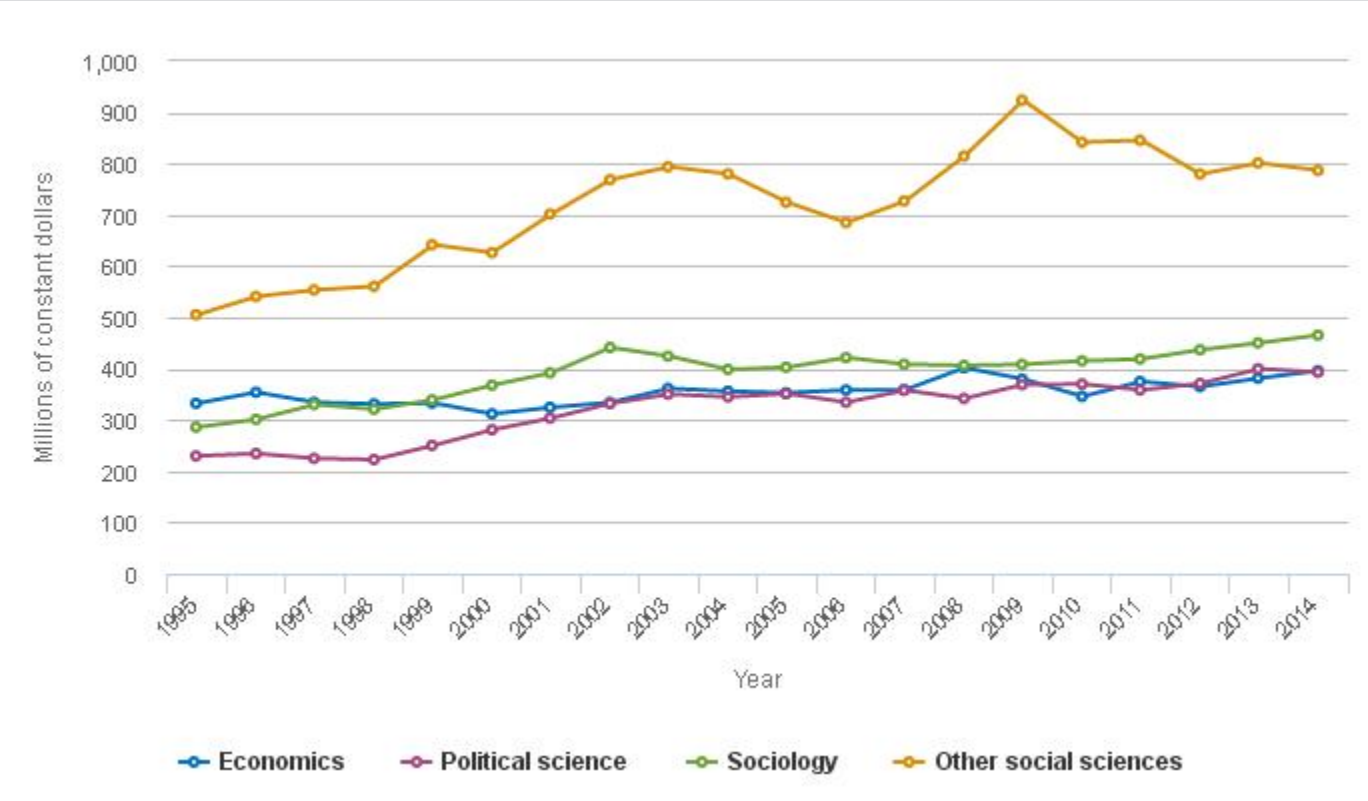
In 2014, academic R&D spending in social sciences constituted 3.5% of total spending in S&E fields and a lesser share (2.5%) of federal spending. Spending trends in the social sciences differed somewhat from spending trends in other fields (Figure 5-7). Economics grew by a fairly steady annual average of 1% over the entire two-decade period, with somewhat greater growth in the most recent decade. Political science, by contrast, saw 5% growth from 1995 to 2004 before dropping to 1% annual average growth. Sociology followed a similar pattern, with greater growth from 1995 to 2004 than from 2005 to 2014. The largest share of social sciences spending (just under 40% in 2014) occurred in fields not classified within economics, political science, or sociology. These social sciences include archaeology, city and community studies, criminal justice, history of science, linguistics, and urban studies, among other disciplines. They do not include the humanities, which is classified as a non-S&E field (Table 5-1).

Figure 5-7

Academic R&D expenditures, by social sciences field: FYs 1995–2014



NOTES: Gross domestic product deflators come from the U.S. Bureau of Economic Analysis and are available at http://www.bea.gov/national/, accessed 18 February 2015. See appendix table 4-1.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey.

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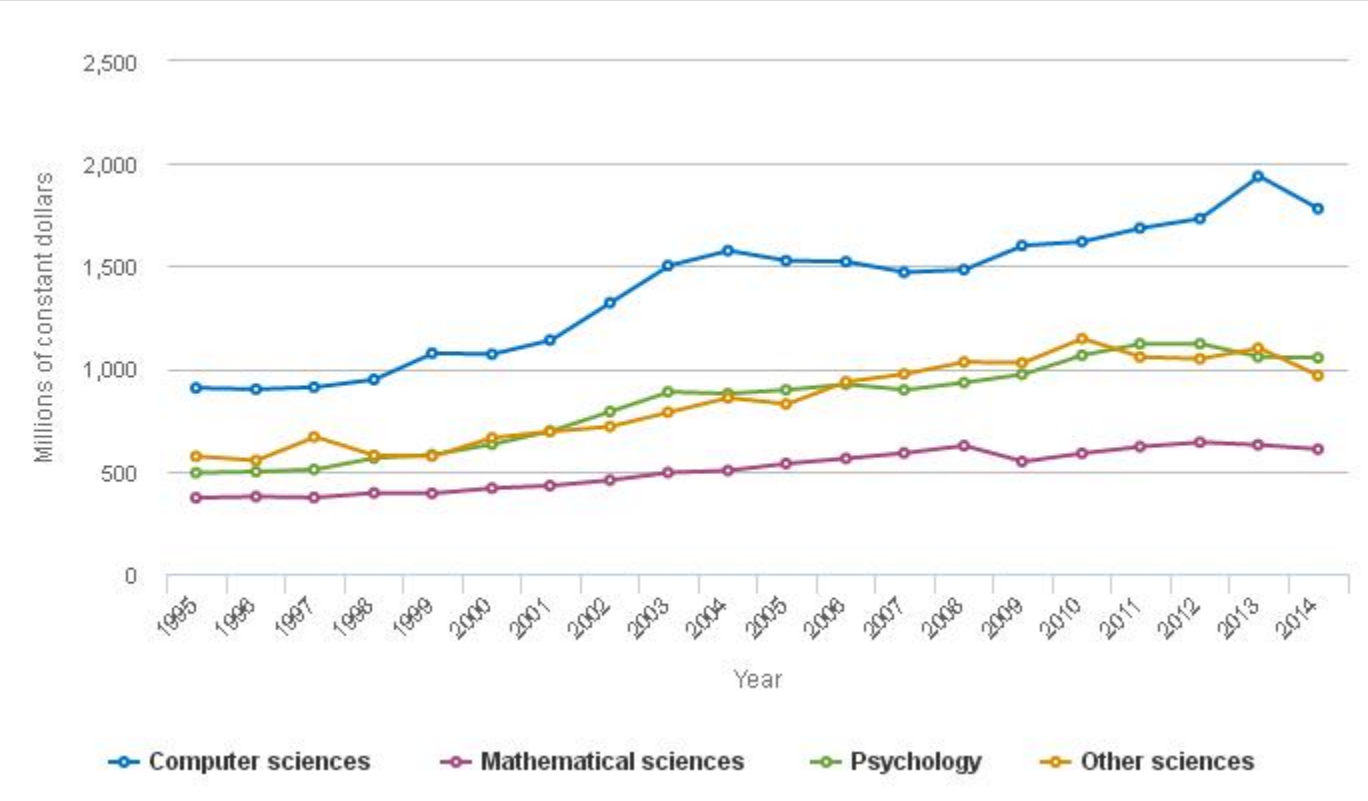
Growth trajectories of two dissimilar fields stand out. Spending in computer sciences grew by a 6% annual average from 1995 to 2004, followed by 2% thereafter. Psychology had a 7% annual average growth rate from 1995 to 2004 and 2% thereafter. The mathematical sciences grew by about 1% from 2005 to 2014 after a faster growth rate in the preceding decade (4%) (Figure 5-8).

Figure 5-8

Academic R&D expenditures, by selected fields: FYs 1995–2014



NOTES: Gross domestic product deflators come from the U.S. Bureau of Economic Analysis and are available at http://www.bea.gov/national/, accessed 18 February 2015. See appendix table 4-1.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey.

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In 2014 as in prior years over the past decade, around 2% of total and federal spending for academic R&D in S&E has been devoted to interdisciplinary or multidisciplinary work that cannot readily be assigned to a specific field (see sidebar, Interdisciplinary Research: Strategic Implications and Measurement Challenges).

Interdisciplinary Research: Strategic Implications and Measurement Challenges

The National Academy of Sciences defines *interdisciplinary research* (*IDR*) as "a mode of research by teams or individuals that integrates information and techniques, tools, perspectives, concepts, and/or theories from two or more disciplines or bodies of specialized knowledge to advance fundamental understanding or to solve problems whose solutions are beyond the scope of a single discipline or area of research practice" (NAS/NAE/IOM 2005). By engaging experts from different disciplines, IDR has the potential to provide a comprehensive approach for understanding and solving problems.

Because of the variety of forms, contexts, and outcomes of IDR, national quantitative data to measure IDR do not exist. Typically, the efforts to measure IDR have relied on bibliometric data. Other efforts to

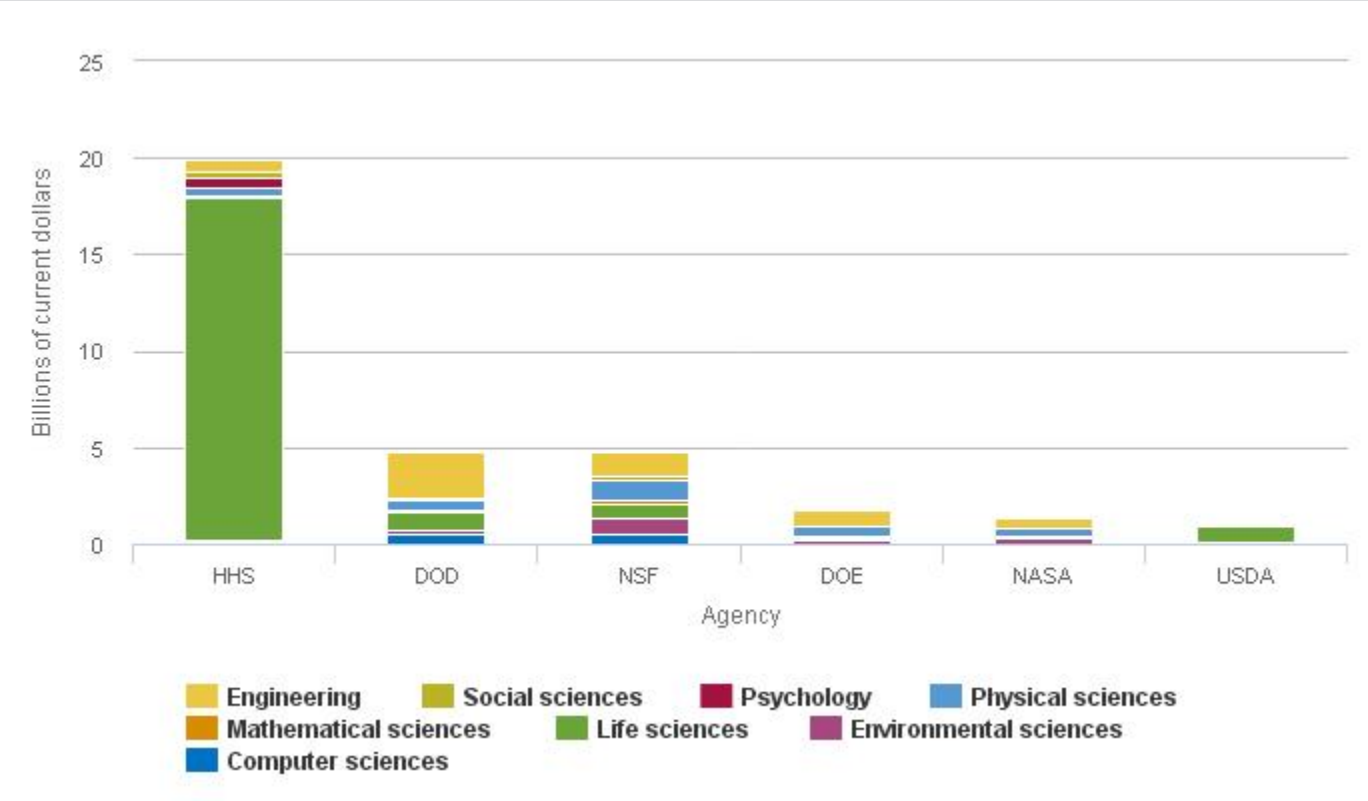
measure IDR have focused on proposal review, for example, by counting the stated disciplines of research proposals as well as enumerating the various disciplines represented by co–principal investigators. Recently, more sophisticated techniques for tracking IDR are also being attempted via text mining and mapping clusters of research interest. Surveys, interviews, and site visits can also shed light on interactions and collaborations of researchers from various academic disciplines.

Within U.S. higher education, national survey data indicate an increasing tendency of knowledge integration from multiple disciplines. Specifically, over the last decade, universities responding to the National Science Foundation's (NSF's) annual Higher Education Research and Development Survey have reported steady growth on R&D that spans more than one field of S&E. Additionally, in 2013, 40% of respondents to NSF's 2013 Survey of Earned Doctorates reported two or more dissertation research fields, up from 24% in 2001.

The federal government's role in funding R&D in the various fields of S&E hinges on each agency's mission focus (Figure 5-9). HHS—primarily NIH—supports the vast majority of federal funding in life sciences (84%) and is also the lead funding agency in psychology and the social sciences (Appendix Table 5-4). By contrast, with smaller shares of total academic R&D funding, DOD, DOE, NASA, and NSF have more diversified funding patterns. In 2014, as in previous years, NSF was the lead federal funding agency for academic research in physical sciences, mathematics, computer sciences, and environmental sciences. In 2014, DOD was the lead funding agency in engineering and spent almost as much as NSF in computer sciences.

Figure 5-9

Federally financed academic R&D expenditures, by agency and S&E field: FY 2014



DOD = Department of Defense; DOE = Department of Energy; HHS = Department of Health and Human Services; NASA = National Aeronautics and Space Administration; NSF = National Science Foundation; USDA = U.S. Department of Agriculture.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey, 2014. See appendix table 5-4.

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Federal funding has played a larger role in overall support for some fields than for others (Appendix Table 5-5). The federal government is the dominant funder in fields such as atmospheric sciences (78% in 2014), physics (73%), computer sciences (72%), and aeronautical and astronautical engineering (72%). It plays a smaller role in other fields, such as agricultural sciences (32%), economics (32%), and political sciences (34%).

Academic R&D, by Public and Private Institutions

The federal government is the primary source of financing for academic R&D in S&E fields, but it accounts for a substantially greater share of private institutions' R&D spending (66%) than that of their public counterparts (54%) (Figure 5-10).[i] Conversely, public institutions derive about 8% of their R&D funds from state government sources versus 2% for private ones.

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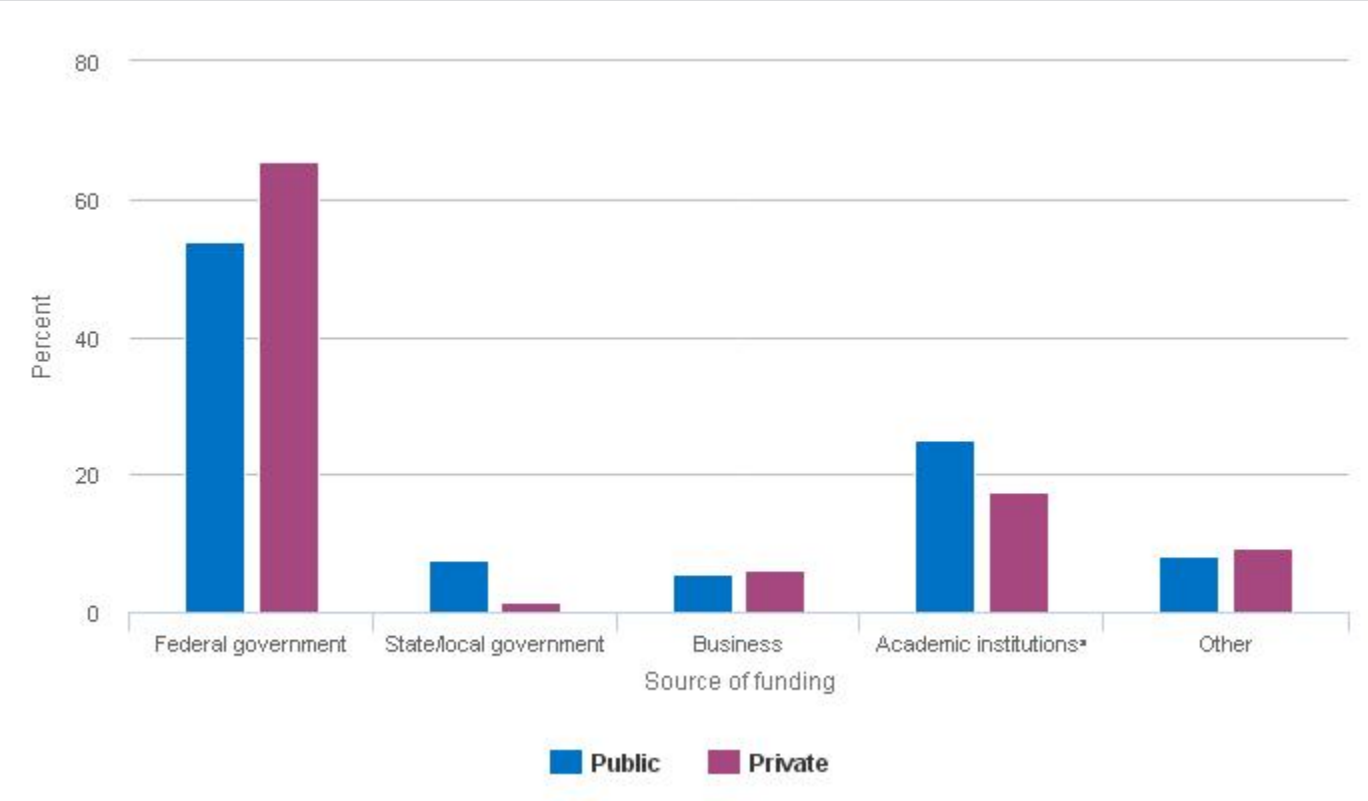
[i] See also the chapter 2 section on "Trends in Higher Education Expenditures and Revenues" for a discussion of average per-student financial flows at public and private institutions.

Figure 5-10

Sources of S&E R&D funding for public and private academic institutions: FY 2014



[a] Academic institutions' funds exclude research funds spent from multipurpose accounts.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey, 2013. See appendix table 5-3.

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Public universities pay for about 25% of their R&D from their own institutional funds, while private universities pay for a smaller share (18%) (Table 5-6). This larger proportion of institutional R&D funds in public institutions may reflect general-purpose government funds that public institutions direct toward R&D. Private institutions also reported a larger proportion of unrecovered indirect costs in their institutional total in 2014 (35% versus 28% for public institutions) (Table 5-7).[ii], [iii]

[ii] These data are available for academic R&D spending across all fields, including S&E and non-S&E funds. HERD does not provide breakouts for S&E only.

[iii] In 1991, the Office of Management and Budget capped reimbursement of administrative costs at 26% of total direct costs. As a result, actual unrecovered indirect costs at both public and private universities may be somewhat higher than the amounts reported on the HERD Survey.

Table 5-6 Total and institutionally funded R&D expenditures at universities and colleges, by year, institution type, and Carnegie classification: FYs 2010–14

Chapter 5. **Academic Research and Development**

(Thousands of dollars)

	All R&D expenditures[a]		S&E R&D expenditures	
Year, institution type, and Carnegie classification	Total	Institutional funds[b]	Total	Institutional funds[b]
2010	61,253,743	11,940,472	58,356,805	10,673,732
Public	41,231,333	9,330,065	39,079,435	8,393,767
Research universities–very high research activity	28,389,670	6,537,430	27,070,983	5,961,451
Private	20,022,410	2,610,407	19,277,370	2,279,965
Research universities–very high research activity	16,251,746	2,099,604	15,747,784	1,865,536
2011	65,276,179	12,610,368	61,992,171	11,130,017
Public	43,915,002	9,897,596	41,508,388	8,812,273
Research universities–very high research activity	30,013,886	6,909,899	28,530,915	6,248,587
Private	21,361,177	2,712,772	20,483,783	2,317,744
Research universities–very high research activity	17,227,320	2,090,861	16,646,487	1,818,092
2012	65,729,338	13,633,435	62,201,879	12,031,470
Public	44,162,988	10,455,853	41,612,532	9,300,101
Research universities–very high research activity	30,386,473	7,359,656	28,830,163	6,663,763
Private	21,566,350	3,177,582	20,589,347	2,731,369
Research universities–very high research activity	17,523,071	2,492,532	16,832,136	2,159,238
2013	67,014,807	14,984,948	63,360,571	13,264,458
Public	44,851,358	11,193,056	42,297,456	9,987,420
Research universities–very high research activity	31,192,547	7,876,152	29,571,921	7,123,842
Private	22,163,449	3,791,892	21,063,115	3,277,038
Research universities–very high research activity	18,085,899	3,013,479	17,280,423	2,618,997
2014	67,154,642	15,753,517	63,742,539	14,279,085
Public	44,657,466	11,649,654	42,154,026	10,493,742

Year, institution type, and Carnegie classification	All R&D expenditures[a] Total	All R&D expenditures[a] Institutional funds[b]	S&E R&D expenditures Total	S&E R&D expenditures Institutional funds[b]
Research universities–very high research activity	31,176,923	8,335,437	29,514,304	7,544,998
Private	22,497,176	4,103,863	21,588,513	3,785,343
Research universities–very high research activity	18,379,538	3,249,291	17,744,487	3,041,937

[a] All R&D expenditures include S&E and non-S&E R&D expenditures.

[b] Institutional funds exclude research funds spent from multipurpose accounts.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey.

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Table 5-7 Higher education R&D expenditures at all universities and colleges financed by institutional funds, by source, year, institution type, and Carnegie classification: FYs 2010–14

(Thousands of dollars)

Year, institution type, and Carnegie classification	All R&D expenditures[b]	Institutional funds[a] Total	Institutional funds[a] Institutionally financed research	Institutional funds[a] Cost sharing	Institutional funds[a] Unrecovered indirect costs
2010	61,253,743	11,940,472	6,194,288	1,085,116	4,661,068
Public	41,231,333	9,330,065	5,202,327	742,848	3,384,890
Research universities – very high research activity	28,389,670	6,537,430	3,624,936	479,886	2,432,608
Private	20,022,410	2,610,407	991,961	342,268	1,276,178
Research universities – very high research activity	16,251,746	2,099,604	668,713	292,051	1,138,840
2011	65,276,179	12,610,368	6,844,738	1,159,675	4,605,955
Public	43,915,002	9,897,596	5,704,522	790,084	3,402,990
Research universities – very high research activity	30,013,886	6,909,899	3,958,178	520,785	2,430,936
Private	21,361,177	2,712,772	1,140,216	369,591	1,202,965
Research universities – very high research activity	17,227,320	2,090,861	736,403	304,676	1,049,782
2012	65,729,338	13,633,435	7,735,781	1,292,462	4,605,192

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		Institutional funds[a]			
Year, institution type, and Carnegie classification	All R&D expenditures [b]	Total	Institutionally financed research	Cost sharing	Unrecovered indirect costs
Public	44,162,988	10,455,853	6,340,188	851,547	3,264,118
Research universities – very high research activity	30,386,473	7,359,656	4,441,962	586,974	2,330,720
Private	21,566,350	3,177,582	1,395,593	440,915	1,341,074
Research universities – very high research activity	17,523,071	2,492,532	918,236	385,897	1,188,399
2013	67,014,807	14,984,948	8,922,398	1,364,685	4,697,865
Public	44,851,358	11,193,056	7,008,443	886,125	3,298,488
Research universities – very high research activity	31,192,547	7,876,152	4,911,547	608,879	2,355,726
Private	22,163,449	3,791,892	1,913,955	478,560	1,399,377
Research universities – very high research activity	18,085,899	3,013,479	1,359,326	416,674	1,237,479
2014	67,154,642	15,753,517	9,605,160	1,394,088	4,754,269
Public	44,657,466	11,649,654	7,438,364	899,795	3,311,495
Research universities – very high research activity	31,176,923	8,335,437	5,324,197	621,904	2,389,336
Private	22,497,176	4,103,863	2,166,796	494,293	1,442,774
Research universities – very high research activity	18,379,538	3,249,291	1,532,708	433,587	1,282,996

[a] Institutional funds exclude research funds spent from multipurpose accounts.

[b] All R&D expenditures include S&E and non-S&E R&D expenditures.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey.

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In 2014, nonprofit organizations funded about 5% of total R&D expenditures in public institutions and 7% in private institutions. Among the nation's 73 most research-intensive public universities according to Carnegie classification, nonprofit funds were the source of an average of 4% of these schools' total R&D spending in S&E. Percentages ranged from less than 1% to over 17%, with most schools (46) receiving less than 5% from nonprofit funds and only 3 schools receiving over 10% of their total academic R&D monies from nonprofit funds. The story is somewhat different at the nation's 35 most research-intensive private institutions, where nonprofit funds were the source of an average of 7% of these institutions' total R&D spending in S&E. Percentages ranged from 2% to 14%, with most schools (22) receiving at least 6% from nonprofit organizations and 7 schools receiving 10% or more of total R&D funds from nonprofit organizations.

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Universities and colleges received about 6% of their R&D support from business in 2014. Business funding was slightly higher as a share at the nation's most research-intensive private institutions (6%) than at their public counterparts (5%). Funding from all other sources was around 3% in both institution types.

Distribution of R&D Funds across Academic Institutions

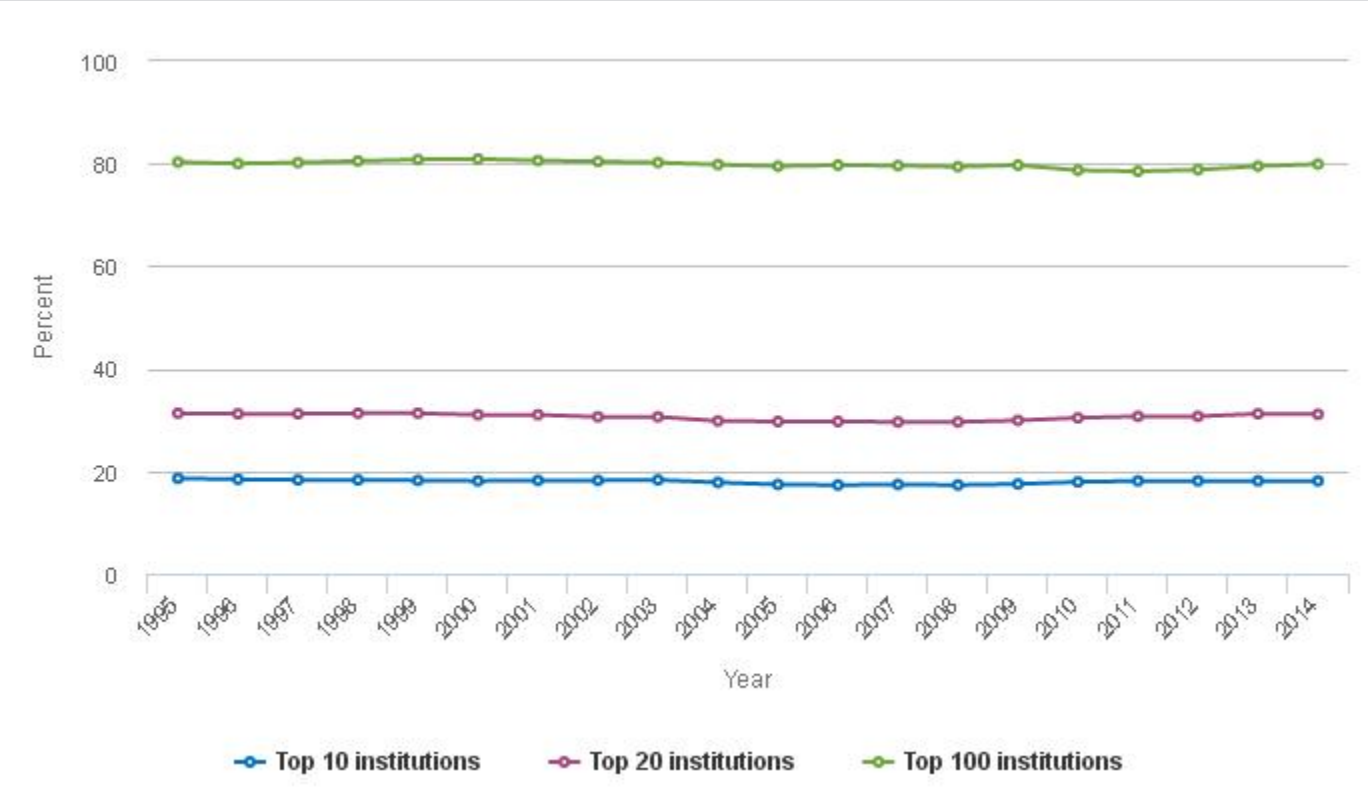
In 2014, a total of 395 public institutions spent $42.2 billion on R&D in S&E fields, and a total of 239 private institutions spent $21.6 billion (Appendix Table 5-3). Among the top 100 universities in academic R&D expenditures in 2014, two-thirds were public universities and colleges, and one-third were private schools (Appendix Table 5-6).

Academic R&D expenditures are highly concentrated in a relatively small number of institutions. In 2014, out of approximately 3,000 baccalaureate-, master's-, and doctorate-granting institutions, 634 reported spending at least $1 million on R&D.[iv] The top-spending 20 institutions accounted for over 30% of total academic R&D spending in S&E fields in 2014, and the top-spending 100 institutions accounted for 80%. The relative shares of the large research universities have been remarkably stable over the past two decades (Figure 5-11), although the identities of the top 20 or top 100 institutions have varied over time.

[iv] An additional 261 institutions reported spending less than $1 million on academic R&D in FY 2013. These institutions received a shorter version of the survey questionnaire and are not represented in this chapter.

Figure 5-11

Share of academic S&E R&D, by institution rank in R&D expenditures: FYs 1995–2014



SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey. See appendix table 5-6.

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R&D Collaboration between Academic Institutions

Research collaboration involving multiple institutions is a growing trend. Federal initiatives encourage it, interdisciplinary research areas invite it, and technological advances facilitate communication and provide opportunities to mobilize specialized skills beyond the capacity of individual institutions. Opportunities to share risk and increase research credibility contribute to R&D collaboration's growth (Cummings and Kiesler 2007). The rise of academic R&D collaboration across different organizations is also evident in the growth of research articles with authors at different institutions (see Outputs of S&E Research: Publications and Patents in this chapter).

The trend is also evident in the growing flow of funds among institutions to support collaborative research activities—that is, the amount of their total expenditures for R&D that universities pass through to other organizations, including academic institutions and others. Available data on pass-through funding encompass S&E R&D from 2000 to 2009 and total R&D (including non-S&E as well as S&E funds) from 2010 to 2014. From a low base in 2000, academic pass-through funds increased more rapidly than R&D expenditures through 2009, doubling in amount over this period in constant dollars, while total academic R&D grew by about 50% (Hale 2012).[v] As with overall academic R&D funding, pass-through funding arrangements are heavily concentrated in the most research-intensive institutions.

Funds that universities passed through to other higher education institutions increased substantially from 2010 to 2011, coinciding with the highest levels of ARRA spending, and then remained relatively flat from 2011 to 2014. As with overall academic R&D funding, the federal share of funds that universities passed through to other higher education institutions declined somewhat from 2013 to 2014 (Figure 5-12). However, the federal government continues to be the major provider of pass-through funds; in 2014 (as in prior years), it was the source for about 90% of all pass-through funds that universities and colleges provided to or received from other higher education institutions (Appendix Table 5-7). Both public and private universities engage actively in pass-through funding arrangements (Table 5-8 and Table 5-9).

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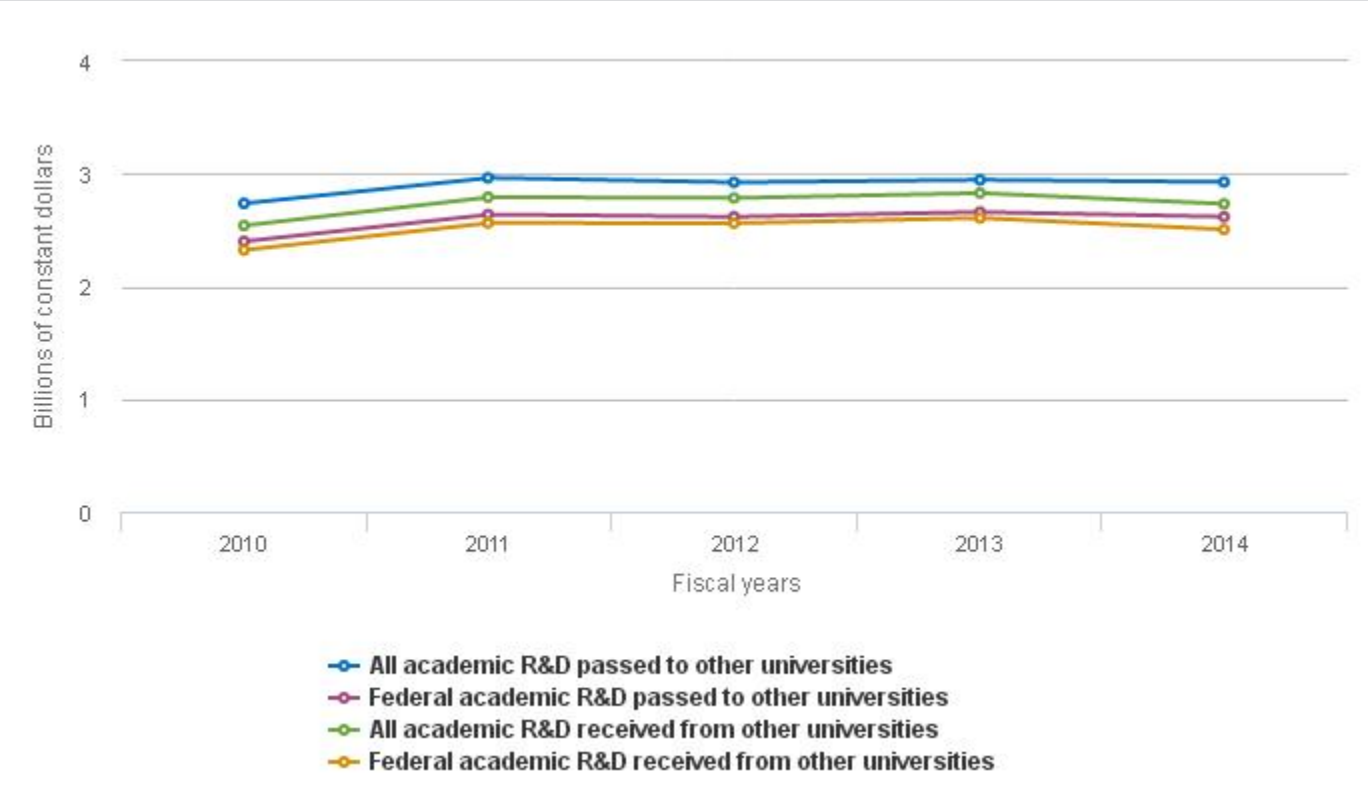
[v] During the early years of the 2000–09 decade, survey questions on pass-through funding were voluntary, with relatively high nonresponse (11% in 2000 versus 4% in 2009).

Figure 5-12

Total and federally funded academic R&D pass-throughs: FYs 2010–14



SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey.

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Table 5-8 Total and federally financed higher education R&D expenditures passed through to subrecipients, by institution type: FY 2014

(Thousands of dollars)

		R&D expenditures passed through to subrecipients				
R&D expenditures and type of institution	All R&D expenditures	Total	Higher education subrecipients	Businesses	Nonprofit organizations	Other subrecipients
Total R&D, all institutions	67,154,642	5,715,966	3,168,555	1,071,503	948,947	526,961
Public	44,657,466	3,566,961	2,020,333	707,107	534,275	305,246
Private	22,497,176	2,149,005	1,148,222	364,396	414,672	221,715
Federally financed R&D, all institutions	37,922,314	4,899,188	2,834,727	833,508	815,462	415,491
Public	23,493,609	3,086,201	1,785,680	601,383	459,493	239,645

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		R&D expenditures passed through to subrecipients				
R&D expenditures and type of institution	All R&D expenditures	Total	Higher education subrecipients	Businesses	Nonprofit organizations	Other subrecipients
Private	14,428,705	1,812,987	1,049,047	232,125	355,969	175,846

NOTE: Data include S&E and non-S&E R&D expenditures.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey, 2014.

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Table 5-9 Total and federally financed higher education R&D expenditures received as a subrecipient, by institution type: FY 2014

(Thousands of dollars)

		R&D expenditures received as a subrecipient				
R&D expenditures and type of institution	All R&D expenditures	Total	Higher education pass-through entities	Businesses	Nonprofit organizations	Other pass-through entities
Total R&D, all institutions	67,154,642	6,526,751	2,958,040	1,068,695	1,420,380	1,079,636
Public	44,657,466	4,535,620	1,907,434	765,042	958,764	904,380
Private	22,497,176	1,991,131	1,050,606	303,653	461,616	175,256
Federally financed R&D, all institutions	37,922,314	5,556,238	2,712,063	825,726	1,125,912	892,537
Public	23,493,609	3,792,648	1,753,883	561,311	731,263	746,191
Private	14,428,705	1,763,590	958,180	264,415	394,649	146,346

NOTE: Data include S&E and non-S&E R&D expenditures.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Higher Education Research and Development Survey, 2014.

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The growth in pass-through funding has been accompanied by changing research practices, seen particularly in the growth of larger research teams, including many that span or integrate multiple disciplines (see sidebar, Interdisciplinary Research: Strategic Implications and Measurement Challenges).

Infrastructure for Academic R&D

Physical infrastructure is an essential resource for the conduct of R&D. Traditionally, the capital infrastructure for R&D consisted primarily of research space (e.g., laboratories and computer rooms) and instrumentation. Accordingly, the square footage of a designated research space and counts of instruments have been the principal indicators of the status of research infrastructure.

Advances in information technology (IT) have brought significant changes to both the methods of scientific research and the infrastructure necessary to conduct R&D. The technologies, human interfaces, and associated processing capabilities resulting from these innovations are often called *cyberinfrastructure.* The value of research facilities, research equipment, and cyberinfrastructure to the academic R&D infrastructure is highlighted below.

Research Facilities

Research Space

The nation's colleges and universities had 211.8 million net assignable square feet (NASF) of research space available at the end of 2013 (Appendix Table 5-8).[i] This was 4.7% above the NASF at the end of 2011, continuing more than two decades of expansion. The average rate of increase for all biennial periods measured from 1988 to 2013 was 5.2% (Figure 5-13).

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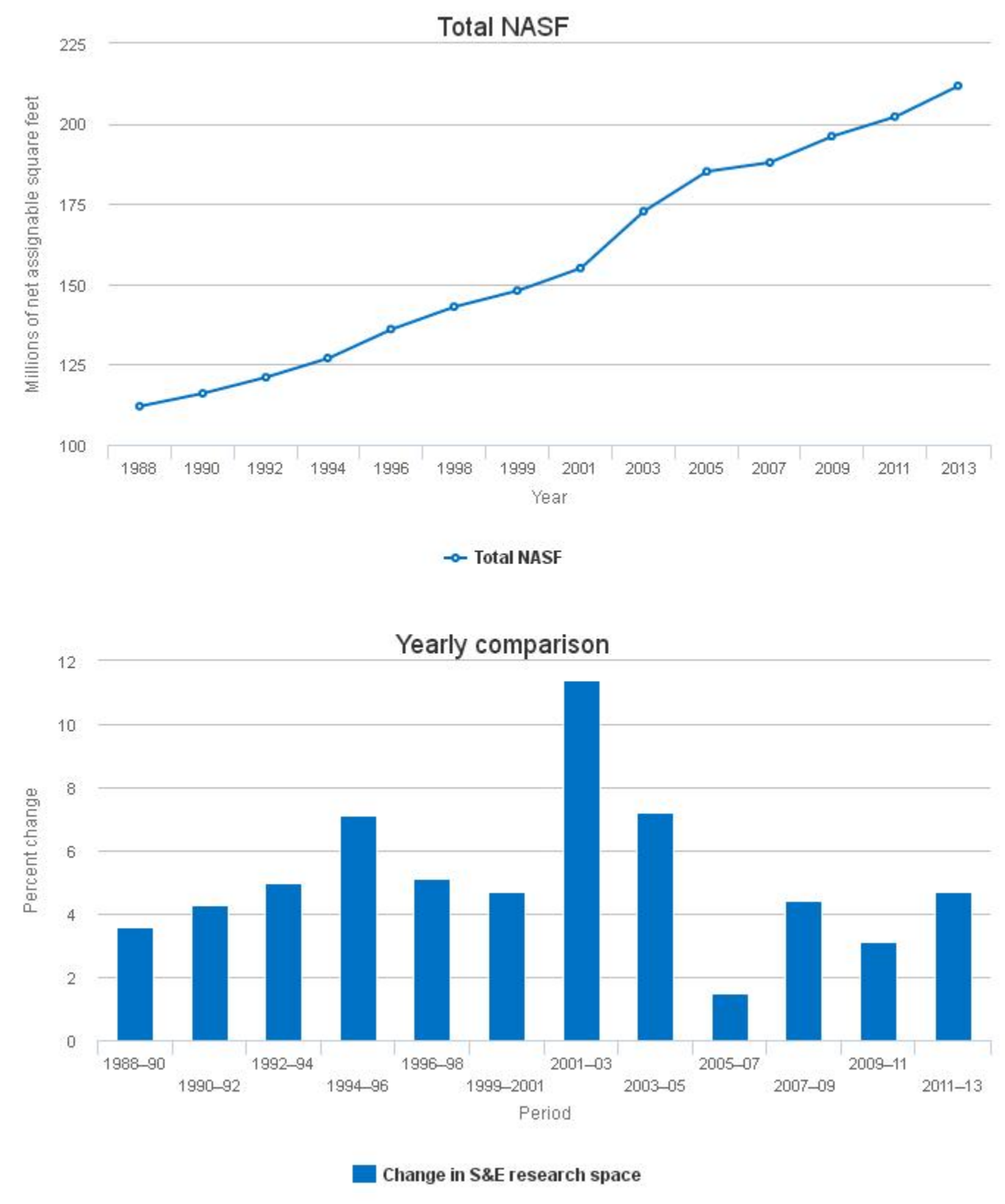
[i] Research space here is defined as the space used for sponsored R&D activities at academic institutions and for which there is separate budgeting and accounting. Research space is measured in net assignable square feet (NASF). This is the sum of all areas on all floors of a building assigned to, or available to be assigned to, an occupant for a specific use, such as research or instruction. NASF is measured from the inside faces of walls. Multipurpose space that is partially used for research is prorated to reflect the proportion of time and use devoted to research.

Figure 5-13

Change in S&E research space in academic institutions, by 2-year period: FYs 1988–2013



NASF = net assignable square feet.

NOTE: The biennial survey cycle ran on even years from 1988 to 1998 and on odd years from 1999 to 2013.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Science and Engineering Research Facilities.

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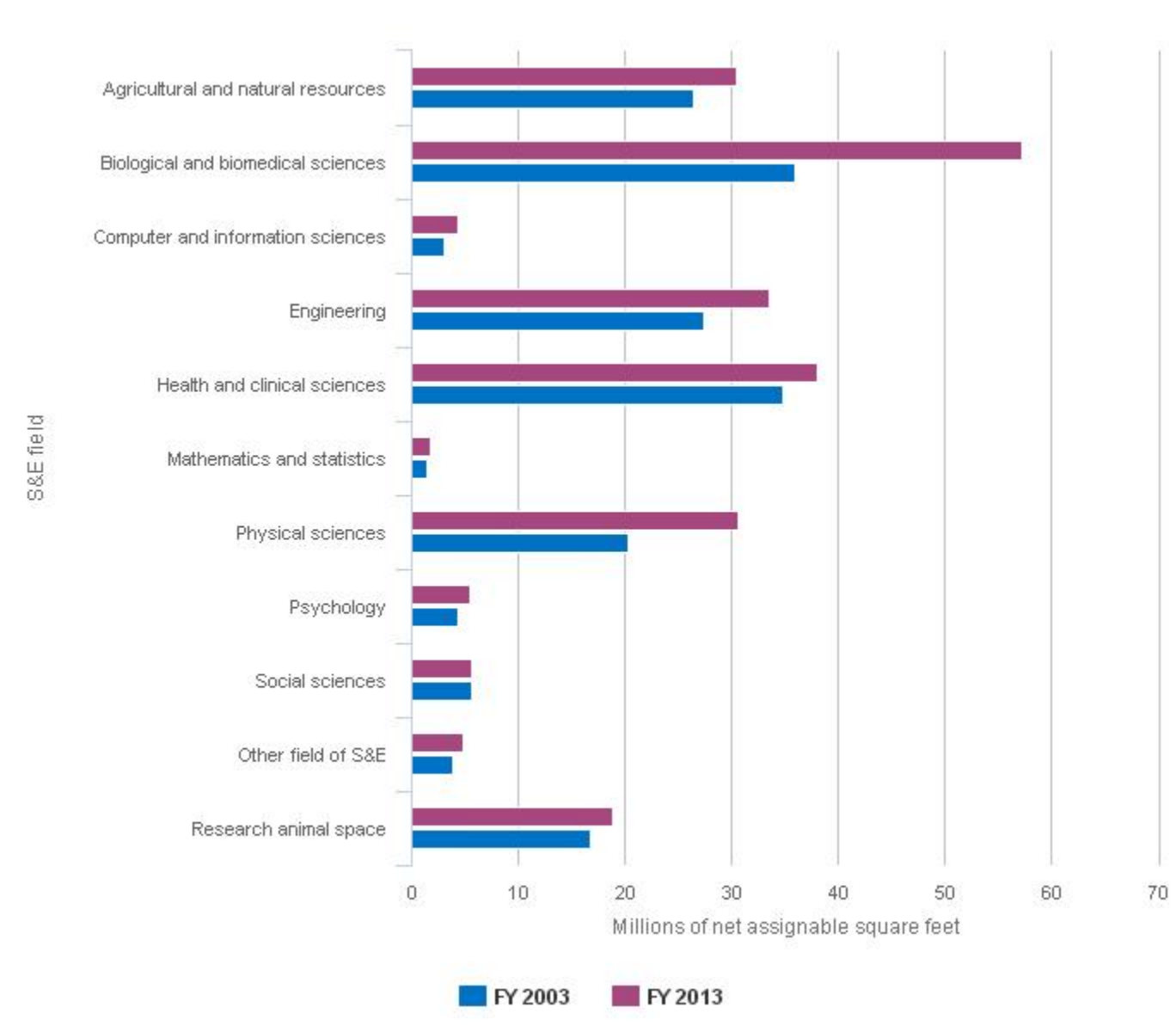
The biological and biomedical sciences constituted the largest share (27.0%, or 57.2 million NASF) of all academic research space in 2013, which is slightly more than the share it held in 2011 (26.6%) (Appendix Table 5-8). This field, along with the agricultural and natural resources sciences, accounted for two-thirds of the 9.6 million in NASF growth from 2011. Research space in the biological and biomedical sciences increased 6.5% (3.5 million NASF) during the 2011–13 period. Space in the agricultural and natural resources sciences increased 10.5% (2.9 million NASF).[ii] From 2003 to 2013, research space in biological and biomedical sciences grew 58.9% (Figure 5-14); this is the only field that increased space in each of the five biennial periods since 2003. The related field of health and clinical sciences was the second largest in 2013, accounting for 17.9% of the total, or 38.0 million NASF. However, this total is slightly lower than the 39.7 million NASF of health and clinical sciences research space in use in 2005 after the near-doubling of the NIH budget from 1998 to 2003. The remaining large fields in 2013 were engineering (15.8%, or 33.5 million NASF); physical sciences (14.5%, or 30.7 million NASF); and agricultural and natural resources (14.4%, or 30.5 million NASF).[iii]

[ii] The S&E fields used in the National Science Foundation Survey of Science and Engineering Research Facilities are based on the National Center for Education Statistics Classification of Instructional Programs (CIP)—which is updated every 10 years (the current version is dated 2010). The S&E fields used in the FY 2011 and FY 2013 Survey of Science and Engineering Research Facilities reflect the 2010 CIP update. Both the FY 2007 and FY 2009 surveys reflect the 2000 CIP standard. For a comparison of the subfields in the FY 2005 and FY 2007 surveys, see the detailed statistical tables for S&E Research Facilities: FY 2007 (NSF/NCSES 2011). No major impacts on these data resulted from the CIP 2010 update.

[iii] The science and technology field and subfield definitions were updated to the 2000 Classification of Instructional Programs starting with the FY 2007 Survey of Science and Engineering Research Facilities. Some of the observed declines in research space for health and clinical sciences and for physical sciences between FY 2005 and FY 2007 could reflect definition changes.

Figure 5-14

Research space at academic institutions, by S&E field: FYs 2003 and 2013



NOTES: S&E fields are those used in the National Center for Education Statistics (NCES) Classification of Instructional Programs (CIP). NCES updates the CIP every 10 years. S&E fields here reflect the NCES 2010 CIP update.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Science and Engineering Research Facilities. See appendix table 5-8.

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In 2013, 81% of research space was reported by academic institutions as being in superior or satisfactory condition (Table 5-10).[iv] Fifteen percent of space required renovations, while the remaining 4% required replacement. These percentages changed very little over the past decade. In 2003, 79% of academic research space was reported as being in superior or satisfactory condition, 16% required renovations, and 5% required replacement. Between 79% and 85% of research space was rated as either superior or satisfactory across all but two major fields in 2013. Ninety-one percent of research space in the computer and information sciences (4.3 million NASF) was

rated as superior or satisfactory, while 77% of space in the agricultural and natural resources sciences (30.5 million NASF) was similarly rated.

[iv] For the FY 2013 Survey of Science and Engineering Research Facilities, 588 academic institutions were asked to identify the percentage of research NASF (including research animal space) that fell into each of the four following condition categories: *superior condition*—suitable for the most scientifically competitive research in this field over the next 2 years (FY 2014 and FY 2015); *satisfactory condition*—suitable for continued use over the next 2 years (FY 2014 and FY 2015) for most levels of research in this field but may require minor repairs or renovation; *requires renovation*—will no longer be suitable for current research without undergoing major renovation within the next 2 years (FY 2014 and FY 2015); *requires replacement*—should stop using space for current research within the next 2 years (FY 2014 and FY 2015).

Table 5-10 **Condition of S&E research space in academic institutions, by field: FY 2013**

		Condition (% NASF)			
Field	NASF (millions)[a]	Superior	Satisfactory	Requires renovations	Requires replacement
All research space	211.2	35	46	15	4
Agricultural and natural resources sciences	30.5	24	53	19	4
Biological and biomedical sciences	57.0	39	43	14	4
Computer and information sciences	4.3	48	43	7	2
Engineering	33.4	35	46	16	3
Health and clinical sciences	37.9	41	44	12	3
Mathematics and statistics	1.7	29	53	15	3
Physical sciences	30.5	31	48	18	4
Earth, atmospheric, and ocean sciences	7.8	31	47	18	4
Astronomy, chemistry, and physics	22.7	31	48	17	4
Psychology	5.5	35	45	15	4
Social sciences	5.6	28	56	14	2
Other	4.8	42	43	8	6

NASF = net assignable square feet.

[a] NASF is the amount of NASF located at only those institutions that also rated the condition of their space. Consequently, this table accounts for approximately 0.6 million fewer NASF than other tables.

NOTES:	Detail may not add to total due to rounding. Condition was assessed relative to the usage of the current research program.
SOURCE:	National Science Foundation, National Center for Science and Engineering Statistics, Survey of Science and Engineering Research Facilities, FY 2013. *Science and Engineering Indicators 2016*

New Construction

New research space is added each year through new construction projects and the repurposing of existing space. Similarly, some space is withdrawn from use through decommissioning and repurposing. The net result has been an increase in research space for more than two decades. As part of this process, academic institutions broke ground on 6.7 million NASF of new S&E research space construction projects in 2012–13, the lowest total in a decade. This total is 17.3% lower than the new research space construction that began in 2010–11 and 56.8% lower than the NASF of new building that began in 2002–03 (Table 5-11). Public institutions accounted for 73.4% of new construction space, which is within the typical range of 73%–78%.

Table 5-11 **New construction of S&E research space in academic institutions, by field and time of construction: FYs 2002–13**

Field	Started in FY 2002 or FY 2003	Started in FY 2004 or FY 2005	Started in FY 2006 or FY 2007	Started in FY 2008 or FY 2009	Started in FY 2010 or FY 2011	Started in FY 2012 or FY 2013	Planned to start in FY 2014 or FY 2015
	Net assignable square feet (millions)						
All fields	15.5	10.1	8.8	9.9	8.1	6.7	8.8
Agricultural and natural resources	0.8	0.4	0.5	0.4	0.4	0.4	0.5
Biological and biomedical sciences	3.7	3.2	2.9	3.5	2.0	2.0	2.0
Computer and information sciences	0.9	0.3	0.6	0.3	0.1	0.2	0.5
Engineering	2.2	1.5	1.3	2.1	1.3	1.4	1.6
Health and clinical sciences	4.9	3.3	1.7	1.9	2.8	1.6	1.9
Mathematics and statistics	*	*	*	*	*	*	*
Physical sciences	2.0	0.8	1.0	1.0	0.9	0.8	1.7
Earth, atmospheric, and ocean sciences	0.5	0.3	0.3	0.1	0.3	0.2	0.8
Astronomy, chemistry, and physics	1.5	0.5	0.7	0.9	0.6	0.6	0.9

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Field	Started in FY 2002 or FY 2003	Started in FY 2004 or FY 2005	Started in FY 2006 or FY 2007	Started in FY 2008 or FY 2009	Started in FY 2010 or FY 2011	Started in FY 2012 or FY 2013	Planned to start in FY 2014 or FY 2015
Psychology	0.2	0.2	0.1	0.3	0.1	*	0.1
Social sciences	0.2	0.1	0.1	0.2	0.1	0.1	0.1
Other sciences	0.7	0.3	0.7	0.3	0.3	0.1	0.3
Research animal space[a]	1.4	1.2	1.0	0.8	0.6	0.7	na
	Share of total new construction square feet (%)						
All fields	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Agricultural and natural resources	5.1	3.9	5.7	4.0	4.9	6.0	5.7
Biological and biomedical sciences	23.6	31.4	33.0	35.4	24.7	29.9	22.7
Computer and information sciences	5.9	2.9	6.8	3.0	1.2	3.0	5.7
Engineering	14.2	14.7	14.8	21.2	16.0	20.9	18.2
Health and clinical sciences	31.4	32.4	19.3	19.2	34.6	23.9	21.6
Mathematics and statistics	*	*	*	*	*	*	*
Physical sciences	12.5	7.8	11.4	10.1	11.1	11.9	19.3
Earth, atmospheric, and ocean sciences	3.1	2.9	3.4	1.0	3.7	3.0	9.1
Astronomy, chemistry, and physics	9.4	4.9	8.0	9.1	7.4	9.0	10.2
Psychology	1.1	2.0	1.1	3.0	1.2	*	1.1
Social sciences	1.3	1.0	1.1	2.0	1.2	1.5	1.1
Other sciences	4.6	2.9	8.0	3.0	3.7	1.5	3.4
Research animal space[a]	9.0	11.8	11.4	8.1	7.4	10.4	na

* = > 0 but < 50,000 net assignable square feet; na = not applicable.

	[a] Figures for research animal space are listed separately and are also included in individual field totals.
NOTES:	Detail may not add to total because of rounding. S&E fields are those used in the National Center for Education Statistics (NCES) Classification of Instructional Programs (CIP). NCES updates the CIP every 10 years; S&E fields here reflect the NCES 2010 CIP update. For comparison of subfields in the FY 2005 and FY 2007 surveys, see S&E Research Facilities: FY 2007, detailed statistical tables.
SOURCE:	National Science Foundation, National Center for Science and Engineering Statistics, Survey of Science and Engineering Research Facilities.
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Although the growth rate of new construction projects has declined over the past decade, institutions initiated new construction in all fields in this latest period. Construction projects for the biological and biomedical sciences accounted for 2.0 million NASF in 2012–13, the largest amount of space initiated for any field. While the amount of new construction in the field has remained the same since 2010–11, it is lower than each of the four data collection periods from 2002 to 2009. Health and clinical sciences combined with engineering to add 3.0 million NASF, resulting in these S&E fields (biological and biomedical sciences, health and clinical sciences, and engineering) accounting for 74.6% of new research space construction in 2012–13. Overall, an estimated 8.8 million NASF of new research space construction are planned for 2014–15, and these three fields are projected to account for nearly two-thirds (62.5%) of this new construction.

Academic institutions draw on various sources to fund their capital projects, including the institutions' own funds, state or local governments, and the federal government (Appendix Table 5-9). Institutions provide the majority of funds for construction of new research space, typically accounting for over 60.0% of the cost.[v] For the construction of new research space initiated in 2012–13, 67.5% of the funding came from institutions' internal sources, 26.9% from state and local governments, and the remaining 5.7% from the federal government, which was never a major funder of academic research facilities. Three-quarters of federal funding ($235.8 million) went to public doctorate-granting institutions. The total estimated cost of $5.5 billion reported for new construction started in 2012–13 was the lowest total reported in over a decade.

Repair and Renovation

Academic institutions expended $3.7 billion on major repairs and renovations of S&E research space in 2012–13 (Appendix Table 5-10).[vi] They anticipated $3.4 billion in costs for planned repair and renovation of research space with start dates in 2014–15. Over $901 million were planned to improve space in biological and biomedical sciences as well as more than $817 million for improvements to health and clinical sciences space. In addition to these slated improvements, academic institutions reported $5.4 billion in repair and renovation projects from their institutional plans that were not yet funded or scheduled to start in 2014–15. An additional $2.9 billion in needed improvements were identified that lay beyond institutional plans. Public institutions spent 51.6% of the total $3.7 billion, which is below the average share of 56.1% for the 2004–11 period.

The total backlog of deferred improvements was greater than all projects started or planned for the 2012–15 period. The costs for deferred repairs and renovations have consistently been greater than those started or planned for similar cycles in the past. This is due in part to the longer time frames of institutional plans that often run to 5 years or more.

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[v] *Institutional sources* include universities' operating funds, endowments, private donations, tax-exempt bonds and other debt financing, and indirect costs recovered from federal and nonfederal sources.

[vi] Only projects whose prorated cost was estimated to be $250,000 or more for at least one field of S&E were included.

Research Equipment

In 2014, about $2 billion in current funds were spent for movable equipment necessary for the conduct of academic S&E research projects (Appendix Table 5-11).[i] This spending accounted for 3.1% of the $63.7 billion of total academic S&E R&D expenditures. Spending decreased 11.3% from 2013 to 2014 when adjusted for inflation. Expenditures for academic research equipment reached the highest mark in several decades in 2004. Research equipment expenditures reached this level again in 2011 due in part to ARRA funding. After this temporary increase, the 2012 expenditures fell to the lowest constant-dollar level since 2007 before rising almost 10% in 2013. The recent fluctuations continued in 2014, with the lowest total in constant dollars since 2001.

Research equipment expenditures continue to be concentrated in just three fields, which accounted for 87.1% of the 2014 total: life sciences (36.9%), engineering (32.9%), and physical sciences (17.3%). The shares for these three fields have consistently accounted for about 80% or more of total equipment expenditures, although the 2014 combined shares are the highest on record (Appendix Table 5-11).

When adjusted for inflation, the 2014 level of equipment spending in engineering was slightly below its decades-high level reached in 2013 and also 36.7% greater than the 2004 spending level (Figure 5-15). This is notable because all science equipment spending in constant dollars decreased 26.7% from 2004 to 2014 (Appendix Table 5-11). Computer science equipment spending saw a 1-year jump in 2013 due in large part to federal funding of the Blue Waters and Stampede supercomputers that were formally launched in 2013 (NSF 2013a, 2013b).

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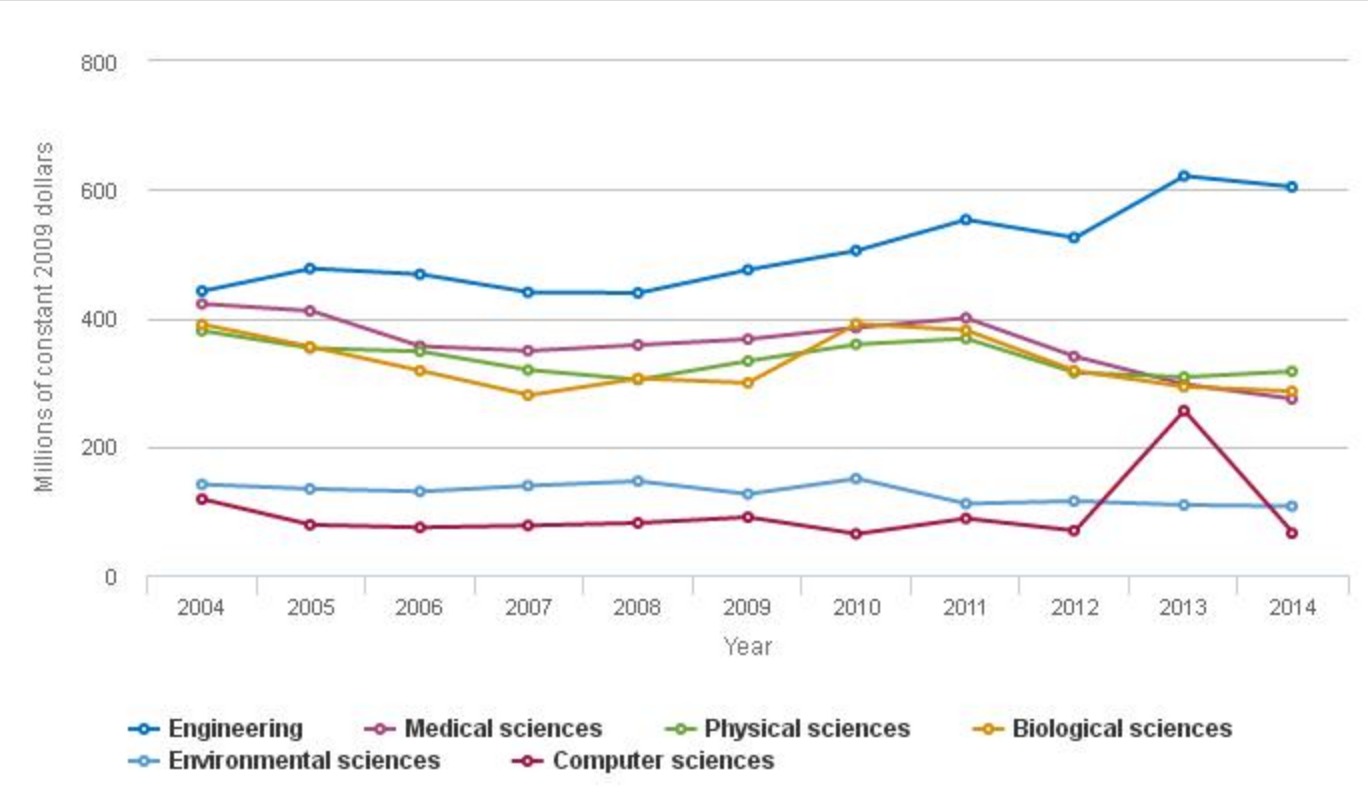
[i] Because of rising capitalization thresholds, the dollar threshold for inclusion in the equipment category has changed over time. Generally, university equipment that costs less than $5,000 would be classified under the cost category of “supplies.”

Figure 5-15

Current fund expenditures for S&E research equipment at academic institutions, by selected fields: FYs 2004–14



NOTES: Gross domestic product deflators come from the U.S. Bureau of Economic Analysis and are available at http://www.bea.gov/national, accessed 18 February 2015. See appendix table 4-1.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Research and Development Expenditures at Universities and Colleges, and Higher Education Research and Development Survey. See appendix table 5-11.

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Most academic research equipment funding typically comes from the federal government. These federal funds are generally received as part of research grants or as separate equipment grants. In 2014, the federal government supported 45.1% of total academic S&E research equipment funding, which marked the first time federal support fell below 50% since data were initially collected in 1981 (Appendix Table 5-12). Seventy-two percent of equipment funding went to public institutions in 2014. Public institutions also garnered 65% of federal funding and 77.7% of nonfederal funding support for research equipment.

The federal share of funding varies significantly by S&E field. Only physics (79.8%) and atmospheric sciences (79.6%) received greater than 70% federal funding for R&D equipment, while four fields (agricultural sciences, economics, metallurgical/materials engineering, and sociology) received less than 30%.

Cyberinfrastructure

Advances in computing technology and IT have changed the nature of scientific research and the infrastructure for conducting it over the past three decades. Cyberinfrastructure includes resources such as high-capacity networks,

which are used to transfer information, and data storage systems, which are used for short-term access or long-term curation. It may also involve HPC systems used to analyze data, create visualization environments, or facilitate remote use of scientific instrumentation (NSF 2012). Cyberinfrastructure helps researchers process, transfer, manage, analyze, and store large quantities of data.

Quantifying these resources has proven difficult. The 2004–14 editions of *Science and Engineering Indicators* included analyses of data collected through NSF's Survey of Science and Engineering Research Facilities on various computing and networking capacity metrics. After a comprehensive review, NSF determined that the computing and networking infrastructure data did not provide adequate coverage of the academic research cyberinfrastructure because of rapid changes in the field, the survey's focus on capacity as opposed to usage, and the challenges that institutions have in accounting for these resources. Many researchers access computing, storage, software, and networking resources on their own rather than through the resources provided by their university. Increasingly, academic institutions are centralizing their cyberinfrastructure resources to increase efficiency. Providing metrics on these trends creates an incomplete and possibly misleading picture, although the centrality of cyberinfrastructure to S&E research is clear (CASC 2015).

Doctoral Scientists and Engineers in Academia

Academically employed research doctorate holders in science, engineering, and health (S&E) hold a central role in the nation's academic R&D enterprise.[i] Through the R&D they undertake, S&E doctorate holders produce new knowledge and contribute to marketplace innovation. They also teach and provide training opportunities for young people who may then go on to earn S&E doctorates; some of these will then train the next generation of scientists and engineers, while others will contribute through their employment in business or in government.

This section examines trends in the demographic composition of the doctoral S&E academic workforce and its deployment across institutions, positions, and fields. Particular attention is paid to the component of this workforce that is more focused on research, including graduate assistants; those employed in postdoc positions; and researchers receiving federal support. A central message of this section is that, whether looked at across 15–20 years or across four decades, the demographic composition of the academically employed S&E workforce, like the S&E workforce throughout the economy, has changed substantially. There also have been noteworthy changes in the types of positions or job titles held by S&E doctorates employed at academic institutions. Changes in academic doctoral employment across institution types and fields of S&E have been more modest.

Longer-term comparisons from 1973 to 2013 are made to illustrate fluctuations over multiple decades and trends that continue to unfold. Shorter-term comparisons (from the early to mid-1990s to 2013) are made to illustrate what the past two decades have brought forth.[ii] Since individuals in faculty and nonfaculty positions both conduct R&D, much of the discussion addresses the overall academic employment of U.S.-trained S&E doctorate holders, regardless of position or rank. However, at various points, full-time faculty and those who work outside of the full-time faculty population are discussed separately. (For an overview of the sources of data used, see sidebar, Data on Doctoral Scientists and Engineers in Academia and sidebar, Foreign-Trained Academic S&E Doctoral Workforce)

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[i] For purposes of this discussion, health sciences are combined with biological, agricultural, and environmental life sciences to create the broad field of life sciences.

[ii] In the discussion covering the age composition of the academic doctoral workforce, comparisons are made between 1995 and 2013 because the Age Discrimination in Employment Act of 1967 applied to the professoriate starting in 1994. Comparisons over the 10-year period from 2003 to 2013 are used in the discussion of minorities in the academically employed workforce because data prior to this time are not directly comparable to data from 2003 forward. In the section on federal support of doctoral researchers, comparisons are made between 1973, the very early 1990s, and 2013 because of the availability of relatively comparable data for these years. In most discussions of full-time faculty, comparisons are made between 1997 and 2013 because comparable data on senior and junior faculty groupings are available for these years.

Data on Doctoral Scientists and Engineers in Academia

Data on academically employed research doctorate holders are drawn primarily from the Survey of Doctorate Recipients (SDR), a biennial National Science Foundation (NSF) survey of individuals, including foreign-born individuals, who received their research doctorate in a science, engineering, or health field from a U.S. institution. This survey provides the most comprehensive data available on these individuals. Data are provided on educational background, employment status, occupation, and demographic

characteristics. Unless specifically stated, estimates of S&E doctorates come from the SDR. The latest survey is available at http://www.nsf.gov/statistics/srvydoctoratework/surveys/srvydoctoratework_nat2013.pdf.

Because the SDR covers only U.S.-trained individuals, it substantially undercounts postdoctoral researchers (postdocs), many of whom were trained outside the United States, and provides no estimates of foreign-trained doctoral holders in other positions in academia, such as full-time faculty. Two other surveys referenced in this section supplement SDR data to provide coverage of the foreign-trained doctorate recipients. To obtain more complete counts of postdocs, this section supplements SDR's estimated counts with counts provided in the Survey of Graduate Students and Postdoctorates in Science and Engineering, an annual survey cosponsored by NSF and the National Institutes of Health. Data on graduate assistants are also provided from this survey. The latest survey is provided here: http://nsf.gov/statistics/srvygradpostdoc/surveys/srvygradpostdoc-2013.pdf.

To provide more data on the role of foreign-trained doctorate holders in academic R&D, this section draws from NSF's National Survey of College Graduates (NSCG). Although the NSCG provides less detail on academic employment, it provides estimates of the foreign-trained component. See the sidebar "Foreign-Trained Academic S&E Doctoral Workforce" for data on foreign-trained individuals' presence in academic employment. The latest NSCG forms are available at http://www.nsf.gov/statistics/srvygrads/surveys/srvygrads-newrespond2013.pdf and http://www.nsf.gov/statistics/srvygrads/surveys/srvygrads-returnrespond2013.pdf.

Foreign-Trained Academic S&E Doctoral Workforce

U.S. universities and colleges have long employed S&E doctorate holders from foreign countries; most received their doctorate from a U.S. institution, but many earned it overseas. In 2013, approximately 59,000 foreign-trained S&E doctorate holders worked in U.S. higher education institutions. Approximately two-thirds of the foreign-trained doctorate holders were men and one-third were women, similar to the gender distribution of their U.S.-trained counterparts.

Because the Survey of Doctorate Recipients (SDR) uses a more restrictive definition of the research doctorate, some complications exist in comparing National Survey of College Graduates S&E fields with those from the SDR, particularly with regard to the life sciences and psychology. Taking these complications into consideration, the field distribution of the foreign-trained doctorate holders nonetheless varies from the U.S.-trained doctorate holders. The majority (about 60%) of the foreign-trained individuals hold doctorates in the life sciences, while the majority of their U.S.-trained counterparts hold doctorates in either the life sciences (36%) or the social sciences (18%) (Appendix Table 5-13). In 2013, female foreign-trained S&E doctorate holders were largely concentrated in the life sciences (Table 5-B).

Table 5-B **Foreign-trained S&E doctorate holders employed in academia, by degree field and sex: 2013**

Field	Total	Male	Female
Full-time positions			

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Field	Total	Male	Female
All fields	55,000	38,000	17,000
Physical sciences	11,000	10,000	1,000
Computer and mathematical sciences	4,000	3,000	S
Life sciences	34,000	20,000	14,000
Social sciences and psychology	3,000	2,000	D
Engineering	3,000	3,000	D
Part-time positions			
All fields	4,000	2,000	1,000

NOTE: D = suppressed for reasons of confidentiality; S = suppressed for reasons of data reliability.
Detail may not add to total due to suppression.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2015) of the 2013 National Survey of College Graduates.
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The foreign-trained doctorate holders have a substantial presence in conducting academic R&D, with about 90% reporting that research was their primary or secondary work activity in 2013 and almost two-thirds reporting support from federal grants and contracts. A smaller percentage of foreign-trained S&E doctorate holders are heavily engaged in teaching. In 2013, about 35% reported that teaching was their primary or secondary work activity (Table 5-C).

Table 5-C Foreign-trained S&E doctorate holders employed in academia, by research and teaching focus: 2013

(Percent)

Field	Federal support	R&D	Teaching
Full-time positions			
All fields	63.6	89.1	34.5
Physical sciences	54.5	90.9	45.5
Computer and mathematical sciences	50.0	75.0	75.0
Life sciences	67.6	88.2	23.5
Social sciences and psychology	D	66.7	66.7
Engineering	66.7	100.0	33.3

Field	Federal support	R&D	Teaching
Part-time positions			
All fields	25.0	50.0	75.0

NOTES: D = suppressed for reasons of confidentiality.

The percentage of R&D is the percentage of SEH doctorate holders reporting that their primary or secondary work activity is R&D. The percentage teaching is the percentage of SEH doctorate holders reporting that their primary or secondary work activity is teaching.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2015) of the 2013 National Survey of College Graduates.

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Trends in Academic Employment of S&E Doctorate Holders

Academic employment of S&E doctorate holders grew over the past three decades and reached an estimated 368,000 in 2013. Of this total, the large majority—almost 309,000—were U.S. trained. There was an increase of about 14,000 over the employment numbers estimated in 2010 (Appendix Table 5-13).

The U.S. employment pattern of S&E doctorate holders is distinctive from that of other countries: relatively fewer than elsewhere in academia, more in business and industry, and fewer in government. A 2009 comparison of doctorate holders from 18 countries in all fields, including S&E and other fields, found that, in most of these countries, more than half and up to 90% of the doctorate holders were employed in academia, compared with about 40% for those in the United States. In the United States, along with Belgium, Denmark, and the Netherlands, a fairly large share (roughly one-third) of doctorate holders worked in business, contrasting with fewer than 15% in other jurisdictions including Lithuania, the Russian Federation, Romania (2008), Malta, Turkey, Taiwan, Portugal, and Poland (2008). The United States also had one of the smallest fractions employed in government (less than 10%) (Auriol 2010; Auriol, Misu, and Freeman 2013). In recent decades, growth in the number of doctoral scientists and engineers in the academic sector has been slower than the rate of growth in the business and government sectors, resulting in a decline in the academic sector's share of all S&E doctorates, from 55% in the early 1970s to just under 50% in the early 1990s to about 40% in 2013.

Trends in Types of Academic Positions Held

The doctoral academic workforce discussed in this section includes doctorate holders in S&E who are employed at 2-year and 4-year colleges and universities, including medical schools and university research institutes. This workforce includes full and associate professors (senior faculty); assistant professors (junior faculty); postdocs; persons in other full-time positions, such as instructors, lecturers, adjunct faculty, research associates, and administrators; and those employed in part-time positions of all kinds.

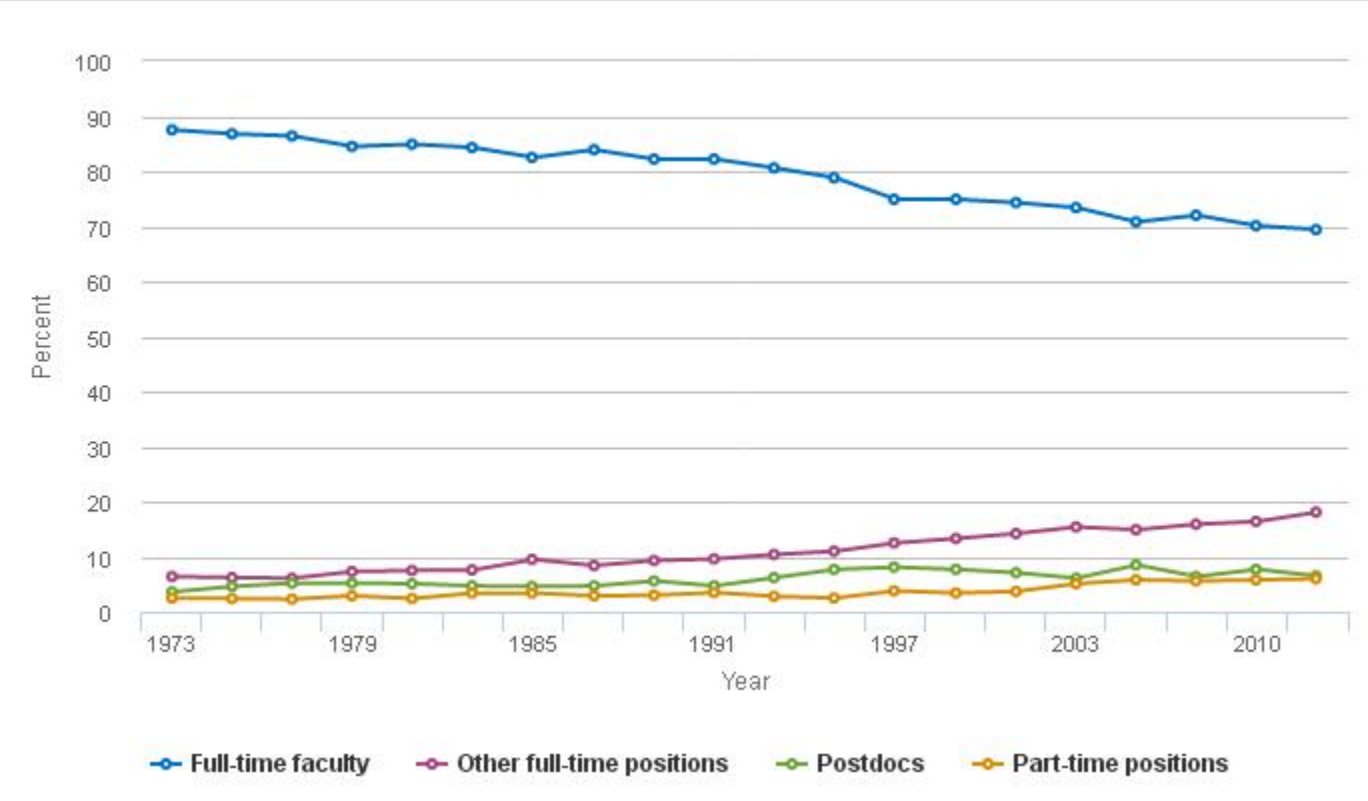
Taking a look at broad trends by position title over the past 40 years, very different patterns emerge. The total number of academically employed doctorate holders in S&E almost tripled over the period from 1973 to 2013, rising from 118,000 to 309,000, while the number of full-time faculty more than doubled (from 103,000 to 214,000) (Appendix Table 5-13). By contrast, the number of other full-time positions increased by over 600% from 1973 to 2013, rising rapidly from a low base of 7,600 (6% of the total) to 55,800 (18% of the total). Greatest growth was

registered over the period from 2006 to 2013 in these nonfaculty positions. Finally, the period from 1989 to 2006 was a slow one in terms of growth in employment as full professors. Almost the same number of people held these positions in 1989 (83,000) as in 2006 (85,000).

Full-time faculty positions as either senior or junior faculty continue to be the norm in academic employment, but S&E doctorate holders are increasingly employed in other full-time positions, in postdoctoral positions, and in part-time positions (Figure 5-16). The share of full-time faculty among all U.S.-trained, academically employed S&E doctorate holders fell from almost 90% (103,000 of 118,000 total) in the early 1970s to about 80% by the mid-1990s and then dropped further, to about 70% in 2013 (214,000 of 309,000 total) (Appendix Table 5-13). The decline in the proportion of full-time faculty was evident among doctorate holders in all S&E fields (Appendix Table 5-13).

Figure 5-16

S&E doctorate holders employed in academia, by type of position: 1973–2013



NOTES: Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes. Full-time faculty includes full, associate, assistant professors, and instructors (from 1973 to 1995), and full, associate, and assistant professors from 1997 to 2013. Other full-time positions includes positions such as research associates, adjunct appointments, instructors (from 1997 to 2013), lecturers, and administrative positions. Part-time positions excludes those held by students or retired persons.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2014) of the 1973–2013 Survey of Doctorate Recipients.

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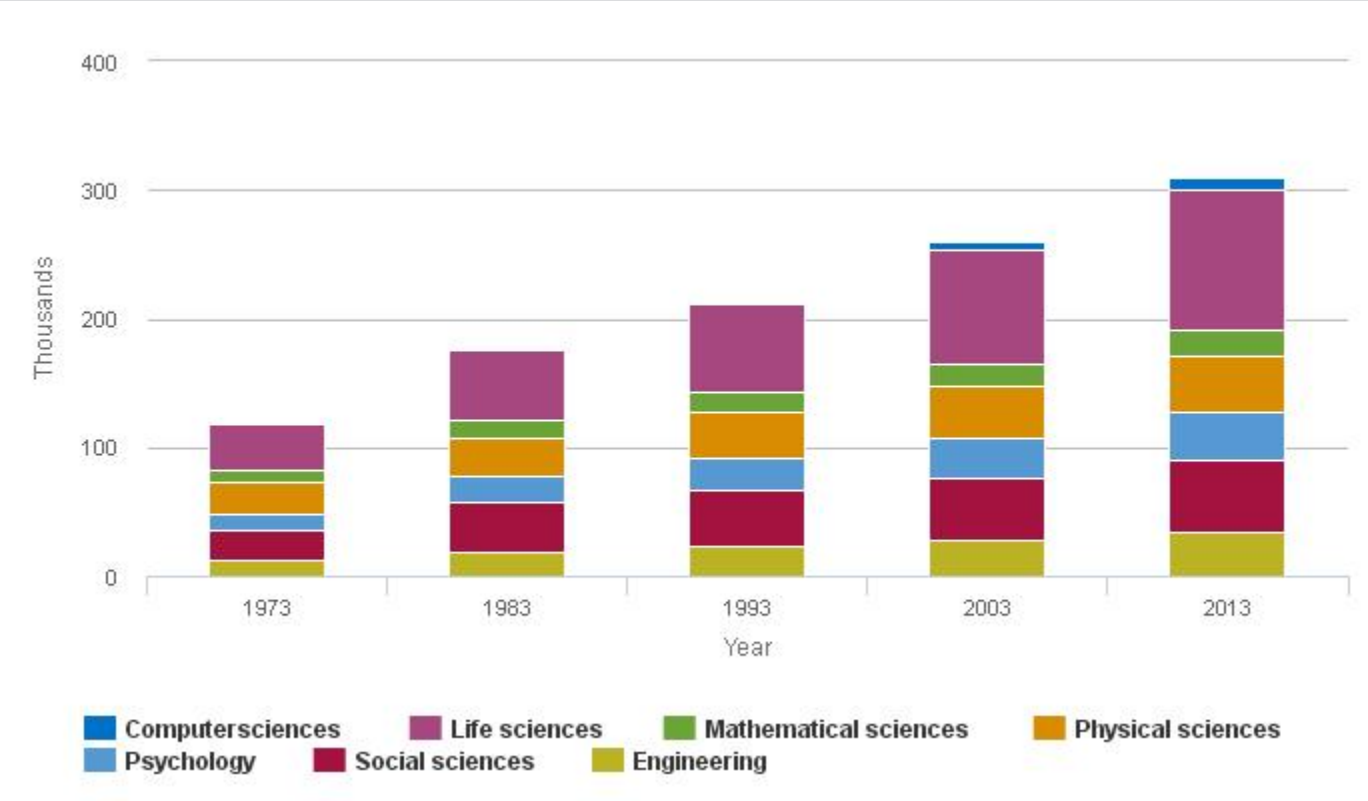
Additionally, from the early 1970s to 2013, the share of U.S.-trained postdocs increased from 4% in 1973 (4,200) to 7% in 2013 (20,200), and the share of part-time positions increased from 2% in 1973 (2,900) to 6% of all academic S&E doctorate holders in 2013 (18,500). There has also been a decrease in the percentage of U.S.-trained doctorate holders in tenured positions (discussed below).

From the early 1970s through 2013, growth in the academic employment of life scientists, psychologists, and engineers was greater than for doctorate holders in other S&E fields (Figure 5-17). Starting from a very small base around 1980, there was also consistent, rapid growth in computer scientists. Growth in academic employment slowed in the early to mid-1990s for social sciences, physical sciences, and mathematics. It has increased since then in social sciences and mathematics and, very recently, in the physical sciences (Appendix Table 5-13). Similar to spending patterns discussed in the expenditures section of this chapter, the most recent decade saw greater growth in the number of engineers in academic employment than their peers in most fields of science, while hiring of computer scientists continued to grow rapidly in numbers from a continuing small base (Figure 5-17).

Figure 5-17

S&E doctorate holders employed in academia, by S&E field: Selected years, 1973–2013



na = not applicable.

NOTES: Data for computer sciences are not available for 1973. Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, excluding those employed part time who are students or retired. Physical sciences include earth, atmospheric, and ocean sciences; life sciences include biological, agricultural, environmental, and health sciences.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2014) of the 1973–2013 Survey of Doctorate Recipients.

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Trends in Tenure Status

Among U.S.-trained S&E doctorate holders working full-time in academia, the proportion that has achieved tenure has diminished since 1997, although the proportion in tenure-track positions has not. In 1997, about 53% (123,000) of U.S.-trained S&E doctorate holders in academic employment held tenured positions; this decreased to 47% in 2013 (144,600) as nontenured positions grew as a share of overall doctoral academic employment.[i] About the same percentage of individuals in 1997 (16%, 37,800 individuals) as in 2013 (15%, 47,600 individuals) was untenured but on a tenure track. Drawing on different data sources (U.S. Department of Education data on overall academic employment without regard to field or degree level), the American Association of University Presidents (AAUP) found larger decreases of about 10 percentage points over the past 15–20 years in tenured positions' share of academic employment (AAUP 2013). Broadening the scope of analysis to both tenured and tenure-track positions, AAUP reports that a 13% decline in the share of tenured and tenure-track positions (as a group) was matched with a 13% increase in the share of contingent positions.

In both 1997 and 2013, the distribution of tenured status varied by S&E field (Table 5-12). For those with doctoral degrees in psychology, engineering, or mathematical sciences, the percentage of tenured positions decreased from 1997 to 2013 by about 8–10 percentage points. For those with doctoral degrees in life sciences, physical sciences, or social sciences, there was a somewhat smaller decrease in the percentage of tenured positions of about 4–5 percentage points over this period of time. For those with a degree in computer and information sciences, the percentage in tenured positions was higher in 2013 (57%, 8,400 individuals) than in 1997 (46%, 3,300 individuals).

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[i] These other positions included positions at universities and colleges where no tenure system exists and where there are various nontenured-track positions.

Table 5-12 **Tenured status, by field of doctorate: 1997 and 2013**

(Percent)

Field of doctorate	1997	2013
Mathematical sciences	70.3	61.6
Social sciences	63.0	58.1
Computer and information sciences	45.5	57.1
Engineering	58.6	49.0
Physical and related sciences	50.7	47.0
Psychology	50.4	42.1
Life sciences	43.6	38.3

NOTE: Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, including medical schools and university research institutes.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2014) of the Survey of Doctorate Recipients.

Science and Engineering Indicators 2016

Tenure status varied by age (Table 5-13). In 2013, lower percentages of S&E doctorate holders at each age group were tenured, compared with 1997.[ii] For example, 39% of those 40–44 years of age held tenured positions in 2013, compared with 47% in 1997. For older cohorts, there were also large differences between 1997 and 2013 in tenure status by age. For example, 67% of those 60–64 years of age held tenured positions in 2013, while 85% of those in this age range held tenured positions in 1997. In a reflection of the lifting of age restrictions on university faculty discussed below, there was a much larger presence in the doctoral academic workforce of those ages 65–75 years in 2013 (30,300, just under 10%) than in 1997 (8,500, 4%), making it difficult to compare changes in tenure status in this age range over time.

[ii] In addition, individuals aged 70–75 years grew as a share of the total doctoral academic workforce from 1995 to 2013. In 1995, less than 1% of the doctoral academic workforce was between 70 years of age and 75 years of age; this increased to 3% in 2013.

Table 5-13 **Tenured S&E doctorate holders employed in academia, by age: 1997 and 2013**

(Percent)

Age	1997	2013
All ages	52.6	46.8
< 30	D	D
30–34	4.9	2.4
35–39	24.9	19.6
40–44	46.9	38.5
45–49	63.0	54.1
50–54	72.0	61.1
55–59	78.3	66.4
60–64	84.6	66.8
65–75	80.0	73.6

NOTE: D = suppressed to avoid disclosure of confidential information.
Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2014) of the Survey of Doctorate Recipients.
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The reduction from 1997 to 2013 in tenured positions' share of total positions occurred across most (but not all) Carnegie classifications (see the chapter 2 sidebar, "Carnegie Classification of Academic Institutions" for a discussion of Carnegie classifications). In 1997, an estimated 47% of academically employed S&E doctorate holders at the most research-intensive institutions (research I institutions) held tenured positions (44,400 individuals); this percentage decreased to just over 40% in 2013 (47,900 individuals). Similar reductions occurred at less research-intensive doctorate-granting institutions and at master's-granting institutions. At medical schools and medical centers, a slightly higher percentage of academically employed doctorate holders occupied tenured positions in 1997 (30%, or 12,600 individuals) than in 2013 (27%, or 14,000 individuals).[iii] At baccalaureate institutions, a similar share of academically employed doctorate holders filled tenured positions in 2013 (62%) as in 1997 (58%).

Differences have emerged over the past couple of decades in the tenure status of S&E doctorate holders 7–10 years after having received their degree. In 1997, approximately 232,500 individuals with U.S. S&E doctorates worked in academia. Of these, about 30,300 (13%) had earned their doctorate 7–10 years earlier. In 2013, when about 309,000 U.S.-trained S&E doctorate holders worked in academia, about 45,300 individuals (15%) had earned their doctorate 7–10 years earlier. Greater shares of such S&E doctorate holders held tenured positions in 1997 (37%, or 11,300 individuals) than in 2013 (27%, or 12,000 individuals). Somewhat smaller shares were not on tenure track in 1997 (12%, or 3,500 individuals) than in 2013 (17%). On the other hand, similar shares (around 32%) held tenure-track positions in 1997 as in 2013; similar shares (5%) reported that their institution did not offer tenure-track positions.

[iii] Gaining tenured status has posed particular challenges for doctorate holders employed at medical schools and centers. In 1997, 26% of S&E doctorate holders employed at medical schools and centers (10,900) reported that no tenure system existed for their position; this percentage had increased to 35% by 2013 (18,400). Furthermore, Stephan (2012) notes in *How Economics Shapes Science* that at many medical schools, tenured faculty do not have a commitment for their salary if they do not get grant support; see also (AAMC 2010).

Women in the Academic S&E Workforce

The past 40 years have seen 10-fold growth in the participation of women in the academic doctoral S&E workforce. In 1973, only about 11,000 U.S.-trained female S&E doctorates were employed in academia, contrasting sharply with about 114,000 in 2013.[iv] Over the past two decades alone, academic employment of women with S&E doctorates rose from about 47,000 in 1993 to 114,000 in 2013. Over the four decades, the number of their male counterparts grew by about 80%, from 110,000 to about 200,000 (Appendix Table 5-14).

These differential rates of increase are reflected in the steadily rising share of women with S&E doctorates in the academic workforce. Women constituted 37% of all U.S.-trained, academic S&E doctoral employment and 30% of full-time senior faculty in 2013, up from 9% and 6%, respectively, in 1973 (Appendix Table 5-14). Women's share of academic S&E employment increased markedly over time in all position categories, though to a lesser degree in part-time positions (Table 5-14). Women have held a larger share of junior faculty positions than positions at either the associate or full professor rank, reflecting a decades-long trend in the rising proportion of doctoral degrees earned by women, coupled with their slightly greater propensity to enter academic employment. The share of women in all faculty ranks rose substantially between 1973 and 2013, reaching 24% of full professors, 38% of associate professors, and 45% of assistant professors (Figure 5-18).

[iv] Despite these gains, the number of academically employed, U.S.-trained female S&E doctorate holders in 2013 (114,000) was very similar to the number of their male counterparts four decades earlier (107,000).

Table 5-14 **Women as a percentage of S&E doctorate holders employed in academia, by position: Selected years, 1973–2013**

(Percent)

Position	1973	1983	1993	2003	2013
All positions	9.1	15.0	21.9	30.3	36.9
Full-time senior faculty	5.8	9.3	14.2	22.8	29.5
Full-time junior faculty	11.3	23.5	32.2	39.7	44.9
Other full-time positions	14.5	23.1	30.2	34.8	42.1
Postdocs	14.3	30.1	30.8	38.0	40.6
Part-time positions	48.3	41.7	61.0	54.5	56.8

NOTES: Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes. Senior faculty includes full and associate professors; junior faculty includes assistant professors and instructors in 1973, 1983, and 1993; in 2003 and 2013, junior faculty includes assistant professors. Other full-time positions include positions such as research associates, adjunct appointments, instructors (in 2003 and 2013), lecturers, and administrative positions. Part-time positions exclude those employed part time who are students or retired.

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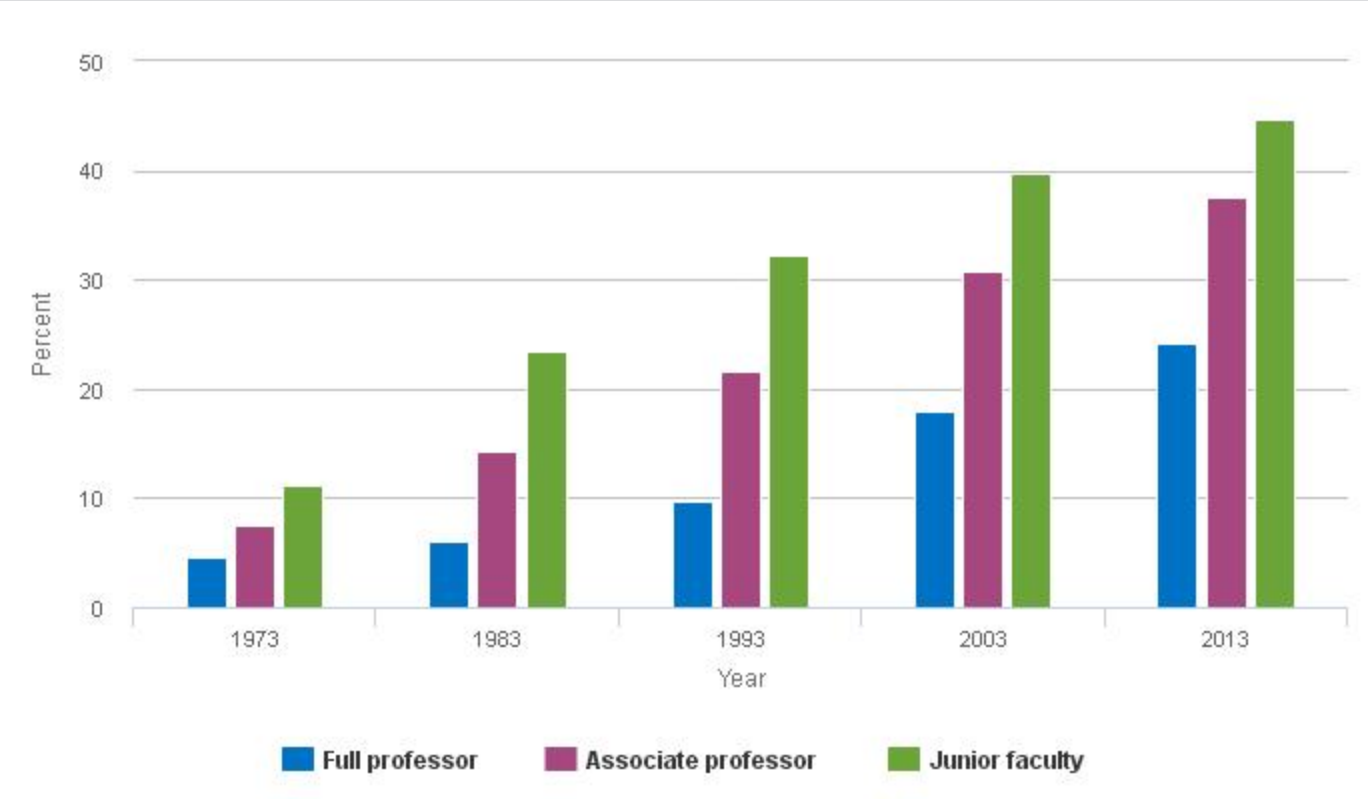
SOURCE:	National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2014) of the 2003 and 2013 Survey of Doctorate Recipients. *Science and Engineering Indicators 2016*

Figure 5-18

Women as a percentage of S&E doctorate holders employed full time in academia, by academic rank: Selected years, 1973–2013



NOTES: Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes, excluding those employed part time who are students or retired. Junior faculty includes assistant professors and instructors in 1973, 1983, and 1993; in 2003 and 2013, junior faculty includes assistant professors.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2014) of the 2003 and 2013 Survey of Doctorate Recipients.

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Women are relatively more concentrated in the life sciences, social sciences, and psychology, with correspondingly lower shares in engineering, physical sciences, mathematics, and computer sciences. Women's share of doctorate holders in each of these fields, however, grew during the 1973–2013 period (Appendix Table 5-14).[v] Although, as noted above, there has been an overall reduction over the past 15–20 years in the proportion of U.S.-trained S&E doctorate holders that have achieved tenure, the experiences of men and women have differed (Table 5-15). Although smaller shares of women than men held tenured positions in both 1997 and 2013, there were greater reductions over this period in the proportion of men in tenured positions across most S&E fields.

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[v] According to 2010 survey data from the American Institute of Physics, despite the economic downturn, women continued to be hired as assistant professors, as well as instructors and adjuncts, at well above their availability rate among doctoral recipients during the latter half of the 2000–09 decade.

Table 5-15 **Tenured S&E doctorate holders employed in academia, by sex and field: 1997 and 2013**

(Percent)

	Total		Female		Male	
Tenured	1997	2013	1997	2013	1997	2013
All fields	52.8	46.8	34.9	36.2	58.9	52.9
Physical sciences	50.7	47.0	30.0	37.5	54.0	50.1
Mathematics and statistics	70.3	61.6	42.9	42.2	74.5	67.1
Computer and information sciences	45.5	57.1	42.9	50.0	42.3	58.2
Life sciences	43.6	38.3	27.8	29.0	50.9	45.6
Psychology	50.4	42.1	34.5	35.5	62.6	52.0
Social sciences	63.0	58.1	49.2	50.9	68.7	63.1
Engineering	58.6	49.0	29.4	31.6	60.6	52.6

NOTE: Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2014) of the Survey of Doctorate Recipients.

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Minorities in the Academic S&E Workforce

Similar to women, members of underrepresented minority groups (i.e., blacks, Hispanics, and American Indians or Alaska Natives) have increased their presence in academic employment over time, but unlike women, they continue to hold a small percentage of S&E doctorate positions (Appendix Table 5-15).[vi] These groups combined constituted 8.8% of total doctoral academic S&E employment in 2013, up from about 7.9% in 2003 and 2.0% in 1973. Underrepresented minorities held 8.3% of full-time faculty positions in 2013, up from 7.0% in 2003 and 1.9% in 1973 (Table 5-16). In 2013, underrepresented minority groups held lower shares of full-time faculty positions than they did of other positions. Compared to white and Asian or Pacific Islander S&E doctorate holders employed in academia, underrepresented minorities in 2013 were somewhat more concentrated in the social sciences and somewhat less in the physical sciences and life sciences (Appendix Table 5-15).

[vi] Analysis of trends in minority and underrepresented minority representation in the U.S.-trained academic doctoral workforce is complicated by changes in the Survey of Doctorate Recipients question about race and ethnicity starting in 2001. Specifically, since 2001, respondents have been allowed to report more than one race. Because of this change, data from 2001 to 2013 are not directly comparable to earlier years' data (Milan 2012).

Table 5-16 **Underrepresented minorities as a percentage of S&E doctorate holders employed in academia, by position: Selected years, 1973–2013**

(Percent)

Position	1973	1983	1993	2003	2013
All positions	2.0	3.7	5.0	7.9	8.8
Full-time faculty	1.9	3.6	5.0	7.0	8.3
Postdocs	2.4	4.8	4.5	7.0	10.4
Other positions	2.9	4.1	5.3	7.3	9.7

NOTES: Underrepresented minorities include blacks, Hispanics, and American Indians or Alaska Natives. Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes. Faculty includes full, associate, and assistant professors plus instructors in 1973, 1983, and 1993. In 2003 and 2013, faculty includes full, associate, and assistant professors. Other positions include part-time positions and full-time positions such as research associates, adjunct appointments, instructors (in 2003 and 2013), lecturers, and administrative positions. Other positions exclude those employed part time who are students or retired.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2015) of the 2003 and 2013 Survey of Doctorate Recipients.

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In both 2003 and 2013, a slightly higher percentage of women than men who are underrepresented minorities held faculty positions.[vii] Female blacks held about 4.7% of full-time faculty positions held by women in 2003 and about 4.6% of these positions in 2013. Male blacks were in about 2.9% of full-time faculty positions held by men in 2003 and about 3.3% in 2013. Similarly, female Hispanics occupied about 4.0% of full-time faculty positions held by women in 2003 and about 4.8% in 2013. Male Hispanics were in about 3.2% of full-time faculty positions occupied by men in 2003 and about 4.1% in 2013. Male and female American Indians or Alaska Natives held about the same percentage of full-time faculty positions in 2003 and 2013 (less than 1%).

The share of Asians or Pacific Islanders employed in the S&E academic doctoral workforce grew dramatically over the past three decades, rising from 4% in 1973 to 17% in 2013.[viii] Asians or Pacific Islanders were heavily represented among those with degrees in engineering and computer sciences, where they constituted 31% and 36%, respectively, of these segments of the doctoral workforce in 2013. They constituted far smaller employment proportions among social scientists (11%) and psychologists (6%) (Appendix Table 5-15).

In both 2003 and 2013, a higher percentage of male Asians or Pacific Islanders held full-time faculty positions than their female counterparts. Male Asians or Pacific Islanders were in about 12.0% of full-time faculty positions occupied by men in 2003 and about 16.3% of these positions in 2013. Female Asians or Pacific Islanders held about 9.3% of faculty positions occupied by women in 2003 and about 13.1% in 2013. Both male and female Asians or Pacific Islanders increased their share of faculty positions from 2003 to 2013.

For those within 7–10 years of having received their S&E doctorate, greater shares were white in 1997 (roughly 79%) than in 2013 (66%), while Asians or Pacific Islanders had larger shares in 2013 (23%) than in 1997 (about 13%). Shares for black or Hispanic doctorates varied little (roughly 4%–5% in 1997 and in 2013).[ix]

Foreign-Born S&E Doctorate Holders in the Academic Workforce

Academia has long employed foreign-born doctorate holders, many with doctorates from U.S. universities, as faculty and other staff. The following discussion focuses on foreign-born individuals who earned their S&E doctorate in the United States.

Academic employment of these foreign-born, U.S.-trained individuals has increased continuously since the 1970s, at a rate faster than that of their native-born counterparts, increasing the foreign-born share of academic S&E

employment from 12% in 1973 to about 27% in 2013 (Figure 5-19). Particularly high proportions are found in engineering (49%) and computer sciences (50%) (Appendix Table 5-16). Nearly half (48%) of all postdoc positions were held by foreign-born doctorate holders in 2013, compared to 26% of full-time faculty positions.

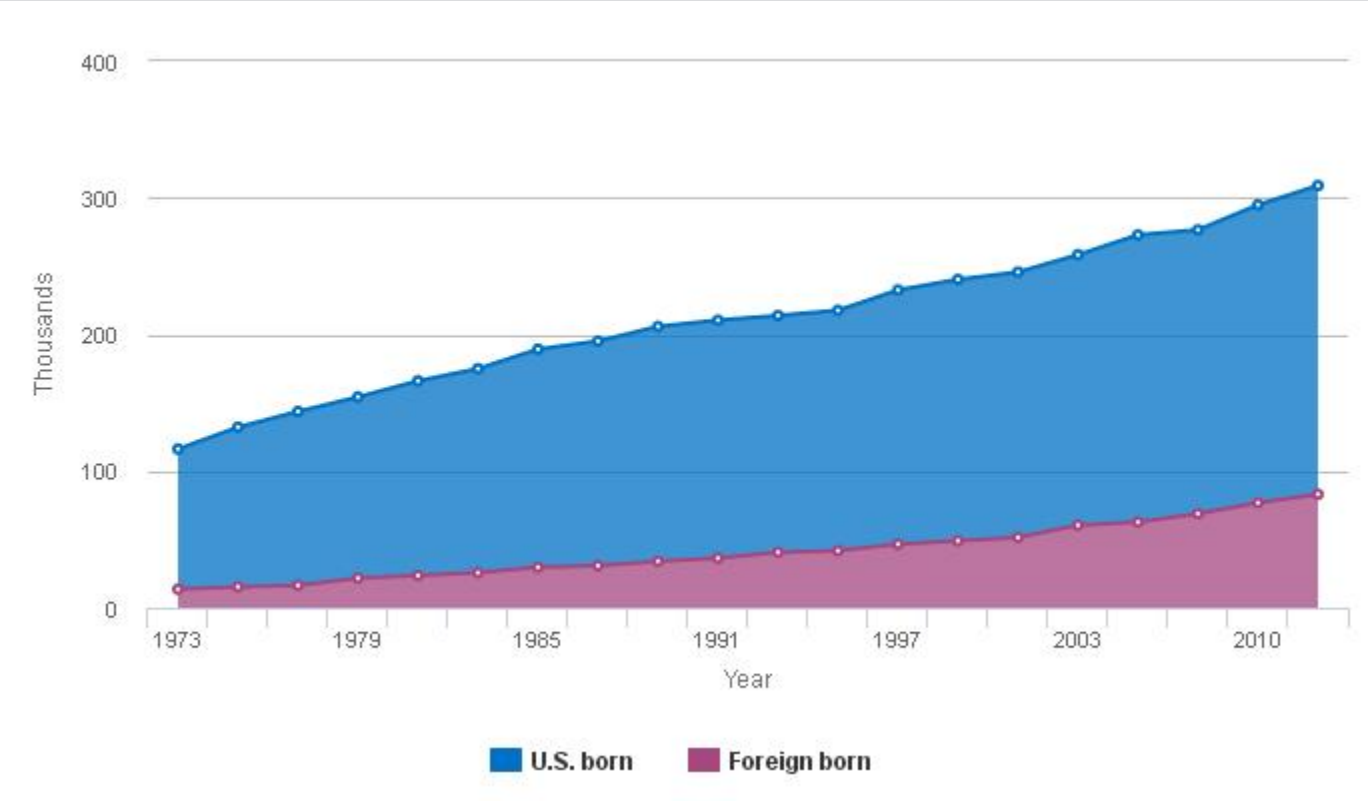
[vii] Estimates of the percentage of underrepresented minorities by sex in the U.S.-trained academic doctoral workforce are based on small samples and are particularly sensitive to sampling error.

[viii] Asians or Pacific Islanders include Native Hawaiians and Other Pacific Islanders.

[ix] Because data on race and ethnicity collected prior to 2001 are not directly comparable to data collected after this year, these estimates are somewhat less precise than if data had been compared from 2001 onward.

Figure 5-19

S&E doctorate holders employed in academia, by birthplace: 1973–2013



NOTE: Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research centers, excluding those employed part time who are students or retired.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2015) of the 2013 Survey of Doctorate Recipients.

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In 2013, about 52,000 U.S.-trained Asian or Pacific Islanders were employed in universities and colleges. Of these, 11% were native-born U.S. citizens, 38% were naturalized U.S. citizens, and 51% were noncitizens. In 2013, Asians or Pacific Islanders represented 51% of the foreign-born, U.S.-trained S&E faculty employed full-time in the United States and nearly 70% of the foreign-born S&E doctorate holders with postdoc appointments.

Age Composition of the Academic Doctoral Workforce

The trend toward relatively fewer full-time faculty positions and relatively more postdoc and other full-time and part-time positions is especially noteworthy because of the steady increase over the past 20 years in the share of full-time faculty positions that are held by those over 60 years of age.

In 1995, individuals ages 60–75 years constituted about 11% of full-time faculty that year; this percentage increased to 24% in 2013.[x] In 1994, the Age Discrimination in Employment Act of 1967 (ADEA) became fully applicable to universities and colleges, prohibiting the forced retirement of faculty at any age. From this point through 2013, as more individuals born during the period of high birth rates from 1946 to 1964 (the "Baby Boomers") began to move through middle age into their 50s and 60s, the proportion of academically employed doctorate holders in the oldest age groups increased (Table 5-17). (See Age and Retirement of the S&E

Workforce within Chapter 3 for a discussion of the age profile and retirement patterns of the broader S&E workforce.)

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[x] Some academically employed S&E doctorate holders were older than 75 years of age in 1995 and in 2013, but the Survey of Doctorate Recipients does not report on this because it drops respondents from the survey sample after they have reached 75 years of age. It is generally believed that individuals over age 75 years hold a small but growing share of academic doctoral employment.

Table 5-17 **Academically employed S&E doctorate holders, by age: 1995 and 2013**

(Percent)

Age	1995	2013
39 and under	29.0	25.9
40–59	61.0	52.7
60–75	10.0	21.4

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2014) of the Survey of Doctorate Recipients.
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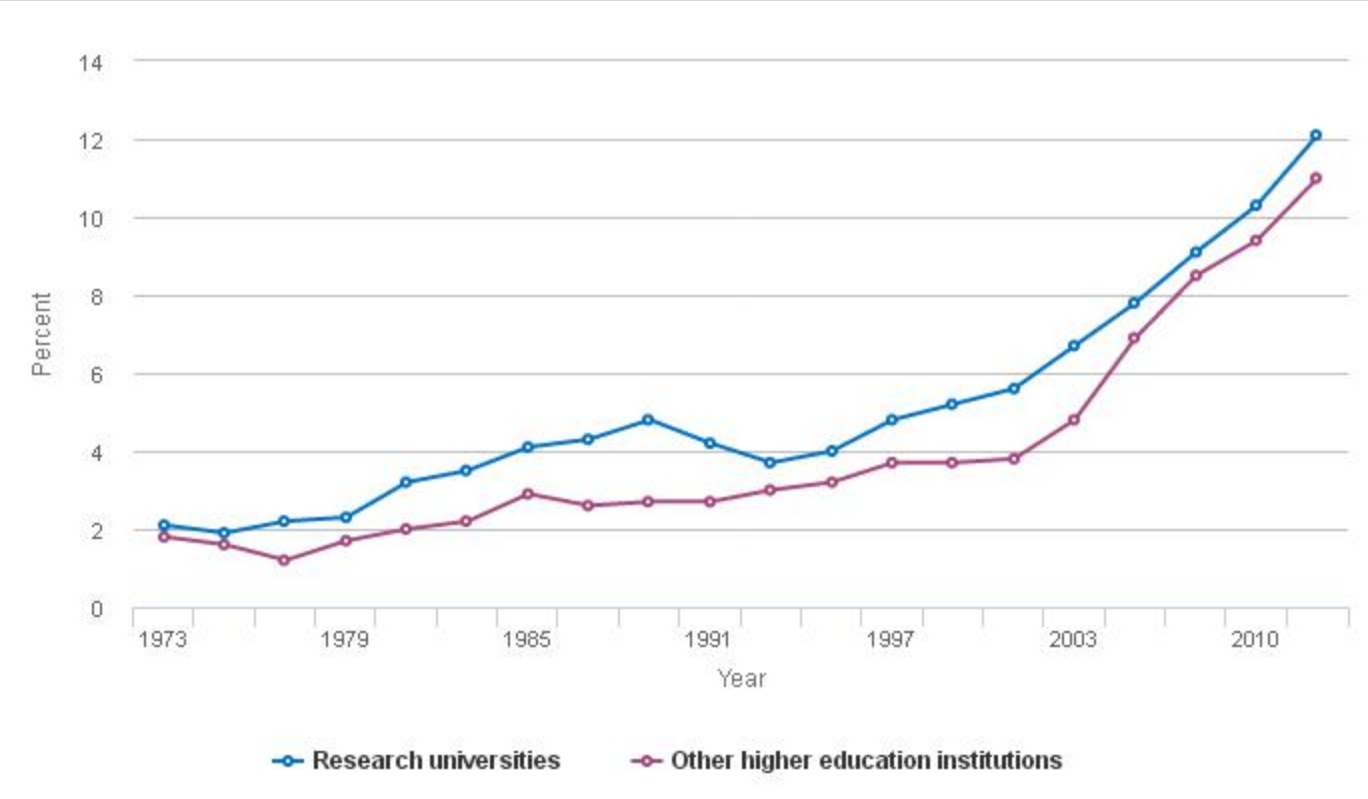
Many of the oldest doctorate full-time faculty work at research-intensive universities, where those ages 60–75 years constituted about 11% of the total in 1995 and about 25% by 2013. Over the same period of time, there was a decline in the proportion of much younger doctorate holders (ages 30–44 years) employed as full-time faculty at research-intensive universities (from about 43% to about 34%).

A comparison of the age distribution of full-time faculty positions at research universities and other universities and colleges shows that there has been a relatively sharp increase since the mid-1990s—when ADEA became applicable to the professoriate—in the percentage of these positions held by those ages 65–75 years. The data show that the share of those ages 65–75 years was gradually rising before the act became mandatory, dipped in the early 1990s at research universities (and leveled off at other institutions), and then rose steeply in most years from 1995 to 2013, particularly at the most research-intensive universities (Figure 5-20; Appendix Table 5-17). By contrast, the percentage of full-time faculty under age 45 years dropped at research universities from 60% in 1973 to 34% in 2013. The trend was broadly similar at other universities and colleges, with those under age 45 years dropping from 65% in 1973 to 34% in 2013.

Figure 5-20

Full-time faculty ages 65–75 at research universities and other higher education institutions: 1973–2013



NOTE: Faculty positions include full, associate, and assistant professors and instructors from 1973 to 1995; from 1997 to 2013, faculty positions include full, associate, and assistant professors.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics, Survey of Doctorate Recipients, 1973–95, and special tabulations (2013, 2015) of the Survey of Doctorate Recipients, 1997–2013. See appendix table 5-17.

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Academic Researchers

The interconnectedness of research, teaching, and public service activities in academia makes it difficult to assess the precise size and characteristics of the academic research workforce by examining the employment trends in academic positions. Individuals with the same academic job titles may be involved in research activities to differing degrees or not be involved in research. Therefore, self-reported research involvement is a somewhat better measure than position title for gauging research activity.[i] This section limits the analysis to two groups of academic S&E doctorate holders, including those who reported that research is their primary work activity (i.e., the activity that occupies the most hours of their work time during a typical workweek) and those who reported that research is their primary or secondary work activity (i.e., the activity that occupies the most or second-most hours of their work time during a typical workweek). Separate breakouts are provided for all doctorate holders and for full-time faculty.

Doctoral S&E Researchers

Chapter 5. **Academic Research and Development**

Since 1973, the number of academic researchers (based on primary or secondary work activity) grew from just over 80,000 to over 200,000 (Appendix Table 5-18). In 2013, of those identified as such researchers, over 140,000 were employed in full-time faculty positions.[ii]

Looking across all doctoral academic positions and across the past four decades, the proportion of researchers has fluctuated between about 60% and 75%. A similar pattern of fluctuation occurred among full-time faculty. In 2013, 65% of S&E doctorate holders in academia and 67% of full-time faculty classified research as their primary or secondary activity.

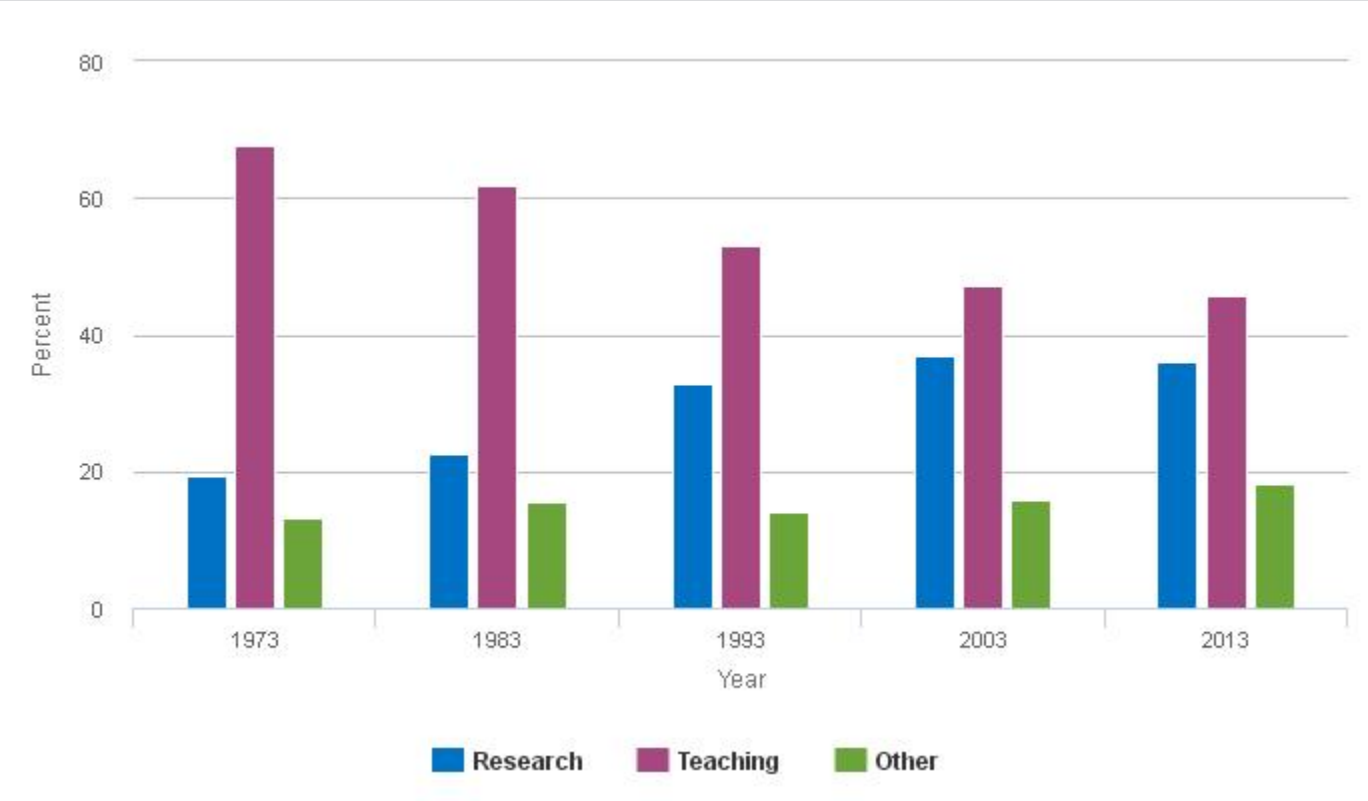
In 2013, the proportions of researchers among the academic doctoral workforce were higher in engineering than in other fields (Appendix Table 5-18). In most fields, the share of researchers declined slightly between 1993 and 2013. Turning to the subset who identify research as their primary work activity, although similar shares of doctorate holders reported this in 2013 as in 1993 (39% versus 38%), somewhat larger shares of full-time faculty did so (36% versus 33%). Looking across the past four decades, the proportion of academically employed S&E doctorate holders who identified research as their primary activity has fluctuated from just below 25% to about 40%. For full-time faculty, this proportion ranged from just under 20% to about 37%. Among full-time doctoral S&E faculty, there was a shift in priority from teaching to research from 1973 to 2003, with the proportion of full-time faculty identifying research as their primary work activity climbing from 19% to 37% and the share of faculty with teaching as their primary activity falling from 68% to 47%. But in the last decade, from 2003 to 2013, the shares of faculty who primarily teach and the shares of faculty who primarily conduct research remained more stable (Figure 5-21).

[i] The Survey of Doctorate Recipients presents respondents with a list of work activities and asks them to identify the activities that occupied the most hours and second-most hours during their typical workweek. This measure was constructed slightly differently prior to 1993, and the data are not strictly comparable across the two periods. Prior to 1993, the survey question asked respondents to select their primary and secondary work activity from a list of activities. Beginning in 1993, respondents were given the same list and asked on which activity they spent the most hours and on which they spent the second-most hours.

[ii] University-reported data from the Higher Education Research and Development Survey indicate that approximately 155,000 people paid from R&D salaries and wages were designated as principal investigators in academic FY 2013 and that an additional 757,000 people, including students paid from R&D accounts, were in positions other than principal investigators. Universities reported salaries, wages, and fringe benefits totaling $28.8 billion in FY 2013 for these research personnel.

Figure 5-21

Primary work activity of full-time doctoral S&E faculty: Selected years, 1973–2013



NOTES: Academic employment is limited to U.S. doctorate holders employed full-time at 2- or 4-year colleges or universities, excluding adjuncts and postdocs. Full-time faculty includes full, associate, and assistant professors and instructors for 1973, 1983, and 1993; for 2003 and 2013, full-time faculty includes full, associate, and assistant professors. Research includes basic or applied research, development, or design. Other activities include a wide range of activities.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2015) of the 2013 Survey of Doctorate Recipients. See appendix table 5-18.

Science and Engineering Indicators 2016

The balance of emphasis between teaching and research varied across the disciplines. A higher share of faculty with doctorate degrees in life sciences and engineering identified research as their primary work activity, and a higher share of faculty with doctorate degrees in mathematics and social sciences reported teaching as their primary activity. Since 1991, the proportion of doctorate holders who reported research as a primary work activity declined among computer scientists and life scientists but grew among mathematicians, psychologists, engineers, and social scientists (Appendix Table 5-18).

Stage of career plays a role in the reported primacy of research, teaching, or other activities. In 2013, 31% of the S&E doctoral faculty who had earned their degree since 2010 identified research as their primary work activity, a lower share than that reported by faculty who had earned S&E doctorate degrees 4–7 years earlier (41%) or 8–11 years earlier (40%) (Table 5-18). The comparable percentage for faculty 12 years or more from receipt of their degree is 35%. A similar pattern across career stages prevailed in most degree fields.

Table 5-18 Full-time S&E faculty reporting research as primary work activity, by years since doctorate and degree field: 2013

(Percent)

Years since doctorate	All fields	Computer and information sciences	Life sciences	Mathematics and statistics	Physical sciences	Psychology	Social sciences	Engineering
All years since doctorate	36.1	37.5	41.3	29.2	35.3	32.8	29.8	40.6
1–3	30.8	50.0	33.3	16.7	25.0	28.6	27.3	37.5
4–7	41.3	33.3	37.3	39.1	37.5	36.7	40.3	58.8
8–11	39.9	33.3	44.4	42.1	35.9	30.2	32.1	52.6
≥ 12	34.5	36.1	41.6	25.2	34.5	32.7	27.0	33.3

NOTES: Academic employment is limited to U.S. doctorate holders employed full-time at 2- or 4-year colleges or universities, medical schools, and university research institutes, excluding adjuncts and post docs. Faculty includes full, associate, and assistant professors. Research includes basic or applied research, development, and design. Physical sciences include earth, atmospheric, and ocean sciences; life sciences include biological, agricultural, environmental, and health sciences.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2015) of the 2013 Survey of Doctorate Recipients. See appendix table 5-18.

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Graduate Research Assistants

The close coupling of advanced training with hands-on research experience is a key feature of U.S. graduate education. Many of the nearly one-half million full-time S&E graduate students in 2013 conducted research as part of their academic studies (Table 5-19).

Table 5-19 Full-time S&E graduate students and graduate research assistants at universities and colleges, by degree field: Selected years, 1973–2013

	1973		1983		1993		2003		2013[a]	
Group and degree field	Thousands	Percent	Thousands	Percent	Thousands	Percent	Thousands	Percent	Thousands	Percent
Graduate students	161.6	100	252.0	100	329.6	100	397.4	100	457.4	100
Computer sciences	2.9	2	10.6	4	17.4	5	30.7	8	39.3	9
Earth, atmospheric, and ocean sciences	7.8	5	12.0	5	11.3	3	11.5	3	12.3	3
Life sciences	40.6	25	69.2	27	91.6	28	122.7	31	124.3	27
Mathematical sciences	10.3	6	11.0	4	14.5	4	14.6	4	19.5	4
Multidisciplinary and interdisciplinary studies[b]	na	na	na	na	na	na	na	na	3.9	1
Physical sciences	21.1	13	25.2	10	30.6	9	30.4	8	36.0	8
Psychology	15.2	9	26.6	11	34.8	11	35.8	9	38.2	8
Social sciences	32.4	20	43.5	17	55.6	17	61.4	15	71.1	16
Engineering	31.3	19	53.9	21	73.8	22	90.2	23	112.8	25
Graduate research assistants	35.9	100	54.9	100	90.2	100	114.3	100	114.9	100
Computer sciences	0.7	2	1.4	3	3.8	4	7.5	7	7.7	7

Chapter 5. **Academic Research and Development**

	1973		1983		1993		2003		2013[a]	
Group and degree field	Thousands	Percent	Thousands	Percent	Thousands	Percent	Thousands	Percent	Thousands	Percent
Earth, atmospheric, and ocean sciences	2.6	7	3.5	6	4.7	5	4.6	4	4.5	4
Life sciences	9.4	26	16.5	30	28.0	31	35.5	31	35.8	31
Mathematical sciences	0.7	2	0.8	1	1.4	2	1.8	2	2.0	2
Multidisciplinary and interdisciplinary studies[b]	na	na	na	na	na	na	na	na	1.0	1
Physical sciences	6.3	18	9.1	17	12.3	14	13.5	12	13.3	12
Psychology	1.9	5	3.0	5	4.6	5	5.6	5	4.9	4
Social sciences	4.0	11	5.0	9	7.4	8	8.4	7	7.2	6
Engineering	10.4	29	15.6	28	28.0	31	37.3	33	38.6	34

NOTES:

na = not available.

[a] Totals exclude fields that were added or reclassified in the 2007 survey (communication, family and consumer sciences, and architecture).

[b] Includes study fields with a science or engineering component.

Graduate research assistants are full-time graduate students with research assistantships as their primary mechanism of support. Physical sciences include astronomy, chemistry, and physics; in prior *Science and Engineering Indicators*, physical sciences also included earth, atmospheric, and ocean sciences in this table. Life sciences include biological, agricultural, and health sciences and, in 2013, the field of neurosciences, which was reclassified as a separate field in the 2007 survey. Detail may not add to total due to rounding.

SOURCE:

National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2015) of the 2013 Survey of Graduate Students and Postdoctorates in Science and Engineering.

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Looking across the period from 1973 to 2013, the number of research assistants—full-time graduate students whose primary mechanism of financial support is a research assistantship—grew faster during most years than graduate enrollment, both overall and in most fields. However, from 2003 to 2013, there was less overall growth in graduate research assistants (0.5%) than there was in the total number of graduate students (15%). Graduate research assistantships were the primary means of support for 25% of graduate students in 2013 and for a similar percentage (22%) of graduate students in the early 1970s.

Academic Employment in Postdoc Positions

About 43,000 S&E doctorate holders were employed in academic postdoc positions in 2013 (see sidebar, Postdoctoral Researchers). The estimate comes from NSF's Survey of Graduate Students and Postdoctorates in Science and Engineering, which reported a total of about 62,000 postdocs in 2013, with about two-thirds (over 43,000) holding positions in S&E and almost one-third (just under 19,000) holding positions in clinical medicine or other health-related fields (Kang 2015).[i] [ii] (See U.S. S&E Workforce: Definition, Size, and Growth within Chapter 3 for more information on biomedical sciences doctorates.) The U.S.-trained component of academically employed postdocs with S&E degrees climbed from 4,200 in the early 1970s to 20,200 in 2013 (Appendix Table 5-13). During that time period, the share of postdocs varied, gradually increasing to just under 9% of all U.S.-trained, academically employed S&E doctorate holders in 2006 and then dipping somewhat to just under 7% in 2013. Postdocs were more prevalent in life sciences, physical sciences, and engineering than in social sciences, psychology, mathematics, and computer sciences. Looking over the decade from 2003 to 2013, there was growth in the proportion of U.S.-trained postdocs in physical sciences and engineering but not in other fields (Figure 5-22; Appendix Table 5-13). The demographic profile of U.S.-trained individuals employed in academic postdoc positions has changed dramatically over the past 40 years. In particular, the proportions of postdocs held by women, racial and ethnic minorities, and foreign-born individuals have climbed (Table 5-20).

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[i] The Survey of Graduate Students and Postdoctorates in Science and Engineering does not include estimates of postdocs employed outside of the academic sector, and comprehensive data are not available on postdocs employed by businesses. See NSF's Survey of Postdocs at Federally Funded Research Development Centers for data on postdocs at FFRDCs (http://www.nsf.gov/statistics/srvyffrdcpd/).

[ii] HERD data report an estimated 66,000 postdocs in 2013 across all fields.

Postdoctoral Researchers

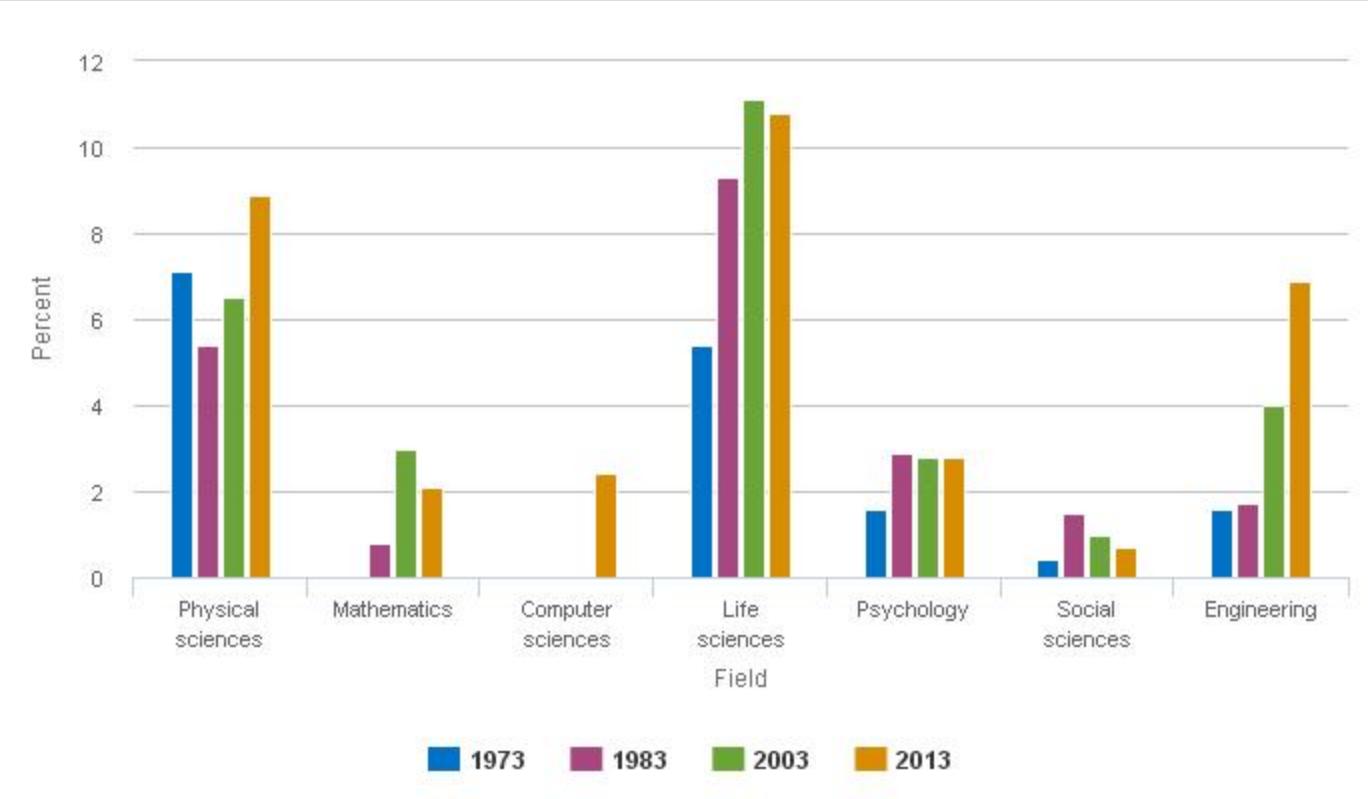
A postdoctorate (postdoc) is a temporary position in academia, industry, a nonprofit organization, or government that is taken after the completion of a doctorate. It serves as a period of apprenticeship for the purpose of gaining additional scientific, technical, and professional skills. Ideally, the individual employed in a postdoc position gains these skills under the guidance of an adviser, with the administrative and infrastructural support of a host institution, and with the financial support of a funding organization. However, the conditions of postdoc employment vary widely between academic and nonacademic settings, across disciplines, and even within institutions, and formal job titles can be an unreliable guide to actual work roles.

Chapter 5. **Academic Research and Development**

Postdoctoral researchers are important to the S&E enterprise and perform a substantial portion of the nation's research. Most have recently earned their doctoral degree, and so they bring new techniques and perspectives that broaden their research teams' experience and make them more competitive in the job market. In addition to conducting research, postdoctoral researchers also educate, train, and supervise students engaged in research; help write grant proposals and papers; and present research results at professional society meetings (COSEPUP 2014).

Figure 5-22

S&E doctorate holders with academic employment in a postdoc position, by degree field: Selected years, 1973–2013



NA = not available; S = data suppressed for reliability.

NOTES: Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes, excluding those employed part time who are students or retired. Physical sciences include earth, atmospheric, and ocean sciences; life sciences include biological, agricultural, environmental, and health sciences.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2015) of the 2013 Survey of Doctorate Recipients.

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Table 5-20 S&E doctorate holders with academic employment in postdoc positions, by demographic group: Selected years, 1973–2013

(Percent distribution)

Demographic group	1973	1983	1993	2003	2013
Sex					
Female	16.7	30.1	30.8	37.6	40.6
Male	83.3	69.9	69.2	62.4	59.4
Race/ethnicity					

Demographic group	1973	1983	1993	2003	2013
White	85.7	81.9	68.4	63.1	52.5
Asian or Pacific Islander	11.9	13.3	27.1	30.6	36.6
Underrepresented minority	2.4	4.8	4.5	7.0	10.4
Place of birth					
United States	82.5	81.7	60.9	57.0	52.5
Foreign	17.5	18.3	39.1	43.0	47.5

NOTES: Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes, excluding those employed part time who are students or retired. Underrepresented minorities include blacks, Hispanics, and American Indians or Alaska Natives.

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2015) of the 2003 and 2013 Survey of Doctorate Recipients.

Science and Engineering Indicators 2016

A temporary postdoc appointment has become a common stop along the career path of S&E doctorate holders, particularly during their early career stages. In 2013, 42% of recently degreed, U.S.-trained S&E doctorate holders in academia were employed in postdoc positions, while 29% were employed in full-time faculty positions (Appendix Table 5-19). For this discussion, *recently degreed* individuals are those who received their doctorate within 1–3 years prior to the 2013 Survey of Doctorate Recipients (SDR); they are a subset of *early career* individuals who received their doctorate within 1–7 years prior to the 2013 SDR. A lower share (17%) of U.S.-trained, academically employed S&E doctorate holders 4–7 years beyond their doctoral degree was employed in academic postdoc positions; 53% held full-time faculty positions (Appendix Table 5-19).

In 2013, just under three-fourths (74%) of recently degreed, U.S.-trained academic postdocs were employed at the most research-intensive universities (Table 5-21). The fields of life sciences and physical sciences have had the highest incidence of postdocs over the years (Figure 5-22).

Table 5-21 S&E doctorate holders with academic employment in postdoc positions, by Carnegie classification of employer and years since doctorate: 2013

(Percent distribution)

		Years since doctorate		
Institution type	Postdocs (thousands)	1–3	4–7	≥ 8
All institutions	20.2	100.0	100.0	100.0
Doctorate-granting, very high research	15.1	73.7	76.3	66.7
Other doctorate-granting institutions	1.7	6.3	8.6	20.0
Medical schools/medical centers	1.6	7.4	8.6	6.7
Other universities and colleges	1.7	12.7	4.3	6.7

NOTES: Academic employment is limited to U.S. doctorate holders employed at 2- or 4-year colleges or universities, medical schools, and university research institutes, excluding those employed part time who are students or

	retired. Institutions are designated by the 2005 Carnegie classification code. For information on these institutional categories, see the Carnegie Classification of Institutions of Higher Education, http://carnegieclassifications.iu.edu/, accessed 1 April 2015. Detail may not add to total due to rounding.
SOURCE:	National Science Foundation, National Center for Science and Engineering Statistics, special tabulations (2015) of the Survey of Doctorate Recipients. *Science and Engineering Indicators 2016*

Federal Support of Doctoral Researchers in Academia

The federal government provides academic researchers with a substantial portion of overall research support. This support may include assistance in the form of fellowships, traineeships, and research grants. This section presents data from S&E doctorate holders in academia who reported on the presence or absence (but not magnitude or type) of federal support for their work. Comparisons are made over the approximately 40-year period between the early 1970s and 2013 and between the roughly two-decade-long period between the very early 1990s and 2013.

To ensure the accountability, transparency, and safety of federally funded research, doctoral researchers must fulfill a wide range of administrative and compliance requirements (see sidebar, National Science Board: Reducing Investigators' Administrative Workload for Federally Funded Research).

National Science Board: Reducing Investigators' Administrative Workload for Federally Funded Research

To ensure the transparency, accountability, and safety of federally funded research, academic researchers must comply with a wide range of regulations and administrative requirements. As these requirements have increased over time, the White House, Congress, federal agencies, and research universities themselves have all engaged in efforts to measure their impact and find ways to maximize their effectiveness. After two surveys by the Federal Demonstration Partnership revealed that administrative requirements occupy a substantial percentage of principal investigators' time, the National Science Board (NSB) in December 2012 convened a task force to examine the administrative workload of federally supported researchers. To identify ways to reduce inefficient requirements while upholding proper oversight of federally funded research, the task force issued a public request for information, held a series of town meetings across the country, and consulted with major associations. In concluding its work in March 2014, NSB issued a report (NSB 2014) with four broad policy recommendations:

- Focus on the Science
- Eliminate or Modify Ineffective Regulations
- Harmonize and Streamline Requirements
- Increase University Efficiency and Effectiveness

To *Focus on the Science*, NSB recommended that agencies limit proposal requirements to those essential for merit review. Nonessential materials could be submitted and reviewed later, once a proposal had been deemed a candidate for funding. NSB also recommended that research progress reports be focused on performance outcomes and scaled according to award size.

To *Eliminate or Modify Ineffective Regulations*, NSB proposed that the Office of Management and Budget (OMB) identify whether payroll certification could replace more burdensome, and arguably ineffective, time and effort reporting. For research involving human subjects, NSB recommended that recently proposed

reforms be encouraged, including the use of a single Institutional Review Board for multi-site studies and simpler oversight of research involving minimal risks to people. With regard to animal research, NSB recommended that regulations that increase investigators' administrative workload without improving animal care be identified. Citing time-consuming but often fruitless literature searches by researchers to identify nonanimal alternatives in order to satisfy particular animal-welfare regulations, NSB recommended that alternative, more effective processes be adopted. NSB recommended that the U.S. Public Health Service's conflict-of-interest regulations not be adopted by other agencies and recommended that they be evaluated to assess their cost, effectiveness, and impact on entrepreneurial activities. And NSB recommended that industry-targeted safety and security requirements imposed on research be reexamined because they are not all appropriate for research settings.

To *Harmonize and Streamline Requirements*, NSB recommended that agencies work together to standardize and simplify proposal submission and post-award requirements and to eliminate agency-specific requirements, where possible. NSB emphasized that audit practices should be uniform, consistent, and more focused on larger expenditures and risks. The report also highlighted opportunities to scale back paperwork associated with subrecipient monitoring. Finally, NSB recommended that a high-level interagency committee with cross-sector representation, including OMB and university stakeholders, be created to respond to the recommendations from NSB and other reports and to ensure that new or modified regulations affecting researchers are efficient, performance oriented, and harmonized.

To *Increase University Efficiency and Effectiveness*, NSB recommended that universities communicate the sources of administrative and regulatory requirements, avoid adding unnecessary ones, and review their procedures governing human subject and animal research with the goal of establishing more efficient procedures for protecting research subjects. The report also recommended that universities provide their researchers with more assistance as they develop their human and animal protection protocols. NSB also recommended that federal agencies collaborate with university stakeholders (researchers, administration, and advocacy groups) to identify and share best practices.

Academic Scientists and Engineers Who Receive Federal Support

The share of S&E doctorate holders and researchers in academia who receive federal support has varied over time according to reported primacy of research activity and type of academic position held (Appendix Table 5-20). In general, a larger share of doctorate holders and researchers received federal support in the late 1980s and very early 1990s than in either the early 1970s or in 2013.[i] In 2013, 44% of all U.S.-trained S&E doctorate holders in academia and 57% of those for whom research was a primary or secondary activity reported federal government support for their work.[ii] About the same percentage (45%) of U.S.-trained, academically employed doctorate holders received federal support in the early 1970s as in 2013. In the very early 1990s, however, a somewhat higher percentage (49%) received federal support. A somewhat smaller share of those for whom research was a primary or secondary responsibility received federal support in 1973 (52%) than in 1991 (58%) or 2013 (57%). The share of full-time faculty who received federal support from 1973 to 2013 fluctuated in a similar fashion, with a somewhat higher share in 1991 (48%) than in 1973 (42%) or in 2013 (44%). By contrast, a larger share of academic doctorate holders employed in nonfaculty positions received federal support in 1973 (60%) and in the very early 1990s (59%) than in 2013 (43%).

Federal support varied by doctoral field. Over the past 40 years, doctorate holders in engineering, physical sciences, and life sciences have been more likely to report receiving federal support than their counterparts in mathematics, psychology, or social sciences (Appendix Table 5-20). The pattern of funding support for engineering

and physical sciences was quite similar overall, with percentages ranging from about 50% in the early 1970s to about 55% in the 1980s to just below 60% in 2013 for engineering and about 53% for physical sciences. Federal funding for life sciences, with some dips in 1985 and 1993–97, generally remained around 60% in most years. Federal support for academic R&D in the relatively small field of computer sciences has grown from about 35% to 50% since its first measurement in the late 1970s.

Federal support is more prevalent in medical schools and in the most research-intensive universities (under Carnegie classification of *very high research activity* institutions) (Appendix Table 5-21). Just under 65% of S&E doctorate holders employed at the most research-intensive universities received federal support in 2013. At medical schools, about 60% of all doctorate holders and just under 55% of full-time faculty received federal support in 2013. The percentage with federal support was just over 45% at *high research activity* institutions; at other universities and colleges, it ranged from about 18% to 32%.

Differences exist by sex, race, and ethnicity in doctorate holders' success in receiving federal support. Among S&E doctorate holders employed at the nation's most research-intensive universities, white and Asian or Pacific Islander men were more likely than their female counterparts to be supported by federal grants or contracts in 2013 (Figure 5-23; Appendix Table 5-22).

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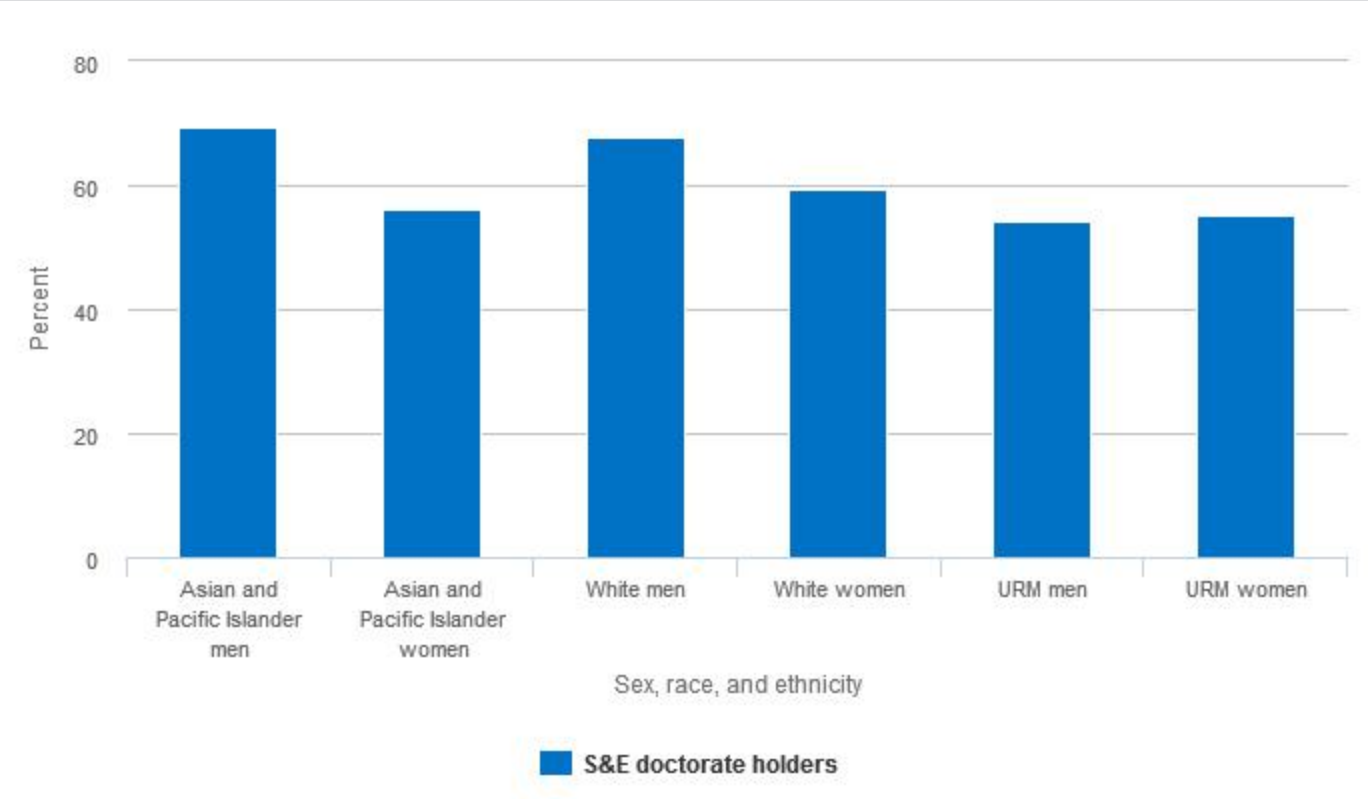
[i] Data on federal support of academic researchers for 1985 and 1993–97 cannot be compared with results for the earlier years or with those from 1999 to 2013 because of changes in the survey question. In 1985, the question focused on 1 month and, from 1993 to 1997, on 1 week. In most other survey years, the reference was to the entire preceding year. Because the volume of academic research activity is not uniform over the entire academic year, a 1-week (or 1-month) reference period seriously understates the number of researchers supported at some time during an entire year.

[ii] A somewhat larger share of the nation's foreign-trained academic doctoral personnel working full time (64%) received federal support in 2013.

Figure 5-23

S&E doctorate holders in very high research activity institutions with federal support, by sex, race, and ethnicity: 2013



URM = underrepresented minority (black, Hispanic, and American Indian or Alaska Native).

SOURCE: National Science Foundation, National Center for Science and Engineering Statistics, 2013 Survey of Doctorate Recipients. See appendix table 5-22.

Science and Engineering Indicators 2016

Available data on the rate at which reviewed research grant applications are funded indicate that funding success rates have declined since the middle of the 2000–09 decade at both NIH and NSF (Table 5-22). Looking over the period from 2001 to 2014, there was an increase during most years in the number of research grant applications that NIH and NSF received.

Table 5-22 NIH and NSF research grant applications and funding success rates: 2001–14

Agency	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
NIH														
Proposals	21,967	22,212	24,634	27,461	28,423	29,097	27,325	26,648	26,675	27,850	28,781	29,626	28,044	27,502
Awards	6,965	6,799	7,430	6,991	6,463	6,037	6,456	6,116	5,924	6,217	5,380	5,436	4,902	5,163
Success rates (%)	32	31	30	26	23	21	24	23	22	22	19	18	17	19
NSF														
Proposals	23,096	25,241	28,676	31,553	31,574	31,514	33,705	33,643	35,609	42,225	41,840	38,490	39,249	38,882
Awards	6,218	6,722	6,846	6,509	6,258	6,708	7,415	6,999	10,011	8,639	7,759	8,061	7,652	7,923
Success rates (%)	27	27	24	21	20	21	22	21	28	20	19	21	19	20

NOTES: NIH = National Institutes of Health; NSF = National Science Foundation.

Available data vary by agency and are not directly comparable to one another. NIH data shown are for R01-equivalent grants, calculated according to the NIH success-rate definition, which counts initial grant applications and resubmitted grant applications received in the same fiscal year as one application (see http://report.nih.gov/success_rates/index.aspx). NIH grant applications exclude grants funded by the American Recovery and Reinvestment Act of 2009 (ARRA). NSF data shown are based on research grant applications received and are counted in the fiscal year in which the award or decline action is taken. NSF data include ARRA grants.

SOURCES: NIH, Office of Extramural Research, Office of the Director; NSF, Office of Budget, Finance, and Award Management.

Science and Engineering Indicators 2016

Federal Support of Early Career S&E Doctorate Holders

In recent years, very recently degreed S&E doctorate holders have received relatively less federal support than in past decades. This holds for those in full-time faculty positions (22% in 2013 versus 38% in 1991) as well as for postdocs (77% in 2013 versus 84% in 1991) (Appendix Table 5-23). Individuals in full-time faculty positions who had received their doctorate 4–7 years earlier were more likely to receive federal support than those with more recently earned doctorates. This was not the case for those in postdoc positions, however, where similar percentages from each group received federal support. As with recent doctorate recipients, the share of full-time faculty and postdocs 4–7 years beyond their doctorate who received federal support also declined from the early 1990s. Looking across the academic doctoral workforce without regard to faculty or postdoc position, the shares of early career doctorate holders with federal support were generally higher in some fields (life sciences, physical sciences, and engineering) than in others (mathematics and social sciences) in 2013.

Outputs of S&E Research: Publications and Patents

Chapter 2 of this volume discusses the human capital outputs of higher education in S&E, and the preceding sections of the current chapter discuss key inputs to academic research, including spending, infrastructure, and academically employed doctorate holders. Despite the resources devoted to academic R&D, its impact and productivity are intangible and thus hard to quantify. This section provides metrics on two components of academic research output: publications and patents. Indicators show the overall distribution of these outputs, indicators of collaboration across nations, economies, and U.S. sectors, as well as citation-derived quality measures. Patents provide a measure of the portion of this knowledge that has been accorded the protection of private property. Citations in patent documents provide indications of the sources and recipients of inventive knowledge.

S&E research has traditionally been presented in peer-reviewed S&E journals, books, and conference proceedings. *Bibliometric* data are consistently organized information about these written publications (see sidebar, Bibliometric Data and Terminology) that can be used to understand the dimensions of national and global scientific activity. For example, a count of the coauthorships on U.S. publications is an indicator of the partnerships involved in the U.S. scientific effort. Likewise, measures involving citations and patents can be indicators of international patterns of scientific influence and of invention based on scientific research. These indicators are calculated for different countries. Because peer-reviewed publications are also produced outside of academia, these measures are also provided within the United States alone for different institutional sectors.

Overall, the indicators provide insight into five broad areas. The first section, "S&E Publication Output," examines the quantity, national origin, and U.S. sectoral origin of S&E publications. The second section, "Coauthorship and Collaboration in S&E Literature," investigates the national, international, and U.S. sectoral partnerships in these publications. The third section, "Trends in Citation of S&E Publications," looks at various patterns of knowledge flows and influences across regions, countries, and sectors. The fourth section, "Citation of S&E Publications by USPTO Patents," investigates the acknowledgment of S&E literature by inventors in patents filed with the U.S. Patent and Trademark Office (USPTO). Finally, the fifth section, "Academic Patenting," explores patenting and related activities in academia.

The following discussions of regional and country indicators examine patterns and trends for the largest producers of S&E publications, as well as for developed and developing countries, as classified by the International Monetary Fund (IMF). Countries classified by the IMF as advanced economies are considered *developed*; those classified as emerging market are considered *developing*.[i]

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[i] For more information on the IMF economic classification of countries, see http://www.imf.org/external/pubs/ft/weo/2014/02/weodata/groups.htm.

Bibliometric Data and Terminology

The counts, coauthorships, and citations discussed in this section are derived from research materials published in peer-reviewed scientific and technical journals, books, and conference proceedings that have been collected in Elsevier's Scopus database. The types of publications included are articles, conference papers, reviews, and short surveys.* The types of publications excluded from the data set are editorials, errata, letters, and other material whose purpose is not the presentation or discussion of scientific data, theories, methods, apparatuses, or experiments. Working papers, which are not generally peer reviewed,

are also excluded from the data set. For *Science and Engineering Indicators 2016*, more than 17,000 journals were analyzed from the Scopus database for 2013.

Journal selection. The journals in the Scopus database are selected by an international group of subject-matter experts who evaluate candidate journals based on editorial policy, content quality, peer review, citation by other publications, editor standing, regularity of publication, and content availability. Although the publications do not need to be written in the English language, both the publication abstract and the journal home page must be in the English language.

Book selection. The books included in the Scopus database are fully referenced and represent original research or literature reviews. They are selected based on publisher characteristics. These include the reputation and impact of the publisher, the size and subject area of the booklist, the publication and editorial policy, and the quality of content.

Conference selection. The conference materials included in the Scopus database are selected by subject field based on quality and relevancy, including the reputation of the sponsoring organization and the publisher of the proceedings.

More information on the selection of documents is found at http://www.elsevier.com/online-tools/scopus/content-overview.

The bibliometric data are classified into the 13 broad fields of S&E that correspond to the National Center for Science and Engineering Statistics WebCASPAR database system. These fields and their subfields are shown in Appendix Table 5-24. To match the data to these fields, a multistage matching procedure creates a field of science category for each journal in the database. Articles, chapters and conference proceedings are first matched to the National Science Foundation's fields of science based on the ISSN field in the abstract. These articles and fields are then matched to journal titles, with additional analysis by subfield to resolve ambiguous matches (Science-Metrix 2015).

Bibliometric Indicators

The region/country/economy breakouts are reported in Appendix Table 5-25. Data reported in this section are grouped into 13 broad S&E fields and 125 subfields (Appendix Table 5-24).

Publication counts. Counts are the number of peer-reviewed publications produced, by the country, region, or institutional sector. Publications coauthored by multiple countries or institutional sectors are counted two ways. *Fractional counting* divides the publication count by the proportion of each of the countries or institutional coauthors named on the publication. Fractional counting allows the counts to sum up to the number of total publications (appendix tables 5-26–5-40). *Whole (integer) counting* assigns one count to each country or institutional sector coauthoring the publication (appendix tables 5-41–5-54). The sum of publications from countries or institutional sectors will exceed the total number of publications under whole counting. For the United States in 2013, there were 412,542 publications in the Scopus database as measured on a fractional-count basis and 510,047 as measured on a whole-count basis.

Coauthorship. Coauthorship provides a direct measure of collaboration across countries, regions, and institutional sectors. Publication counts of coauthorship use whole counting, resulting in a full count being assigned to each country or institutional sector contributing to the publication. A publication is counted as international coauthorship when there are institutional addresses for authors from at least two different countries. Appendix tables 5-41–5-54 show international coauthorship by field of science.

Index of international collaboration. Coauthorship or collaboration between countries is more likely between countries where each has large shares of international collaboration. The index of international collaboration weights each collaboration relationship by the size of each country's contribution to internationally coauthored publications. The result is a scaled index. The United States was a coauthor on 39.5% of the world's internationally coauthored publications in 2013, and the expected U.S. share of China's internationally coauthored publications would therefore be 39.5%. In fact, 45.6% of China's internationally coauthored publications in 2013 had a U.S. coauthor. Dividing the actual U.S. share of China's internationally coauthored publications by the expected share yields an index value of 1.15. Thus, China coauthors with the United States 15% more than expected. More broadly, if the measure is higher than expected, it will be greater than 1.00; if less than expected, it will be less than 1.00. Index values for any country pair are always symmetrical, so the United States also coauthors with China 15% more than expected. The data for calculating the 2013 indexes in Appendix Table 5-55 are contained in Appendix Table 5-56. U.S. sector publications coauthored with other U.S. sectors and foreign institutions for 1999 and 2013 are shown in Appendix Table 5-57.

Citations. Citations of S&E publications by other S&E publications provide an indicator of the impact of publications as well as of the flow of knowledge or linkage between sectors or geographic locations. Citations are presented for the year when a publication is published, showing the counts of subsequent citations from peer-reviewed literature. For example, 2012 citations are citations to papers published in 2012. At least 3 years of data following publication are needed for a meaningful measure, and more years are preferable (Wang 2012). A 3-year window is used in *Science and Engineering Indicators 2016* for international citations (Appendix Table 5-58) and for the relative citation index between country pairs (Table 5-24). For comparisons across fields of science and across countries, citations are calculated based on all available years of data, and 3 years is the minimum amount of data that is used.

Highly cited publications. Citations to S&E publications or to patents are concentrated on a small portion of the total number of publications or patents. These measures follow the power law, in which a relatively small share of the population is responsible for a relatively large share of the impact. In these highly skewed distributions, the average is substantially different from the median. As a result, average counts alone are an insufficient measure of the impact of S&E publications. Highly cited publications are shown as a relative share of the top percentile of publications (Appendix Table 5-59). Because highly cited articles can continue to receive citations for many years, highly cited publications are calculated for each year with the maximum years of subsequent data available. Thus, these citations can accumulate beyond 3 years.

Average of relative citations (ARC). Citations need to be normalized across fields of science and document types to correct for differences in the frequency and timing of citations (Narin and Hamilton 1996; Wang 2012). The relative citation divides each publication's citation count by the average citation count of all publications in that subfield and document type in that same year. For a given area of geography or sector, these relative citations for each publication are then averaged to create an ARC. An ARC value greater than 1.00 has more citations than average for subfield and year; an ARC value less than 1.00 has fewer citations. *Science and Engineering Indicators 2016* uses the ARC measure for relative citations by region/country/economy. ARCs are calculated for each year with the maximum years of subsequent data available. Thus, these citations can accumulate beyond 3 years. Appendix Table 5-60 shows ARCs for U.S. fields of science and engineering and Appendix Table 5-61 shows ARCs for regions, countries, and economies.

Measurement limitations of bibliometric data. The Scopus database indexes peer-reviewed S&E publications that have been collected and curated by Elsevier to conform to a set of quality standards,

including the stipulation that the abstracts have been written in the English language. Bibliometric researchers have found an own-language preference in citations (Liang, Rousseau, and Zhong 2012). As a result, the indexing of publications with English-language abstracts can undercount citations associated with non-English publications. This linguistic bias has been found to be more substantial in social sciences than in physical sciences, engineering, and mathematics (Archambault et al. 2009). Further, fractional and whole counting allow publications with multiple authors to be attributed to countries, regions, economies, and sectors. The assumption underlying both fractional and whole counting is that each author's contribution is assigned the same weight. In reality, it is often the case that authors make different levels of contribution to a publication. For more information about the difference between Scopus and the data used in earlier years of *Science and Engineering Indicators,* see the sidebar "New Data Source for Indicators Expands Global Coverage."

* Short surveys are reviews of original research that are limited to a few pages but otherwise similar to reviews. For more information, see http://www.elsevier.com/__data/assets/pdf_file/0007/69451/sc_content-coverage-guide_july-2014.pdf.

S&E Publication Output

This section begins by describing and comparing the S&E publication output of the United States to other regions, countries, and economies in the world. After presenting data on S&E publication output by countries and fields of science, this section also examines U.S. publication output in academia, the largest producer of U.S. publications, and other institutional sectors. The bibliometric data presented are compiled and derived from the Scopus database (see sidebar, New Data Source for Indicators Expands Global Coverage). The publication output discussion is based on fractional counting, which divides the credit for a coauthored publication across the coauthors in proportion to their number. On this basis, there were 2,199,704 peer-reviewed S&E publications drawn from the database in 2013 for analysis (Table 5-23).

New Data Source for Indicators Expands Global Coverage

The bibliometric indicators in *Science and Engineering Indicators 2016* are based on Elsevier's Scopus database. This is a change from the bibliometric data set used in earlier volumes of *Science and Engineering Indicators,* which used a subset of Thomson Reuters Science Citation Index (SCI) and Social Science Citation Index (SSCI). This change in data sources is accompanied by several methodological changes intended to simplify the interpretation of the data and increase the cross-field and cross-country comparability of the data.

Motivation

Science and Engineering Indicators aims to provide an accurate comparison of the state of U.S. S&E activity in a global context. Although the United States has dominated S&E publication activity for decades, it has long been hypothesized that the level of S&E knowledge in the developing world would grow faster from a lower base level, eventually reaching parity with the United States (Price 1963). Tracking this growth accurately requires broad global coverage of S&E publications.

The use of the Scopus database for *Science and Engineering Indicators 2016* represents a substantial increase in the global coverage of bibliometric data compared to prior years. The SCI and SSCI data sets

were originally chosen to provide good coverage of a core set of internationally recognized, peer-reviewed scientific journals. The included journals are notable for their high citation rank within their S&E fields and thus can be considered to represent the journals containing the highest-impact articles. For *Science and Engineering Indicators 2014*, the National Science Foundation (NSF) analyzed 5,087 journals from the SCI and SSCI for 2012. The change to the use of the Scopus database allows NSF to present data on the most highly cited S&E publications as well as on a broader set of publications that provide insight into trends in emerging and developing countries. For *Science and Engineering Indicators 2016*, approximately 17,000 S&E journals were analyzed.

In addition to expanded global coverage, the Scopus database used for *Science and Engineering Indicators 2016* includes research output from books and expanded coverage of conference proceedings. Research output from books is particularly important in the social sciences (Hicks 2005; Mingers and Leydesdorff 2015), and conference proceedings are particularly important in computer sciences (Lisée, Larivière, and Archambault 2008; Moed and Visser 2007). For more information on the selection process, see the sidebar "Bibliometric Data and Terminology."

This expansion of global coverage of S&E publications has costs as well as benefits. In particular, the move from SCI and SSCI to Scopus provides greater global coverage at the cost of a somewhat shorter time series of bibliometric data because Scopus data currently begin in 1996. Additionally, Scopus's comprehensive global coverage of journals may include some journals that are not highly cited or have limited international visibility. Further information comparing the bibliometric data from earlier editions of Science and Engineering Indicators to this edition's data can be found in the report, Comparison of 2016 Bibliometric Indicators to 2014 Indicators, at http://science-metrix.com/en/publications/reports#/en/publications/reports/bibliometrics-and-patent-indicators-for-the-science-and-engineering-indicator-0.

Methodological Changes

Fractional counting: The Scopus database allows *Science and Engineering Indicators 2016* to use fractional counting at the level of individual authors instead of at the level of the institution, which was the basis for fractional counting in the past. This change from institution to authors for fractional counting improves the precision of the country and field measures. However, fractional counting remains an imperfect measure of the contribution of each author to a jointly authored publication.

Citations: In *Science and Engineering Indicators 2016,* citations are calculated for each publication in the year that it is published and sum all subsequent citations to that publication. Because it takes at least 3 years to measure citations reliably (Bornmann 2013), citations are presented for publication years through 2012; averages of relative citations are not restricted to a 3-year window and therefore can continue to incorporate citations over time.

In earlier editions of *Science and Engineering Indicators,* citation counts reported for a given year were calculated for the year that the citation was made instead of the year in which the cited article was published. Citations were calculated as the total number of citations made to papers published in a prior 3-year window, with the first of these 3 years of publication beginning 4 years before the citing year. Thus, citations reported in 2012 were to papers published in 2008, 2009, and 2010. Citations to publications outside of that 3-year window were not captured.

Table 5-23 **S&E articles in all fields, by country/economy: 2003 and 2013**

Chapter 5. **Academic Research and Development**

Rank	Country/economy	2003	2013	Average annual change (%)	2013 world total (%)	2013 cumulative world total (%)
-	World	1,117,866	2,199,704	7.0	na	na
1	United States	299,876	412,542	3.2	18.8	18.8
2	China	71,113	401,435	18.9	18.2	37.0
3	Japan	87,389	103,377	1.7	4.7	41.7
4	Germany	67,491	101,074	4.1	4.6	46.3
5	United Kingdom	69,741	97,332	3.4	4.4	50.7
6	India	26,100	93,349	13.6	4.2	55.0
7	France	49,850	72,555	3.8	3.3	58.3
8	Italy	39,096	66,310	5.4	3.0	61.3
9	South Korea	21,802	58,844	10.4	2.7	64.0
10	Canada	35,740	57,797	4.9	2.6	66.6
11	Spain	27,657	53,342	6.8	2.4	69.0
12	Brazil	15,874	48,622	11.8	2.2	71.2
13	Australia	23,274	47,806	7.5	2.2	73.4
14	Russia	24,487	35,542	3.8	1.6	75.0
15	Taiwan	14,415	34,331	9.1	1.6	76.6
16	Iran	3,459	32,965	25.3	1.5	78.1
17	Netherlands	18,739	30,412	5.0	1.4	79.4
18	Turkey	12,689	30,402	9.1	1.4	80.8
19	Poland	14,424	28,753	7.1	1.3	82.1
20	Switzerland	12,436	21,060	5.4	1.0	83.1
21	Sweden	14,034	19,362	3.3	0.9	84.0
22	Malaysia	1,336	17,720	29.5	0.8	84.8
23	Belgium	10,239	16,511	4.9	0.8	85.5
24	Czech Republic	6,134	14,022	8.6	0.6	86.2
25	Portugal	4,203	13,556	12.4	0.6	86.8
26	Mexico	6,330	13,112	7.6	0.6	87.4
27	Denmark	6,988	12,482	6.0	0.6	87.9
28	Austria	7,412	12,031	5.0	0.5	88.5
29	Greece	6,330	11,370	6.0	0.5	89.0
30	Israel	9,269	11,300	2.0	0.5	89.5
31	Romania	2,080	11,164	18.3	0.5	90.0
32	Singapore	5,343	10,659	7.2	0.5	90.5

Rank	Country/economy	2003	2013	Average annual change (%)	2013 world total (%)	2013 cumulative world total (%)
33	Finland	7,259	10,157	3.4	0.5	91.0
34	Norway	4,913	9,854	7.2	0.4	91.4
35	South Africa	4,077	9,679	9.0	0.4	91.9
36	Egypt	3,045	9,199	11.7	0.4	92.3
37	Thailand	2,105	8,631	15.2	0.4	92.7
38	Argentina	4,485	8,053	6.0	0.4	93.0
39	Pakistan	1,282	7,772	19.7	0.4	93.4
40	Saudi Arabia	1,660	7,636	16.5	0.3	93.7
41	New Zealand	4,233	7,244	5.5	0.3	94.1
42	Ukraine	3,976	7,218	6.1	0.3	94.4
43	Ireland	2,904	6,874	9.0	0.3	94.7
44	Hungary	4,153	6,249	4.2	0.3	95.0
45	Serbia	1,227	5,169	15.5	0.2	95.2
46	Chile	2,002	5,158	9.9	0.2	95.5
47	Slovakia	2,083	4,730	8.5	0.2	95.7
48	Colombia	655	4,456	21.1	0.2	95.9
49	Croatia	2,226	4,359	7.0	0.2	96.1
50	Tunisia	975	4,207	15.7	0.2	96.3

NOTES: na = not applicable.
The countries/economies shown each produced 4,000 publications or more in 2013. The countries/economies are ranked based on the 2013 total. Articles are credited on a fractional-count basis (i.e., for articles from multiple countries/economies, each country/economy receives fractional credit on the basis of the proportion of its participating authors). Detail does not add to total because of countries/economies not shown.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com). See appendix table 5-26.
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From the perspective of trends in international S&E publication, the key observation is that the publication output volume of China and other developing countries has increased much more rapidly than that of the United States and other developed countries in recent years. The crossover point, when China's publications would exceed those of the United States, has long been anticipated and has nearly been reached. Although the United States remains a major producer of S&E publications, in 2013 China has a comparable share of S&E publications.

Publication Output, by Country

The top five countries producing S&E publications in 2013 are the United States (18.8%), China (18.2%), Japan (4.7%), Germany (4.6%) and the United Kingdom (4.4%). When treated as one entity, the European Union (EU) accounts for 27.5% of the world's S&E publications in 2013 (Figure 5-24).[i] The EU, the United States, and Japan have been major producers for several decades. Together, the United States, the EU, and Japan account for 51% of the world's S&E publications in 2013 (Appendix Table 5-26). China emerged as a major producer in the mid-2000s.

India's publication volume has grown more gradually and in 2013 reached 4.2% (Figure 5-24). Overall, 50 countries—a quarter of those that produced S&E publications in 2013—account for 96.3% of global output (Table 5-23).

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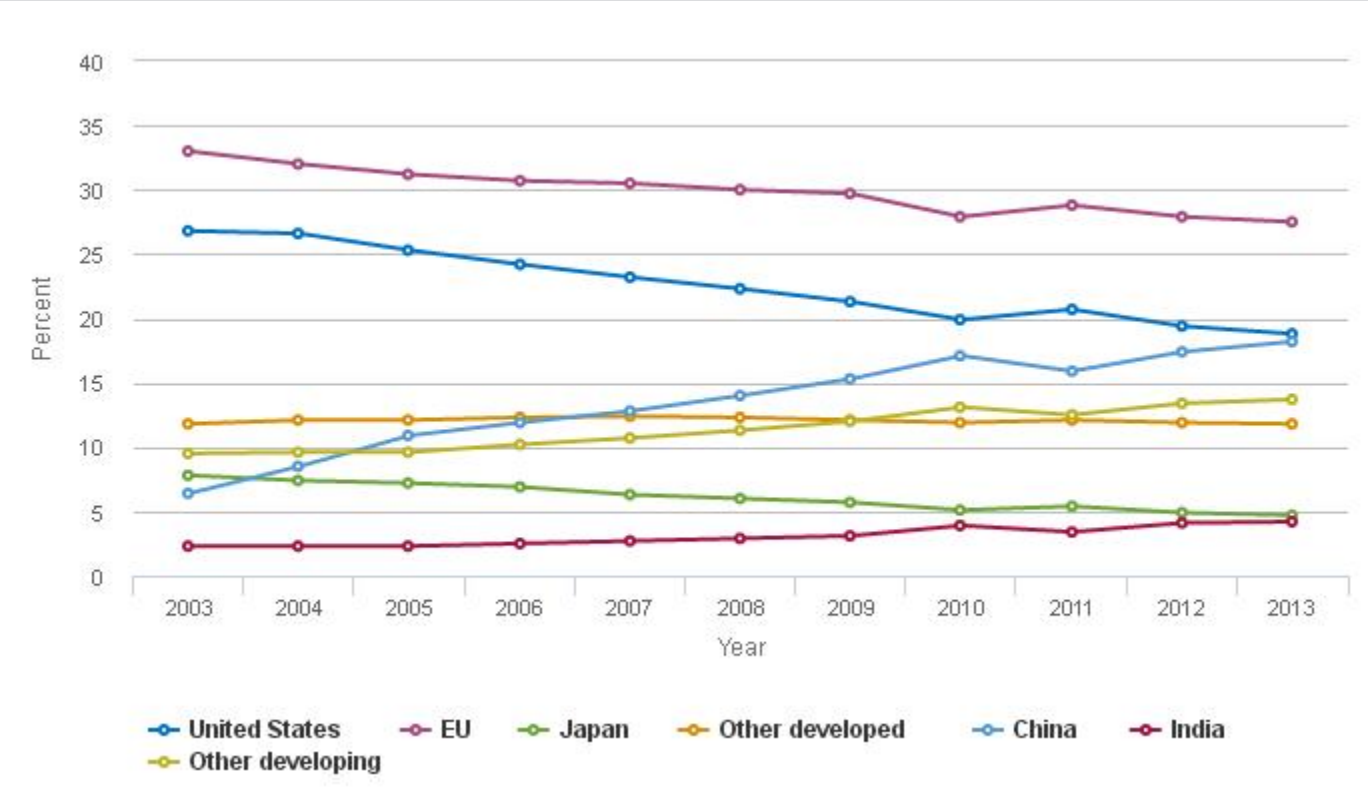
[i] Country assignments refer to the institutional address of authors, with partial credit given for international coauthorship. See the sidebar Bibliometric Data and Terminology for more information on how S&E article production and collaboration are measured.

Figure 5-24

S&E articles, by global share of selected region/country/economy: 2003–13



EU = European Union.

NOTES: Publication counts are from a selection of journals, books, and conference proceedings in S&E from Scopus. Publications are classified by their year of publication and are assigned to a region/country/economy on the basis of the institutional address(es) listed in the article. Articles are credited on a fractional-count basis (i.e., for articles from multiple countries/economies, each country/economy receives fractional credit on the basis of the proportion of its participating authors). Some publications have incomplete address information for coauthored publications in the Scopus database and cannot be fully assigned to a country or economy. These unassigned counts, 1% of the world total in 2013, are used to calculate this figure but are not shown. See appendix table 5-26.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com).

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S&E publications are growing especially fast from authors with institutional addresses in the developing world. Between 2003 and 2013, total world S&E publication output grew at an average annual rate of 7.0%; by 2013, 199 countries had at least one S&E publication. The total for developing countries grew more than twice as fast (14.6%) as the world total.[ii] This growth in S&E publications in the developing world suggests rapidly increasing science and technology capabilities. China (18.9% growth rate of publications) propelled growth of developing countries, resulting in their collective global share climbing from 18.2% to 36.1% (Figure 5-24).

China's growth in S&E publications is concurrent with its enormous increase in gross domestic product over the last decade. This growth is consistent with findings by many researchers that there is a high correlation between these two measures (Narin, Stevens, and Whitlow 1991; Price 1963; Shelton 2008). Given China's demographic, economic, and scientific progress in recent decades, it has long been anticipated that China will overtake the United States in S&E publication output (Royal Society 2011; Price 1963). In 2013, based on Scopus data, China's

S&E publications (18.2%) are within less than 1 percentage point of those of the United States (18.8%) in their share of the world's total S&E publications.

Among other larger emerging economies, publications from India grew at a 13.6% average annual rate over the decade, and those from Brazil grew at an 11.8% average annual rate. As a result, India's and Brazil's global shares increased to 4.2% and 2.2%, respectively (Table 5-23). In 2013, India was the sixth-largest producer of S&E publications after the United States, China, Japan, Germany, and the United Kingdom (Table 5-23). Rapid growth of S&E publications in India and China coincided with increased R&D expenditures and growth in S&E degrees awarded at the bachelor's-degree and doctoral-degree levels (see Chapter 2 Section; International S&E Higher Education).

Smaller developing countries with more than 4,000 publications in 2013 and rapid S&E publication growth (15%–29% annual average rate) were Colombia, Iran, Malaysia, Pakistan, Romania, Saudi Arabia, Serbia, Thailand, and Tunisia.

Developed economies' S&E publication production grew more slowly (4.5%) than that of developing economies (14.6%) over the decade. U.S. growth in S&E publication production was even slower (3.2%) than the average for all developed economies. As U.S. publications leveled off and developing economies' publications grew more rapidly, the U.S. global share fell from 26.8% to 18.8% (Appendix Table 5-26).

The EU, the world's largest producer, grew slightly faster than all developed countries. Among EU member countries, growth rates were slower for the three largest—France, Germany, and the United Kingdom—and generally much faster in smaller member countries. Several countries that are relatively new members of the EU, including the Czech Republic, Estonia, Lithuania, Poland, Slovakia, Romania, and Croatia, had growth rates above 6.0% for the decade. Although EU publication production grew slightly faster than that of the United States, the EU's global share fell from 33.0% in 2003 to 27.5% in 2013 because of the far more rapid growth of developing countries (Figure 5-24). S&E publications of Japan, the fourth-largest producer, grew relatively slowly, with a 1.7% annual average rate over the decade. As a result, Japan's global share dropped from 7.8% in 2003 to 4.7% in 2013.

Publication output by developed economies outside of the EU, the United States, and Japan grew much faster, primarily due to rapid growth (7%–10% annual average) in Australia and three Asian locations: South Korea, Taiwan, and Singapore.

The distribution of S&E publication output by field provides an indication of the priority and emphasis of scientific research in different locations. The S&E publication portfolios of the five major producers—the United States, the EU, China, Japan, and India—have distinct differences by field (Table 5-25; Appendix Table 5-27, Appendix Table 5-28, Appendix Table 5-29, Appendix Table 5-30, Appendix Table 5-31, Appendix Table 5-32, Appendix Table 5-33, Appendix Table 5-34, Appendix Table 5-35, Appendix Table 5-36, Appendix Table 5-37, Appendix Table 5-38, and Appendix Table 5-39). Almost half (48.7%) of the United States' publications are focused on biological sciences, medical sciences, and other life sciences, compared to 38.2% for the world at large. The United States also produces a higher proportion of S&E publications than the rest of the world in psychology and social sciences.[iii] In this context, it is useful to keep in mind that publications in the Scopus database must have an abstract in the English language to be included in the publication counts and that social science publications are frequently published in local languages (Archambault et al. 2009).

[ii] Calculated from Appendix Table 5-26 and the IMF definition of developing countries.

[iii] Social science literature, like the humanities, is more likely to be published in a country's national language.

Table 5-25 **S&E research portfolios of selected regions/countries/economies, by field: 2013**

(Percent)

Field	World	United States	EU	China	Japan	India
All articles (*n*)	2,199,704	412,542	605,536	401,435	103,377	93,349
Engineering	19.8	12.4	13.9	37.7	19.3	20.6
Astronomy	0.6	0.9	0.9	0.2	0.5	0.4
Chemistry	7.9	5.6	7.0	10.6	9.7	12.5
Physics	9.2	7.9	9.4	9.9	14.0	8.5
Geosciences	5.3	4.8	5.3	6.1	3.7	4.7
Mathematics	2.5	2.0	2.7	2.5	1.7	2.1
Computer sciences	8.1	6.2	8.8	9.3	8.0	10.4
Agricultural sciences	2.2	1.2	2.0	1.9	1.7	2.9
Biological sciences	15.8	19.2	15.4	12.1	14.8	19.6
Medical sciences	21.2	27.2	24.2	8.7	24.5	16.4
Other life sciences	1.2	2.3	1.2	0.1	0.3	0.2
Psychology	1.7	3.5	2.1	0.2	0.5	0.1
Social sciences	4.5	6.7	6.9	0.7	1.2	1.5

NOTES: EU = European Union.
Article counts are from a selection of journals in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region/country/economy on the basis of the institutional address(es) listed in the article. Articles are credited on a fractional-count basis. See appendix table 5-25 for countries/economies included in the EU. Percentages may not add to 100% because of rounding.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com). See appendix tables 5-27–5-39.
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Like the United States, the EU is more focused on biological sciences, medical sciences, and other life sciences than the world as a whole (40.8%). Relative to the United States, the EU has higher shares of publications in physics, chemistry, and engineering. Japan's publications are more focused on chemistry, medical sciences, and physics than the world as a whole.

Relative to the world as a whole, S&E publications of China are more heavily focused on engineering and chemistry. Engineering publications made up 37.7% of 2013 output for China, and chemistry publications made up 10.6% of output. China's portfolio also has shares above the world average in computer sciences and physics.

Engineering publications with institutional addresses from India are also above the average for the world as a whole, making up 20.6% of India's S&E output in 2013. India's portfolio has the heaviest concentration of these countries and regions in biological sciences, with a 19.6% share, and is above world average concentrations in chemistry and computer science.

In summary, of the top producers, the United States has the highest concentration of publications in medical sciences, followed by the EU and Japan. India and the United States have the highest concentration of publications in biological sciences. China has the highest concentration in engineering, followed by India.

Publication Output, by U.S. Sector

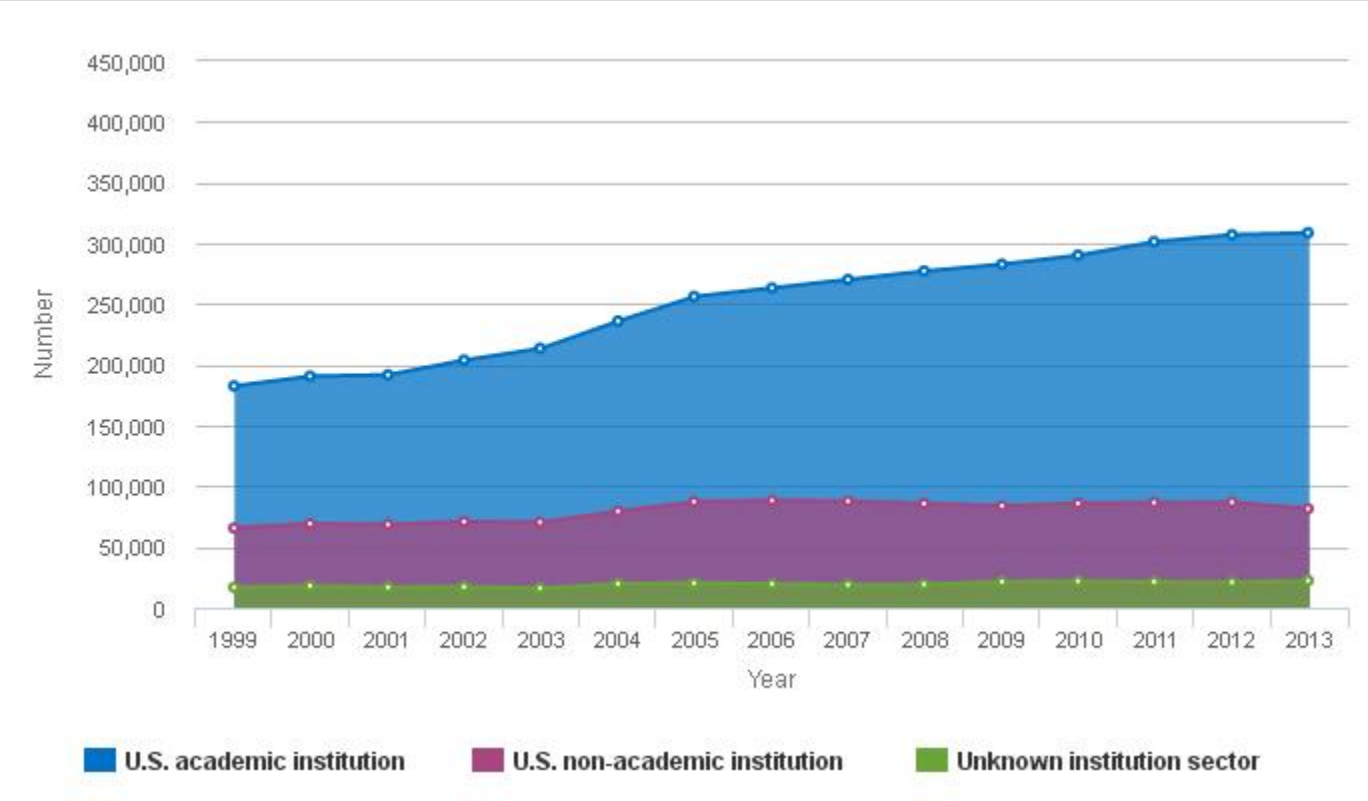
Six U.S. institutional sectors produce S&E publications: the federal government, industry, academia, federally funded research and development centers (FFRDCs), private nonprofit organizations, and state and local governments.[iv] This section describes patterns and trends in the sector distributions of U.S. publication output.

The U.S. academic sector is the largest producer of S&E publications, accounting for three-fourths of U.S. S&E publication output. This sector was largely responsible for the growth of U.S. S&E publication output between 1999 and 2013. The number of academic S&E publications rose from 182,547 to 308,650 between these years. As a result, academia's share of all U.S. publications rose from 69% to 75% (Figure 5-25). Public universities accounted for 45% of all U.S. publications, and private universities accounted for 25% (Appendix Table 5-40).

[iv] In 2013, 5.1% of the U.S. publications could not be assigned to a sector based on the information in the Scopus database. Sector identification is not yet available for other countries.

Figure 5-25

U.S. academic and non-academic S&E articles: 1999–2013



NOTES: Articles refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to fields of science by matching the journal in Scopus to the National Science Foundation's subfields (appendix table 5-24). Articles are credited on a fractional-count basis (i.e., for articles from multiple regions/economies/sectors, each region/country/economy receives fractional credit on the basis of the proportion of its participating authors). The sum of sectors may not add to field total because of rounding. See appendix table 5-40.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com).

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S&E publications in U.S. non-academic sectors rose from 65,661 to 81,521 during this period. These sectors had divergent trends (Appendix Table 5-40):

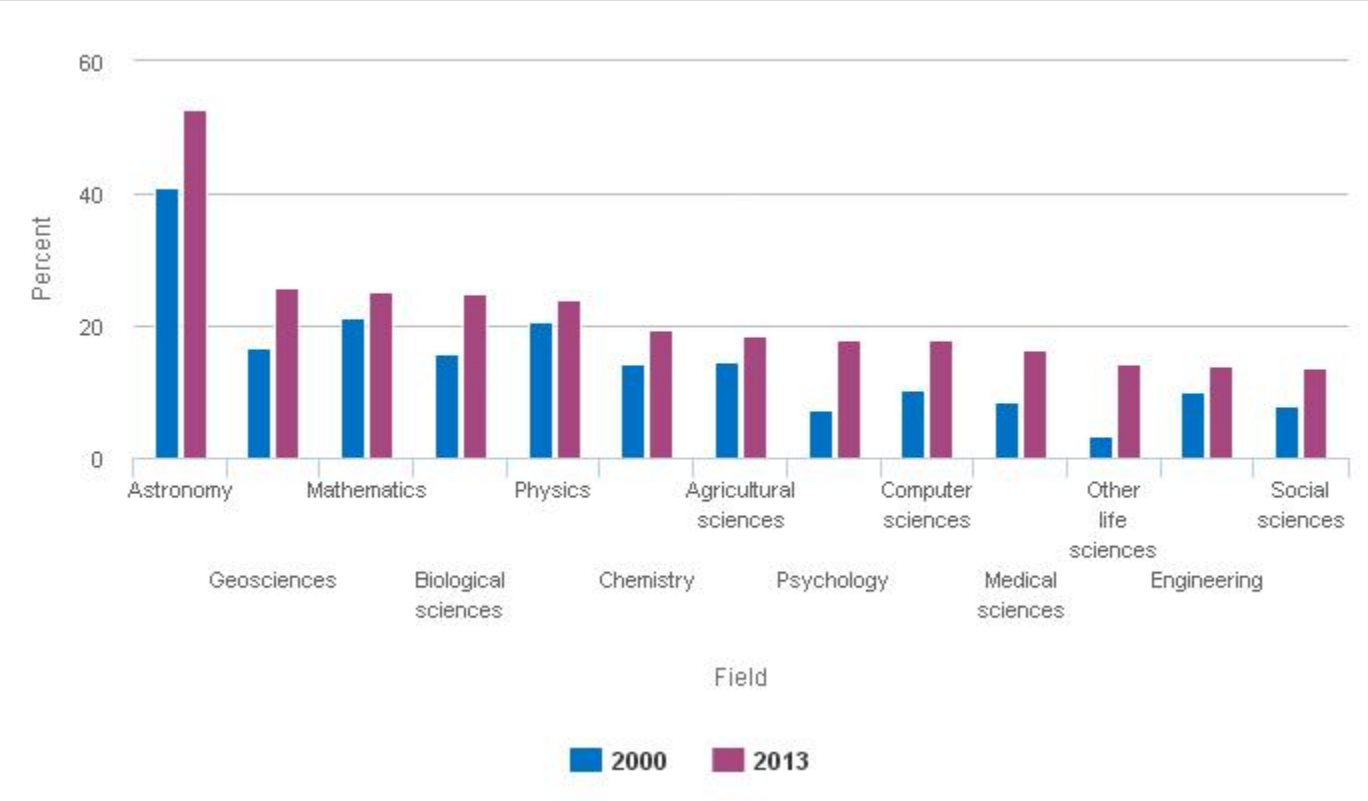
- Publications with institutional addresses in the private nonprofit sector grew from 16,195 in 1999 to 20,792 in 2013, accounting for 5.0% of U.S. publications in 2013.
- Publications from FFRDCs grew to a peak of 10,487 in 2005, declined until 2010, and recovered to above 10,000 for the years 2011–13.
- Federal government publications also grew in the early 2000s and then leveled off after 2006, accounting for 5.4% (22,309) of the U.S. total in 2013.
- Industry publications reached a high of 31,625 in 2005 and then declined steadily to 26,322, or 6.4% of the U.S. total in 2013.

The research portfolios of U.S. sectors are generally dominated by life sciences (biological sciences, medical sciences, and other life sciences), with nearly half or more of all publications in these fields (Table 5-26). The

dominance of life sciences is especially pronounced in the nonprofit sector, where 58.1% of the publications are in medical sciences, 23.8% are in biological sciences, and 4.7% in other life sciences. With a much larger number of publications, academia has 49% of its S&E literature in life sciences. The exception to this focus on life sciences is in the research portfolio of FFRDCs. They are dominated by the physical sciences, physics (33.1%), chemistry (14.2%), and engineering (25.8%).

Figure 5-27

Share of world S&E articles with international collaboration, by S&E field: 2000 and 2013



NOTES: Articles refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region/country/economy on the basis of the institutional address(es) listed in the article. Articles with international collaboration are counts of articles with institutional addresses from more than one country/economy. Articles are credited on a whole-count basis (i.e., each collaborating country /economy is credited with one count).

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com).

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Table 5-26 Share of U.S. S&E articles, by sector and field: 2013

(Percent)

Sector	Federal government	Industry	Academic	FFRDCs	Private nonprofit	State/local government	Unknown institutional sector
All fields combined (*n*)	22,309	26,322	308,650	10,002	20,792	2,096	22,370
Agricultural sciences	3.4	3.4	3.4	3.4	3.4	3.4	3.4
Astronomy	1.6	0.2	0.9	2.4	0.3	0.0	0.3

Sector	Federal government	Industry	Academic	FFRDCs	Private nonprofit	State/local government	Unknown institutional sector
Biological sciences	27.0	13.7	19.5	7.1	23.8	30.3	14.5
Chemistry	4.2	8.0	5.7	14.2	1.4	1.7	3.3
Computer sciences	2.3	11.6	6.5	5.4	0.8	0.9	5.3
Engineering	12.2	29.5	10.9	25.8	2.0	6.3	17.0
Geosciences	10.6	6.4	4.0	8.2	2.1	19.1	7.6
Mathematics	0.7	0.9	2.5	1.0	0.2	0.2	0.9
Medical sciences	23.5	12.8	27.2	1.7	58.1	29.2	30.1
Other life sciences	1.3	1.6	2.3	0.1	4.7	3.9	3.9
Physics	8.5	12.5	7.4	33.1	1.0	1.0	5.0
Psychology	1.7	0.8	4.2	0.1	1.6	1.8	3.4
Social sciences	3.0	1.2	7.8	0.6	3.7	3.7	7.5

NOTES: FFRDC = federally funded research and development center.

Articles refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to fields of science by matching the journal in Scopus to the National Science Foundation's subfields (appendix table 5-24). Articles are credited on a fractional-count basis (i.e., for articles from multiple countries/economies/sectors, each country/economy /sector receives fractional credit on the basis of the proportion of its participating authors). The sum of sectors may not add to field total because of rounding.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com). See appendix table 5-40.

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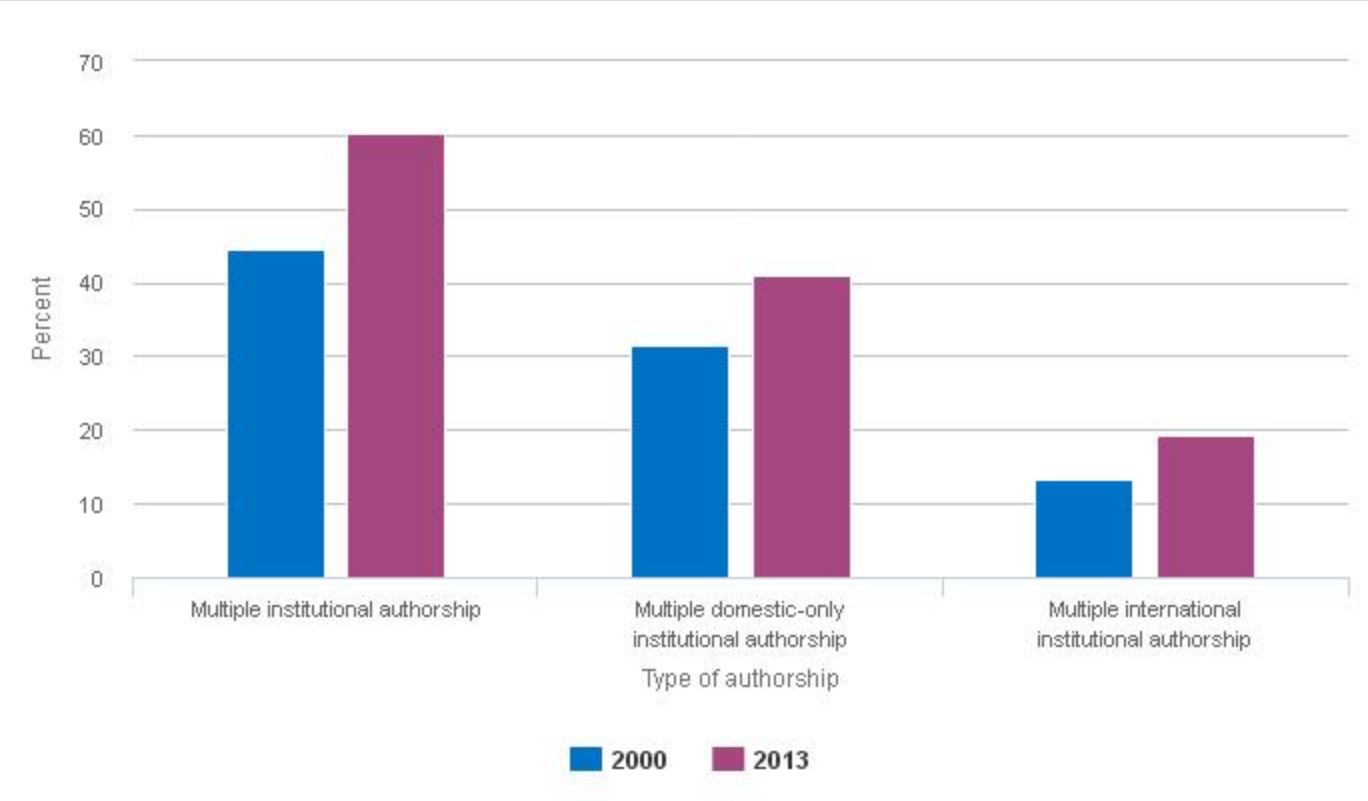
Coauthorship and Collaboration in S&E Literature

Collaboration on S&E research publications can be an indicator of interconnections among researchers in different institutional settings and of the growing capacity of researchers to address complex problems by drawing on diverse skills and perspectives. Collaborative S&E research facilitates knowledge transfer and sharing among individuals, institutions, and nations. Between 2000 and 2013, collaboration has been increasing, with higher shares of scientific publications with institutional and international coauthorships (Figure 5-26). The following two sections explore the growth of collaborative publication.

Figure 5-26

Share of world articles in all fields with authors from multiple institutions, domestic-only institutions, and international coauthorship: 2000 and 2013



NOTES: Article counts refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region/country/economy on the basis of the institutional address(es) listed in the article. Articles are credited on a whole-count basis (i.e., each collaborating country /economy is credited with one count). Articles with multiple institutions are counts of articles with two or more institutional addresses. Articles with multiple domestic institutions only are counts of articles with more than one institutional address within a single country/economy. Articles with international institutions are counts of articles with institutional addresses from more than one country/economy. See appendix table 5-41.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com).

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Collaboration among U.S. Sectors

U.S. coauthorship data at the sector level—academic, nonprofit, industry, FFRDCs, federal and state government—are indicators of collaboration among U.S. sectors and between U.S. sectors and foreign institutions. Over the last decade, the number of collaborations with other U.S. sectors and with foreign institutions increased in all sectors, along with the share of publications that are coauthored with foreign institutions (Table 5-27).[i] The proportion of academic publications coauthored with other U.S. sectors and foreign institutions increased from 45% in 2000 to 61% in 2013. The increase for publications coauthored with foreign institutions was from 19% to 33%. FFRDCs, where the research conducted focuses on the physical sciences, have the highest percentages of international coauthorship of U.S. sectors, at 41% in 2013.

[i] Note that coauthorship counts use *whole counting,* which means that a publication with a foreign coauthor as well as a domestic author from a different sector will be counted as a coauthored paper with another U.S. sector as well as counted as coauthored with a foreign institution.

Table 5-27 **Shares of U.S. sector publications coauthored with other U.S. sectors and foreign institutions: 2000 and 2013**

	U.S. sector					
Year	Academic	Federal government	Industry	FFRDCs	Private nonprofit	State/local government
2000						
All publications (*n*)	264,295	30,741	38,745	11,717	28,565	2,723
Total coauthored	61.8	70.2	60.1	69.2	71.2	74.6
Total coauthored with another U.S. sector and/or foreign institution	45.0	59.4	50.8	64.5	58.5	67.4
Coauthored with another U.S. sector	32.3	49.7	40.2	50.0	50.8	63.9
Coauthored with academic sector	na	42.3	33.9	42.3	46.3	53.9
Coauthored with non-academic sector	32.3	17.1	13.8	16.3	13.4	28.7
Coauthored with foreign institutions	19.3	19.3	18.0	30.1	16.4	11.3
2013						
All publications (*n*)	496,276	48,504	51,146	20,998	46,192	5,566
Total coauthored	75.4	86.9	78.6	82.8	85.0	90.2
Total coauthored with another U.S. sector and/or foreign institution	61.0	80.2	69.4	78.5	76.9	85.8
Coauthored with another U.S. sector	40.5	69.1	52.8	62.8	66.7	80.1
Coauthored with academic sector	na	61.6	46.2	56.5	62.7	69.5
Coauthored with non-academic sector	40.5	23.5	17.8	18.3	17.7	36.0
Coauthored with foreign institutions	32.5	30.9	30.7	40.8	29.5	20.0

na = not applicable.

FFRDCs = federally funded research and development centers.

NOTES:	Article counts are from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a sector on the basis of the institutional address(es) listed in the article. Articles are credited on a whole-count basis (i.e., each collaborating institution type is credited one count in each qualifying group). The sum of articles coauthored with various sectors could exceed the total number of articles coauthored with another sector and/or foreign sector due to articles coauthored by multiple sectors. Articles from unknown U.S. sectors are not shown.
SOURCES:	National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com). *Science and Engineering Indicators 2016*

International Collaboration

The percentage of publications with authors from different countries rose from 13.2% to 19.2% between 2000 and 2013 (Figure 5-26). This increase in part reflects increasing global capabilities in R&D and an expanding pool of trained researchers, as well as improvements in communication technology. These collaborations may also reflect the strengthening of a network of international scholars who increasingly collaborate with each other (Wagner, Park, and Leydesdorff 2015). Finally, the substantial challenges of climate change, food, water, and energy security are ones that are fundamentally global in scope, rather than national (Royal Society, 2011). While these factors affect the overall trend, the patterns of international scientific collaborations also reflect wider relationships among countries, including linguistic and historical factors (Narin, Stevens, and Whitlow 1991), and geography, economic, and cultural relations (Glänzel and Schubert 2005).

Percentages of international collaboration by field. This increase in international coauthorship occurs in every broad field of science. Astronomy is the most international field, with over half of its publications internationally coauthored (52.7%) (Figure 5-27). Geosciences, mathematics, biological sciences, and physics also have percentages of international collaboration above 20%. Factors influencing variations among fields include the existence of formal international collaborative programs and the use of costly research equipment (e.g., atomic colliders and telescopes), which result in cost sharing and collaboration among countries. However, even those fields with relatively low percentages of international collaboration have experienced increases in collaboration between 2000 and 2013.

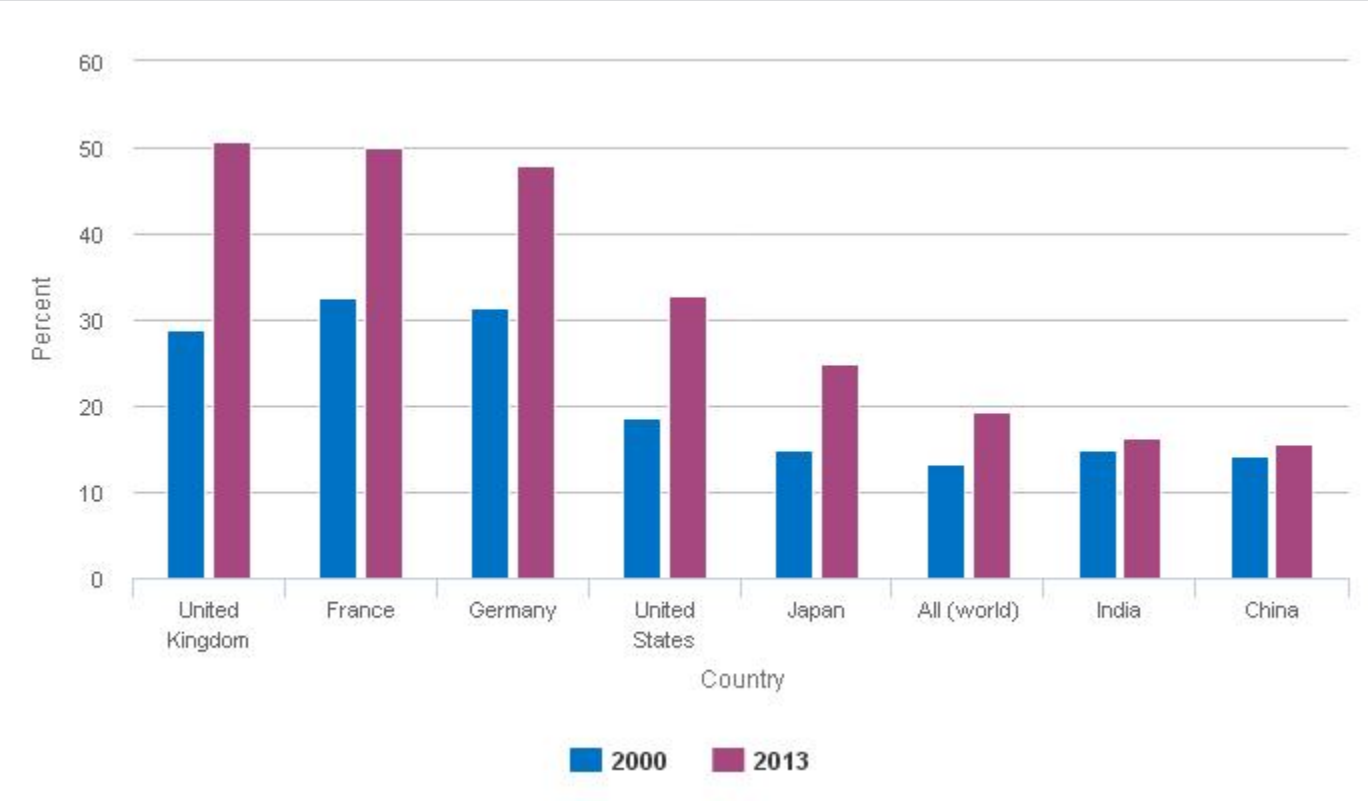
International collaboration, by region/country. Countries vary widely in the proportion of their S&E publications that are internationally coauthored. Scale effects alone play a role in this. Countries with large communities of researchers have many potential domestic coauthors in their field. Researchers in smaller countries are more likely to reach beyond their national borders to find collaborators.

In the publication output data described earlier from Figure 5-24, the 28 nations of the EU are shown as one region.[ii] By individual country, Figure 5-28 shows the percentages of international collaboration for the largest producers of S&E publications in 2013. The nations within this group that had the highest percentages of international collaboration in 2013 were the three EU nations of the United Kingdom, France, and Germany, which are also the three largest European producers of S&E publications. Collaboration increased for each country between 2000 and 2013. China and India increased their percentages of collaboration across the same period but did so at a slower rate than the other nations appearing in Figure 5-28 and were well below the global average.

[ii] Recent analytical work has approached the comparison between the United States and Europe as a comparison of collaboration between the nation states of Europe and the states that make up the United States (Kamalski and Plume 2013).

Figure 5-28

Share of S&E articles internationally coauthored, by selected country: 2000 and 2013



NOTES: Articles refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region/country/economy on the basis of the institutional address(es) listed in the article. Articles are credited on a whole-count basis (i.e., each collaborating country /economy is credited with one count). Articles with international institutions are counts of articles with institutional addresses from more than one country/economy. See appendix table 5-41.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com).

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Collaboration partnerships. Authors from each country have, on average, different propensities to partner with coauthors from other countries for international scientific collaboration. The remainder of this section describes global partnership patterns, with special focus on patterns of U.S. involvement in international collaboration.

U.S. institutional authors collaborate most frequently with authors from the second-largest producer of S&E publications, China. China accounted for 18.7% of U.S. internationally coauthored publications in 2013 (Table 5-28). Other substantial partners for the United States include the United Kingdom (12.7%), Germany (11.8%), Canada (10.4%), France (7.8%), Italy (6.7%), and Japan (5.9%).

Table 5-28 International coauthorship of S&E articles with the United States, by selected country/economy: 2013

(Percent)

Country/economy	U.S. share of country's/economy's international articles	Country's/economy's share of U.S. international articles
World	39.5	na
China	45.6	18.7
United Kingdom	29.0	12.7
Germany	28.8	11.8
Canada	44.4	10.4
France	25.1	7.8
Italy	29.9	6.7
Japan	32.9	5.9
Australia	29.3	5.8
South Korea	50.0	5.4
Spain	25.2	4.9
Netherlands	29.4	4.6
Switzerland	30.4	4.3
India	33.2	3.4
Brazil	35.5	3.2
Sweden	26.9	2.9

NOTES: na = not applicable.
Articles refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a country/economy on the basis of the institutional address(es) listed in the article. Articles are credited on a whole-count basis (i.e., each collaborating country/economy is credited with one count). Articles with international institutions are counts of articles with institutional addresses from more than one country/economy. See appendix table 5-56.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com).
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China and Canada are notable among these countries for having unusually high percentages of U.S. participation in their own internationally coauthored publications (45.6% and 44.4%, respectively). For the other five countries, the comparable shares range from 25.1% to 32.9%.

As a way to gauge the relative impact of relationships between countries, an index of international collaboration highlights shares of international scientific collaboration that differ substantially from what would be expected proportionally, based on country size. Eliminating other factors (language, geography, etc.), one might expect a country's internationally coauthored publications to have coauthors from a nation with a large number of internationally coauthored S&E publications. The index of international collaboration presented in Table 5-29 is 1.00 (unity) when coauthorship between two countries is exactly proportional to their overall shares of international collaborative authorship. A higher index value means that a country pair has a stronger-than-expected tendency to collaborate, and a lower index value means the pair has a weaker tendency to collaborate.

Table 5-29 **Index of international collaboration on S&E articles, by selected country /economy pair: 1999 and 2013**

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(International collaboration index)

Country/economy pair	1999	2013
North/South America		
Canada–United States	1.15	1.12
Mexico–United States	0.99	1.02
Mexico-Argentina	2.31	3.81
Mexico-Chile	2.57	3.66
Argentina-Brazil	4.06	4.98
Argentina-Chile	5.90	8.25
Europe		
France-Germany	0.74	1.04
France-UK	0.73	0.94
UK-Ireland	2.27	2.15
Belgium-Netherlands	2.23	3.09
Poland–Czech Republic	2.14	4.81
Hungary-Romania	4.72	7.20
Spain-Portugal	2.78	3.27
Scandinavia		
Finland-Sweden	3.70	3.93
Finland-Norway	3.94	3.18
Sweden-Denmark	2.90	3.51
Middle East		
Saudi Arabia–Egypt	25.17	18.92
Turkey-Iran	0.66	3.40
Turkey-Israel	0.59	1.39
Asia/South Pacific		
China-Japan	1.63	1.23
South Korea–Japan	1.92	1.89
Australia-Malaysia	1.14	1.39
Australia-China	1.03	1.12
Australia–New Zealand	4.58	3.55

Country/economy pair	1999	2013
India–South Korea	0.91	1.85

NOTES: UK = United Kingdom.
The international collaboration index shows the first country's rate of collaboration with the second country, divided by the second country's rate of international coauthorship. Articles are credited on a whole-count basis (i.e., each collaborating country/economy is credited with one count). Articles with international institutions are counts of articles with institutional addresses from more than one country/economy. See appendix table 5-55.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com).
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Regional collaboration, as measured by this index of international collaboration, shows trends that reflect geographic proximity and other historical factors (Table 5-29; Appendix Table 5-55 and Appendix Table 5-56). In North America, the Canada-U.S. index shows a percentage of collaboration that is 12% (1.12) greater than would be expected by size of overall international collaboration alone and has not changed much between 1999 and 2013. Proximity alone does not explain these relationships: the U.S.-Mexico index is also relatively stable and is just what would be expected by size alone—near unity.

Mexico in turn has very strong collaboration with the Spanish-speaking South American nations of Argentina and Chile (3.81 and 3.66, respectively, for 2013). In turn, Argentina is particularly likely to collaborate with regional neighbors Brazil and Chile. Collaboration between the United Kingdom and Ireland is more than twice what would be expected, 2.15 in 2013. Hungary shares a particularly high collaboration index with Romania, 7.20 in 2013. These countries are not only neighbors; a relatively large share of Romania's population speaks Hungarian.[iii]

In addition to the above-average relationships that reflect geographic proximity, Appendix Table 5-55 shows other strong collaboration relationships that reflect historical and other ties between nations. For example, Spain had a collaboration index measure in 2013 that is between two and three times higher than expected with Mexico, Argentina, and Chile. Despite the substantial geographic distances, the United Kingdom has a higher-than-expected collaboration index with Australia and New Zealand. Malaysia has greater-than-expected collaboration ties with the Middle East nations Iran, Saudi Arabia, and Egypt.

[iii] Six percent of Romania's population speak Hungarian, according to the Central Intelligence Agency's *World Factbook* (https://www.cia.gov/library/publications/the-world-factbook/geos/ro.html).

Trends in Citation of S&E Publications

This section provides indicators of S&E publications that are cited in other S&E publications. Citations indicate impact, and they are increasingly international in scope. Measured by citations and by the shares of the most highly cited publications, the developed world continues to maintain a substantial advantage over the developing world. The developing world is nevertheless making rapid gains.

The next sections examine two aspects of publication citations in a global context: the overall rate of citation of a country's scientific publications, and the share of the world's most highly cited literature authored by different countries. The discussion of publication citations will conclude with an examination of citations to publications authored by researchers at U.S. academic institutions and in other U.S. sectors.

The rate of citations to S&E literature vary across fields of science and are most frequent within a few years following publication. However, even very old publications can "awaken" to receive citations many years after publication (Ke et al. 2015). The average of relative citations (ARC) presented in this chapter is an index designed to allow for lags of varying length and to normalize across fields and countries (see sidebar on Bibliometric Data and Terminology). The international citations patterns presented in Science and Engineering Indicators 2016 are calculated based on only a subsequent 3 years of data.

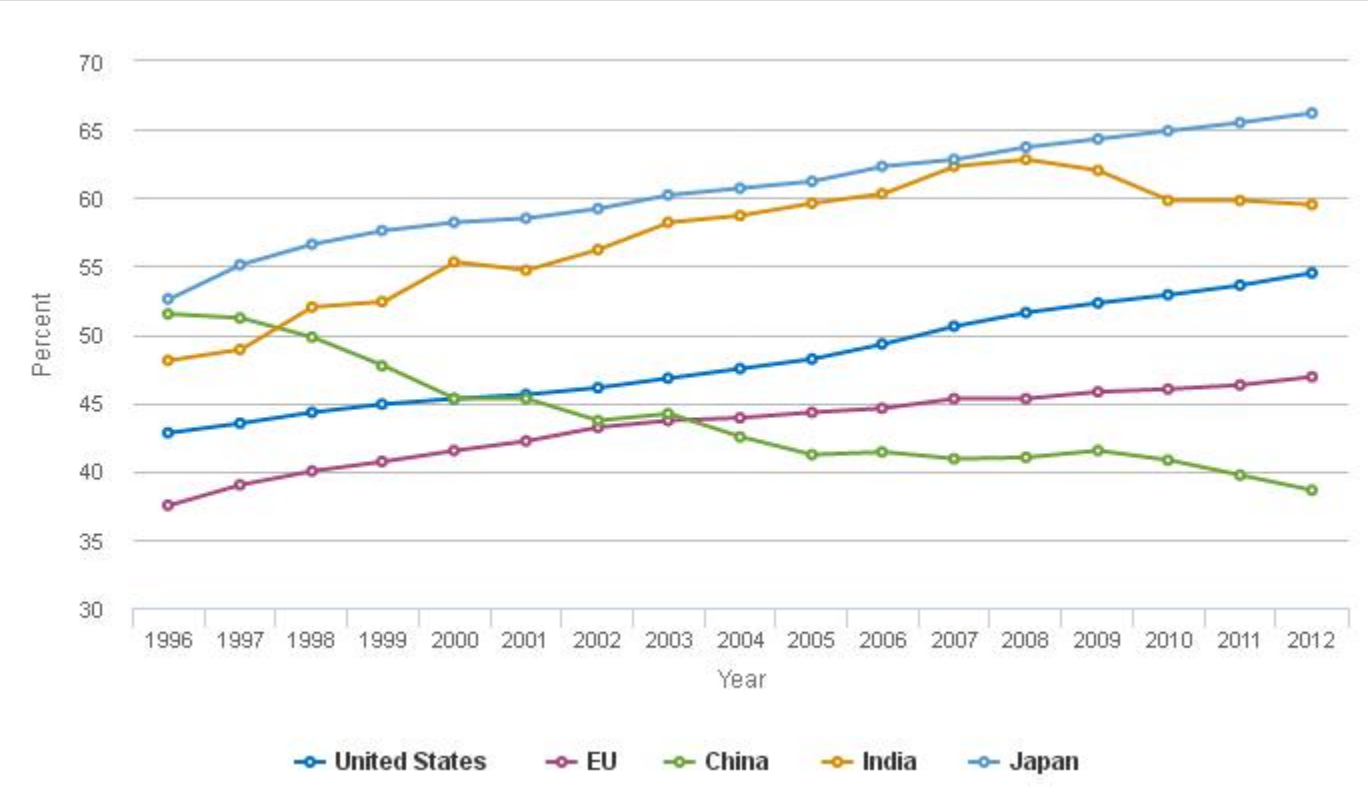
International Citation Patterns

Like the indicators of international coauthorship discussed earlier, cross-national citations provide evidence that S&E research is increasingly international in scope. Citations to a country's publications that come from publications authored outside that country are referred to as *international citations.* Simply due to the scale of S&E research activity, the United States, the EU, and China would be expected to account for large shares of the international citations. This section first reports these shares, then provides a relative measure that normalizes for each country's number of publications.

Between 1996 and 2012, the United States' international share of citations increased from 42.8% in 1996 to 54.5% in 2012 (Figure 5-29). The shares of international citations increased in most countries of the world and in all but one of the world's major S&E publication–producing countries (Appendix Table 5-58). China is the exception. In 1996, 51.5% of citations to Chinese S&E publications came from outside China; by 2012, the proportion had dropped to 38.6% (Figure 5-29). This suggests that China's expanding S&E publication output is being used mostly *within* China. Language barriers are one explanation; many Chinese-language articles are cited by other Chinese-language articles rather than by English-language articles (Li et al. 2014). A relatively small number of Chinese journals serve as citation windows, transmitting results between international and Chinese scholars (Zhou and Leydesdorff 2006).

Figure 5-29

Share of selected region/country/economy citations that are international: 1996–2012



EU = European Union.

NOTES: Articles refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region/country/economy on the basis of the institutional address(es) listed in the article. Citations are presented for the year when the publication is published, showing the counts of subsequent citations from peer-reviewed literature. At least 3 years of data following publication are needed for a meaningful measure. See appendix table 5-58.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com).

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Russia, the 14th-largest producer of S&E publications in 2013, also experienced a drop in its share of international citations. This pattern is different from that of China, however. The decline in international citations is in the recent years of 2007–12, while Russia's share of world publications is shrinking. For Russia, this decline parallels a longer-term trend toward a shrinking R&D workforce. According to the Organisation for Economic Co-operation and Development, total R&D personnel in full-time equivalents declined from 1.1 million in 1996 to 827,000 in 2013 (OECD 2015).

Between 1996 and 2012, almost all of the countries in the EU increased their share of international citations (Appendix Table 5-58).[i] For the EU as a unit, the share of external citations increased from 37.5% to 46.9%. EU internal citations continue to make up over half of EU citations, indicating strength in the EU's scientific base, supported by the Framework Programme to enhance European research and other incentives.[ii]

The impact of one country's S&E publications on S&E researchers of the other country is shown in the patterns of international citations between country pairs. The relative citation index normalizes cross-national citation data for variations in relative size of publication output, much like the collaboration index (see sidebar, Bibliometric Data and Terminology). The expected value is 1.00, but unlike the collaboration index, citation indexes are not symmetric. For example, if country A cites publications by country B 15% more than expected, this does not mean that country B also cites publications by country A 15% more than expected. Table 5-24 shows the relative citation index for the year 2012 for major publishing locations in four regions: North America, the EU, Asia, and South America. These data show the following:

- From among the major producers of S&E publications, U.S. publications cite publications from Canada (1.17) and the United Kingdom (1.15) with shares higher than expected, based on size.
- U.S. authors cite Chinese (0.24), Indian (0.18), and other Asian S&E publications much less than expected.
- Mexico is heavily cited in publications from Argentina and Chile. Likewise, Mexican authors cite South American publications more than they cite publications from other areas of the world.

Inter-European influence is strong, with most country pairs exhibiting index values greater than 1.00.

Similar to the patterns in coauthorship, these data indicate the strong influence that geographic, cultural, and language ties—and, in the case of the EU, long-active incentives—have on citation patterns.

The publication counts and collaboration rates described above provide partial indicators of the quantity of S&E research output and the ties between researchers. Citations provide an additional indicator of the impact of research on subsequent work (Martin and Irvine 1980). The ARCs presented below are calculated to allow for citation lags of varying lengths and to normalize for field and country size (see the Bibliometric Data and Terminology sidebar).

Appendix Table 5-61 provides the ARC for 1996–2012 for countries and regions with enough citations to create valid measures. Through 2012, the United States' ARC held steady around 1.4, or 40% higher than would be expected, based on the number of peer-reviewed publications and representation by fields. China's ARC measure increased across the period, from 0.5 to 0.9, improving from 50% fewer citations as would be expected, based on size, to 10% fewer than would be expected.

When viewed as a group, the countries of the EU increased from as many citations as would be expected by size (1.0) to 20% more (1.2), based on ARCs (Figure 5-30). Appendix Table 5-61 provides country-level measures for the EU that show that Austria, Belgium, Cyprus, Denmark, Estonia, Finland, Ireland, the Netherlands, Sweden, and the United Kingdom had the highest ARCs in 2012, in each case starting with a relative measure below that of the United States in 1996 and rising above the United States by 2012. In East and Southeast Asia, Singapore has the highest ARCs, reaching 1.9 in 2012.

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[i] There were three exceptions, the relatively small S&E producers Latvia, Luxembourg, and Malta.

[ii] The European Union's Framework Programme provides competitive funding for research, including €8.1 billion in 2013 (http://ec.europa.eu/research/fp7/index_en.cfm).

Table 5-24 Relative citation index, by selected country/economy pair: 2012

	Cited country/economy													
	North America			South America			European Union			Asia				
Citing country /economy	Canada	Mexico	United States	Argentina	Brazil	Chile	France	Germany	United Kingdom	China	India	Japan	South Korea	Taiwan
North America														
Canada	8.82	0.35	1.54	0.52	0.32	0.57	0.90	0.94	1.36	0.28	0.22	0.49	0.46	0.45
Mexico	1.01	31.25	1.08	1.60	1.08	1.66	0.89	0.82	0.99	0.42	0.75	0.52	0.67	0.76
United States	1.17	0.31	2.90	0.41	0.26	0.45	0.76	0.92	1.15	0.24	0.18	0.54	0.49	0.38
South America														
Argentina	0.95	1.21	1.09	58.71	1.47	3.42	1.04	1.01	1.04	0.28	0.47	0.46	0.45	0.44
Brazil	0.88	0.99	0.89	2.04	13.98	1.24	0.79	0.74	0.91	0.32	0.60	0.45	0.55	0.56
Chile	1.19	1.16	1.22	3.61	0.97	73.61	1.09	1.00	1.16	0.29	0.36	0.49	0.55	0.46
European Union														
France	1.05	0.39	1.21	0.61	0.34	0.65	7.51	1.27	1.34	0.25	0.23	0.62	0.47	0.37
Germany	0.96	0.26	1.24	0.46	0.25	0.49	1.07	6.21	1.35	0.24	0.19	0.63	0.47	0.33
United Kingdom	1.16	0.29	1.34	0.41	0.28	0.50	1.00	1.16	6.11	0.22	0.20	0.51	0.41	0.34
Asia														
China	0.73	0.39	0.83	0.43	0.30	0.35	0.59	0.67	0.63	2.53	0.57	0.70	1.19	1.09
India	0.63	0.63	0.70	0.59	0.52	0.46	0.58	0.62	0.68	0.69	8.15	0.54	0.98	0.96
Japan	0.75	0.26	1.08	0.34	0.22	0.34	0.81	0.98	0.89	0.37	0.26	7.56	0.89	0.65
South Korea	0.75	0.36	1.05	0.38	0.30	0.35	0.57	0.73	0.72	0.69	0.54	0.92	10.93	1.26
Taiwan	0.78	0.50	0.97	0.39	0.34	0.30	0.60	0.65	0.74	0.74	0.56	0.81	1.51	16.69

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NOTES:	Citations refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a country/economy on the basis of the institutional address(es) listed in the article. Articles are credited on a fractional-count basis (i.e., for articles with collaborating institutions from multiple countries/economies, each country/economy receives fractional credit on the basis of the proportion of its participating institutions). Citation counts are based on all citations made to articles in their publication year and in the following 2 years (i.e., 3-year citation window, for instance, scores in 2012 are based on citations to articles published in 2012 that were made in articles published in 2012–14.
SOURCES:	National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com).
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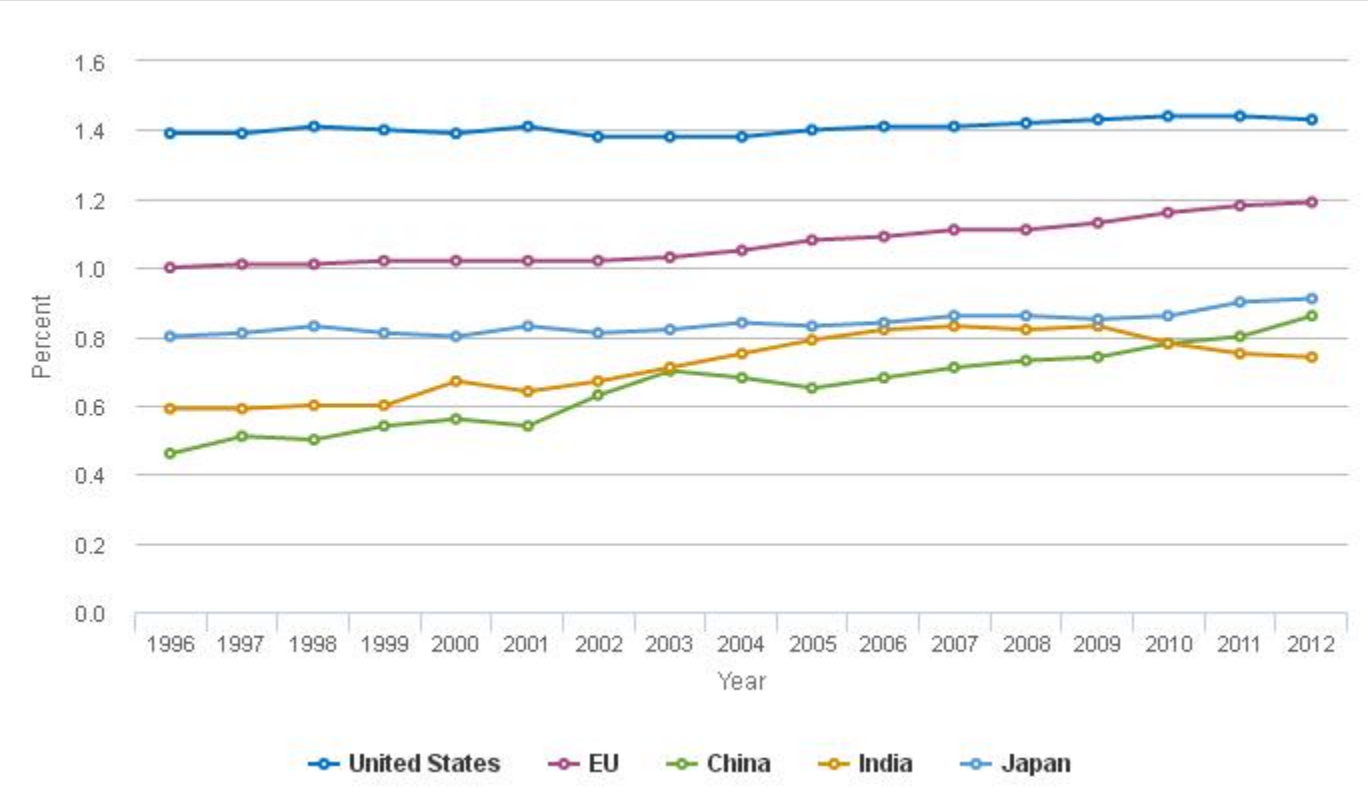
Figure 5-30

Average of relative citations, by region/country/economy: 1996–2012



EU = European Union.

NOTES: Articles are classified by the publication year and are assigned to a region/country/economy on the basis of the institutional address(es) listed in the article. The average of relative citations is presented for the year of publication showing the counts of subsequent citations from peer-reviewed literature. At least 3 years of data following publication are needed for a meaningful measure. See appendix 5-61.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com).

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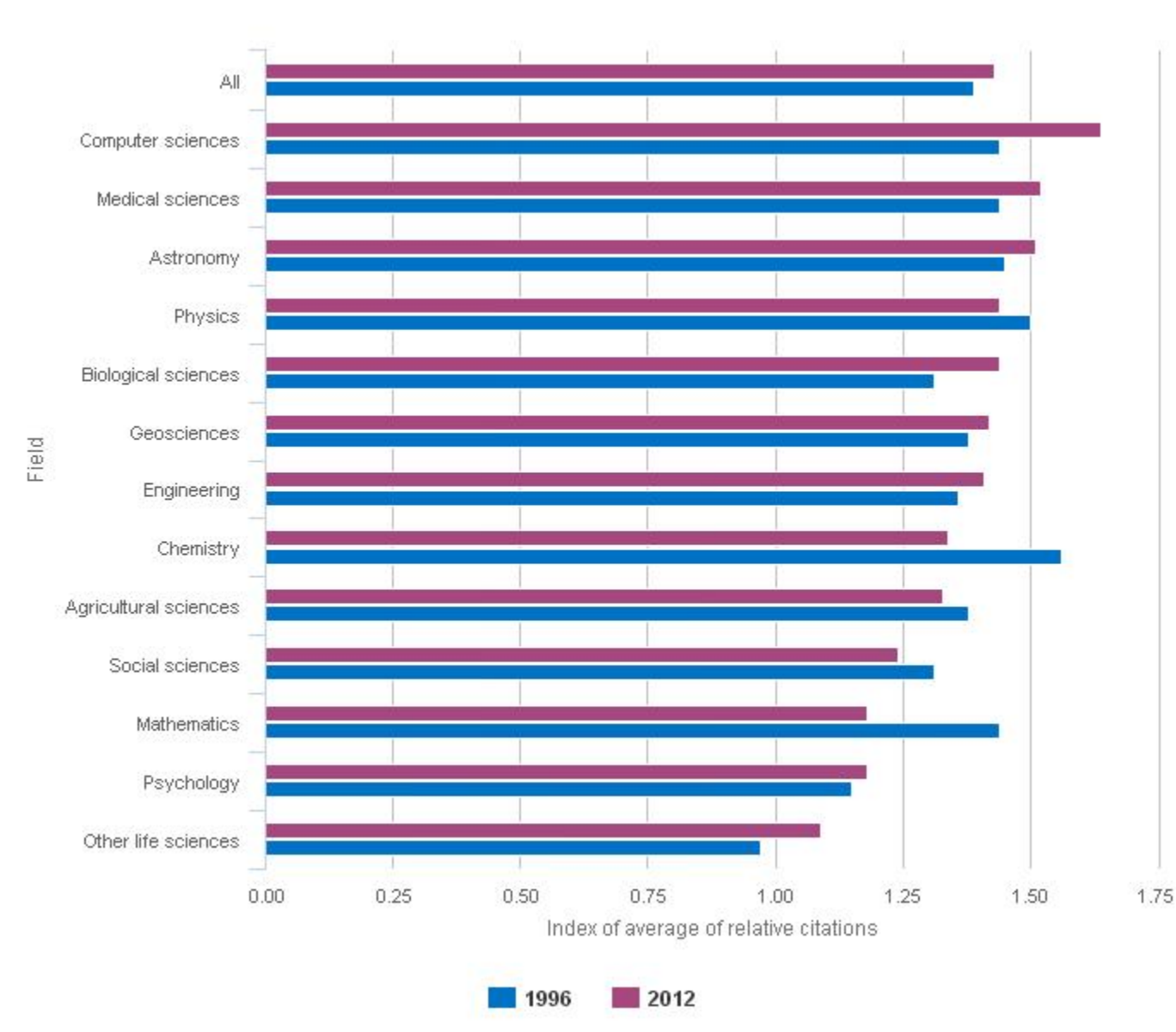
At the field level, the ARC impact of U.S publications is also higher than would be expected based on the number of U.S. peer-reviewed publications and representation by fields, and it increased between 1996 and 2012. U.S. citation impacts for computer sciences are especially high, at 60% higher than the world average value. While U.S. citation impacts remain above the world average for almost all fields, for 5 of the 13 broad fields of science, the U.S. measure has been decreasing relative to the world average between 1996 and 2012. These are physics, agricultural sciences, chemistry, social sciences, and mathematics (Figure 5-31).

Figure 5-31

Average of relative citations for the United States, by scientific field: 1996 and 2012



NOTES: Articles are classified by the publication year and are assigned to a region/country/economy on the basis of the institutional address(es) listed in the article. The average of relative citations is presented for the year of publication showing the counts of subsequent citations from peer-reviewed literature. At least 3 years of data following publication are needed for a meaningful measure. See appendix 5-60.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com).

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Trends in Highly Cited S&E Literature, by Country

Among all publications, only a small share receives more than a handful of citations. Publications that are in the top 1% of total global citations can be considered to have the highest impact, once properly adjusted for subfield and year. This top 1% of publications can be segmented by the institutional addresses of authors to show which

countries and regions are producing S&E publications with the highest impact. Similar to the ARCs, country and region citation rates for highly cited publications need to be normalized for the share of total publications produced. Citations are calculated by percentile rankings, showing what share of publications are in the top 1% of the most highly cited literature. A country with a 2% share of the top 1% has twice as many highly cited articles as would otherwise be expected, based on its number of publications.

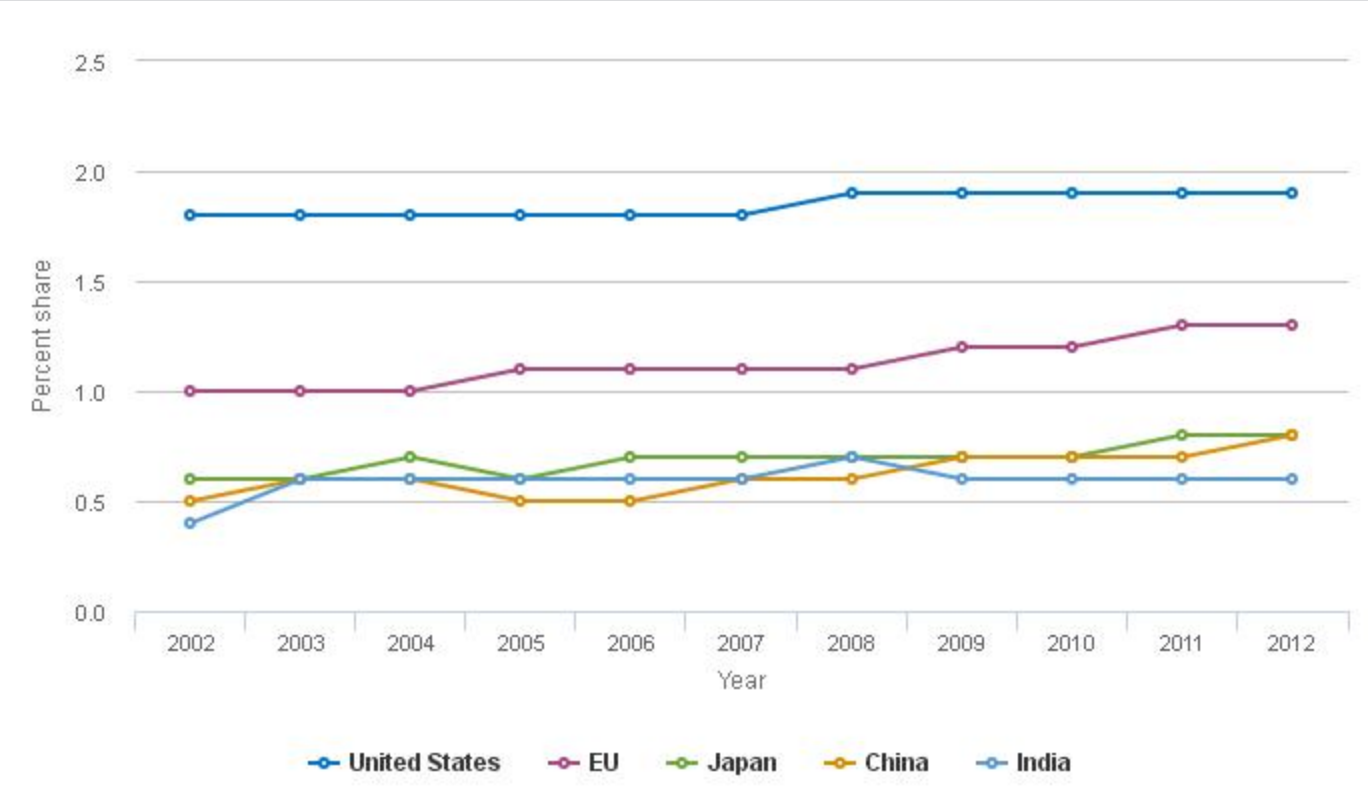
World citations to U.S. research publications show that, in all broad fields of S&E, U.S. publications continue to have citation rates that are among the highest for major S&E producers, even when normalized for overall publication share. In 2012, U.S. S&E publications have a 1.94 share of the top 1%, meaning that these publications were almost twice as likely to be among the top 1% as would be expected, based on the number of U.S. publications produced. This pattern of citations to U.S. publications being higher than expected holds throughout the top half of the percentage distribution; U.S. publications are more likely to be in the top 5%, 10%, and 20% and also are less likely to be in the bottom 50% of the distribution of cited articles (Appendix Table 5-59).

U.S. publications in the fields of medical sciences, computer sciences, physics, and engineering are a growing share of the top 1% articles, with at least twice as many citations as would be expected based on size in 2012. In five fields, the United States' relative share of the top 1% of articles declined between 2002 and 2012; these fields are astronomy, chemistry, mathematics, agricultural sciences, and social sciences (Appendix Table 5-59).

Between 2002 and 2012, China and the EU experienced more rapid growth than the United States in their share of the world's most highly cited publications (Figure 5-32). The share of China's publications in the top 1% increased from 0.5 to 0.8. S&E articles in astronomy, mathematics, chemistry, and social sciences have the highest representation in the top 1% for Chinese authors (Appendix Table 5-59).

Figure 5-32

Share of U.S., EU, Japan, China, and India S&E articles that are in the world's top 1% of cited articles: 2002–12



EU = European Union.

NOTES: This figure depicts the share of publications that are in the top 1% of the world's citations, relative to all the country's publications in that period and field. It is computed as follows: *Sx* = *HCPx*/*Px*, where *Sx* is the share of output from country *x* in the top 1% most cited articles; *HCPx* is the number of articles from country *x* that are among the top 1% most cited articles in the world; and *Px* is the total number of papers from country *x* in the database that were published in 2012 or earlier. Citations are presented for the year of publication, showing the counts of subsequent citations from peer-reviewed literature. At least 3 years of data following publication are needed for a meaningful measure. Publications that cannot be classified by country or field are excluded. Articles are classified by the publication year and assigned to country/economy on the basis of the institutional address(es) listed in the article. See appendix table 5-24 for countries included in the EU. The world average stands at 1.00% for each period and field.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com).

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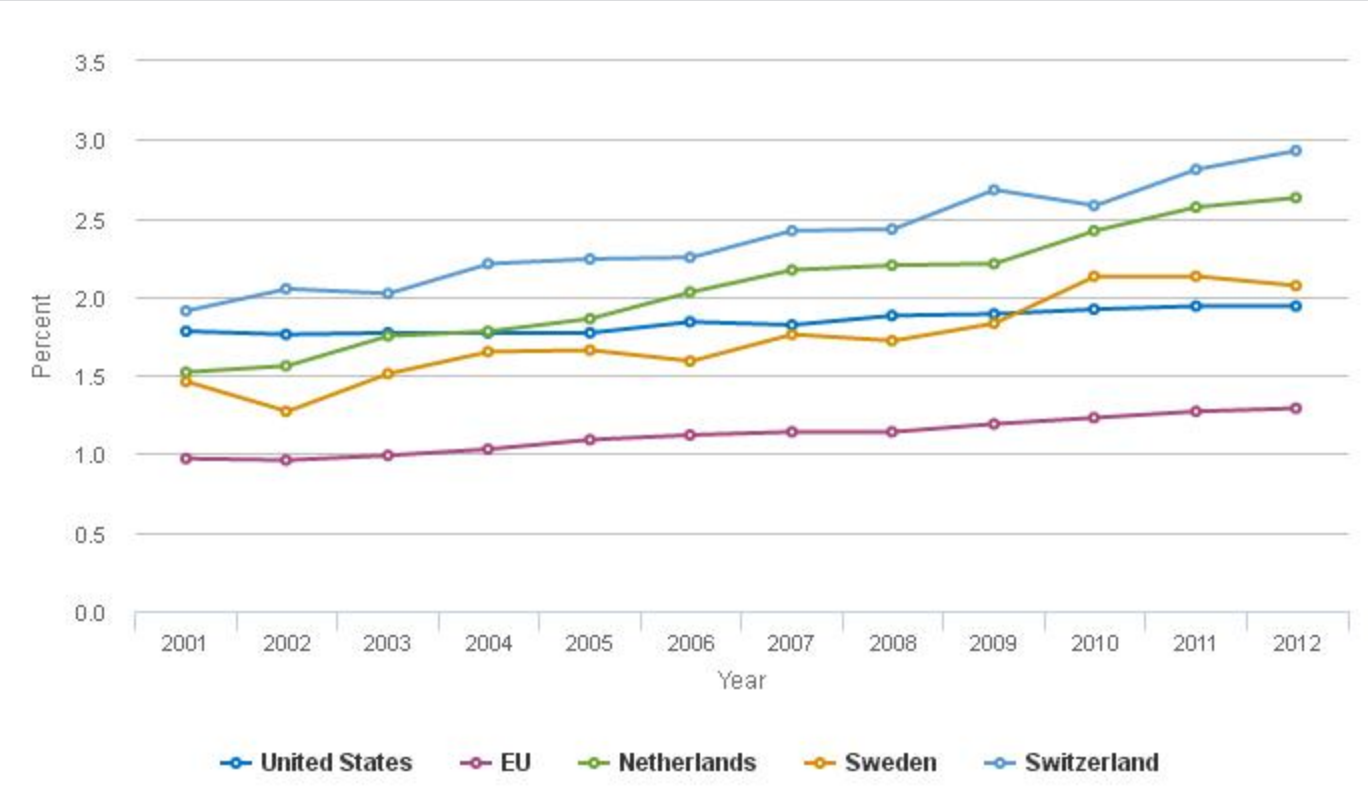
During this same period, several of the smaller research-intensive nations of the EU have made large gains in their relative share of the top 1% of highly cited publications—notably, Denmark, Finland, the Netherlands, Sweden, Iceland, and Switzerland (Appendix Table 5-62). Each of these nations had a top 1% share of world citations, relative to their share of S&E publications, which was above that of the United States in 2012 (Leydesdorff et al. 2014). Figure 5-33 shows the top 1% shares for the United States, the EU, the Netherlands, Sweden, and Switzerland. The relatively new EU nations of Estonia, Lithuania, and Slovenia also had rapidly rising 1% shares in recent years.

Figure 5-33

Share of U.S., EU, and selected European countries' S&E articles that are in the world's top 1% of cited articles: 2001–12



EU = European Union.

NOTES: This figure depicts the share of publications that are in the top 1% of the world's citations, relative to all the country's publications in that period and field. It is computed as follows: *Sx* = *HCPx*/*Px*, where *Sx* is the share of output from country *x* in the top 1% most cited articles; *HCPx* is the number of articles from country *x* that are among the top 1% most cited articles in the world; and *Px* is the total number of papers from country *x* in the database that were published in 2012 or earlier. Citations are presented for the year of publication, showing the counts of subsequent citations from peer-reviewed literature. At least 3 years of data following publication are needed for a meaningful measure. Publications that cannot be classified by country or field are excluded. Articles are classified by the publication year and assigned to country/economy on the basis of the institutional address(es) listed in the article. See appendix table 5-25 for countries included in the EU. The world average stands at 1.00% for each period and field.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com).

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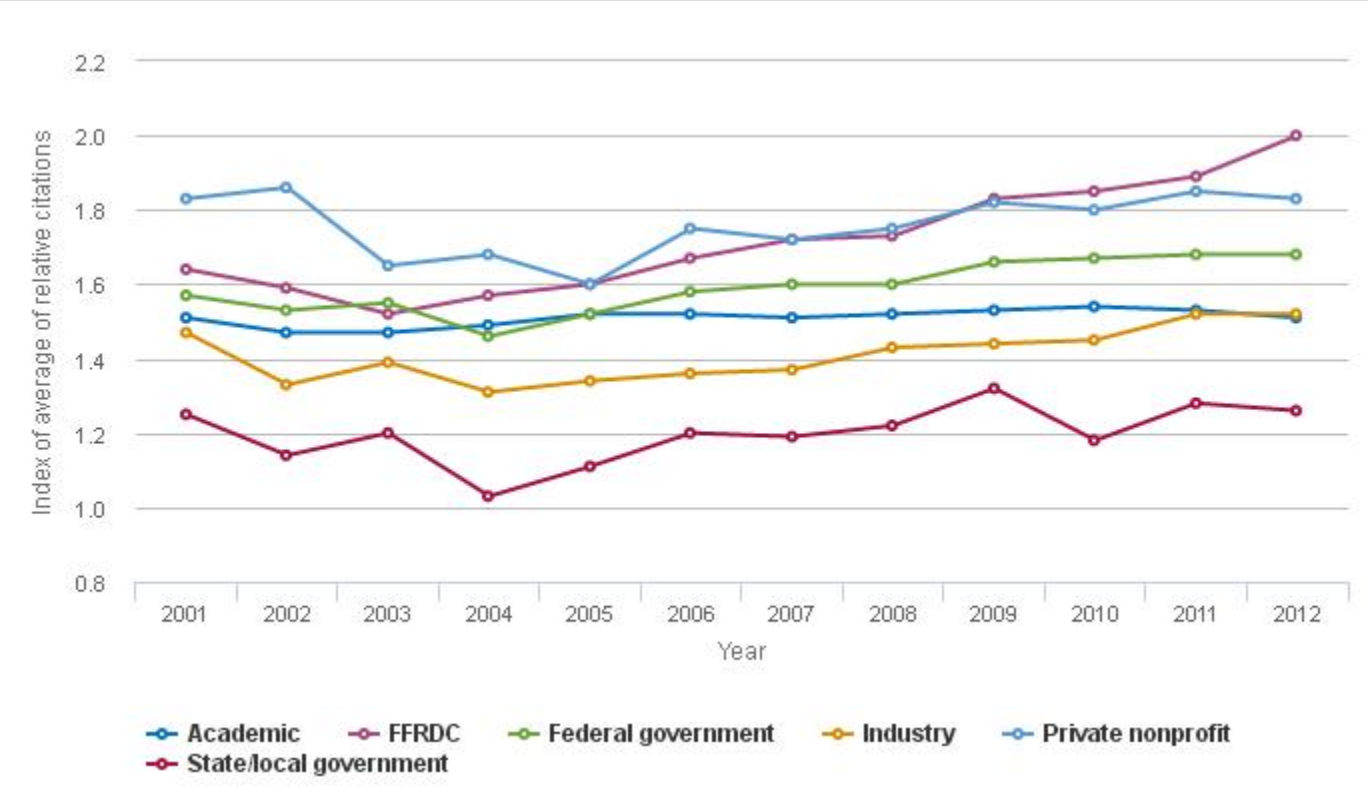
U.S. Cross-Sector Citation Trends

Relative citations can also be used to examine the citation impact of publications by each U.S. sector. Figure 5-34 shows the ARC index values for each of the six sectors of U.S. institutions relative to world output, normalized by field and document type, and how they have changed between 2001 and 2012. U.S. academic publications, which make up the vast majority of U.S. publications, held constant at about 50% higher than would be expected based on the number of publications. Publications authored at FFRDCs have shown a marked improvement since 2003 and in 2012 received the highest index value of all U.S. sectors, 100% more citations than would have been expected when based on size alone.

Figure 5-34

Average of relative citations of U.S. S&E articles, by sector: 2001–12



FFRDC = federally funded research and development center.

NOTES: Articles refer to publications from a selection of journals, books, and conference proceedings in S&E from Scopus. Articles are classified by their year of publication and are assigned to a region/country/economy on the basis of the institutional address(es) listed in the article. Citations are presented for the year when the publication is published, showing the counts of subsequent citations from peer-reviewed literature. At least 3 years of data following publication are needed for a meaningful measure.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; Elsevier, Scopus abstract and citation database (www.scopus.com).

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Citation of S&E Articles by USPTO Patents, and Energy- and Environment-Related Patent Citations

Compared with the production of S&E publications, patenting is a rarer event. In 2013, 412,542 S&E publications were produced by U.S.-affiliated authors (Appendix Table 5-26). By contrast, in the same year 138,496 USPTO utility patents were assigned to U.S. owners. USPTO patents are, like S&E publications, increasingly international. In recent years, half of all USPTO patents were awarded to foreign owners (Appendix Table 5-63). Although patenting by U.S. academic inventors is increasing, it is still relatively rare; in 2014, only 5,990 utility were assigned to U.S. academic owners (Appendix Table 5-63).

In addition to direct patenting by universities, citations to the S&E literature on the cover pages of issued patents are an indicator of the contribution of research to the development of inventions (Narin, Hamilton, and Olivastro

1997). In 2014, a total of 302,485 S&E articles are cited by 72,435 USPTO utility patents (Appendix Table 5-64). Appendix Table 5-64 presents sector characteristics of the assignees of USPTO utility patents that cite S&E literature and the sector characteristics of the publication authors cited by USPTO utility patents.

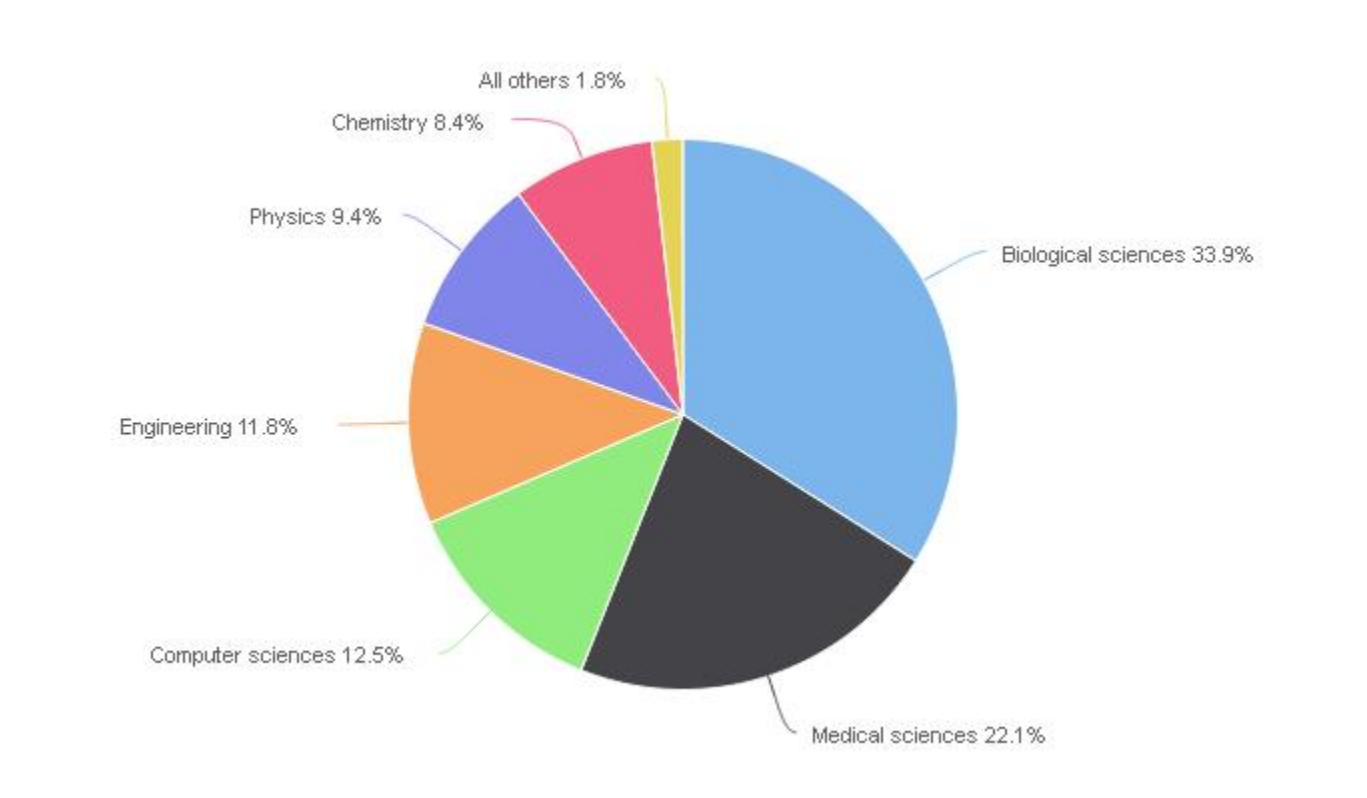
These USPTO patents cited more foreign articles (54%) than U.S. articles (44%).[iii] The share of patent citations to foreign S&E articles has increased with other measures of internationalization, coinciding with a growth in the percentage of U.S. utility patents awarded to foreign assignees and the share of world articles authored outside the United States.

S&E publications can be cited by more than one patent, so the total number of citations can exceed both the number of patents and the number of articles cited. Citations to U.S. articles in 2014 USPTO patents were dominated by articles in biological sciences (34%), medical sciences (22%), computer sciences (13%), engineering (12%), physics (9%), and chemistry (8%). These six fields account for 98% of the total (Figure 5-35; Appendix Table 5-65).

[iii] The remaining 2% of articles could not be attributed to particular country.

Figure 5-35

Citations of U.S. S&E articles in U.S. patents, by selected S&E article field: 2014



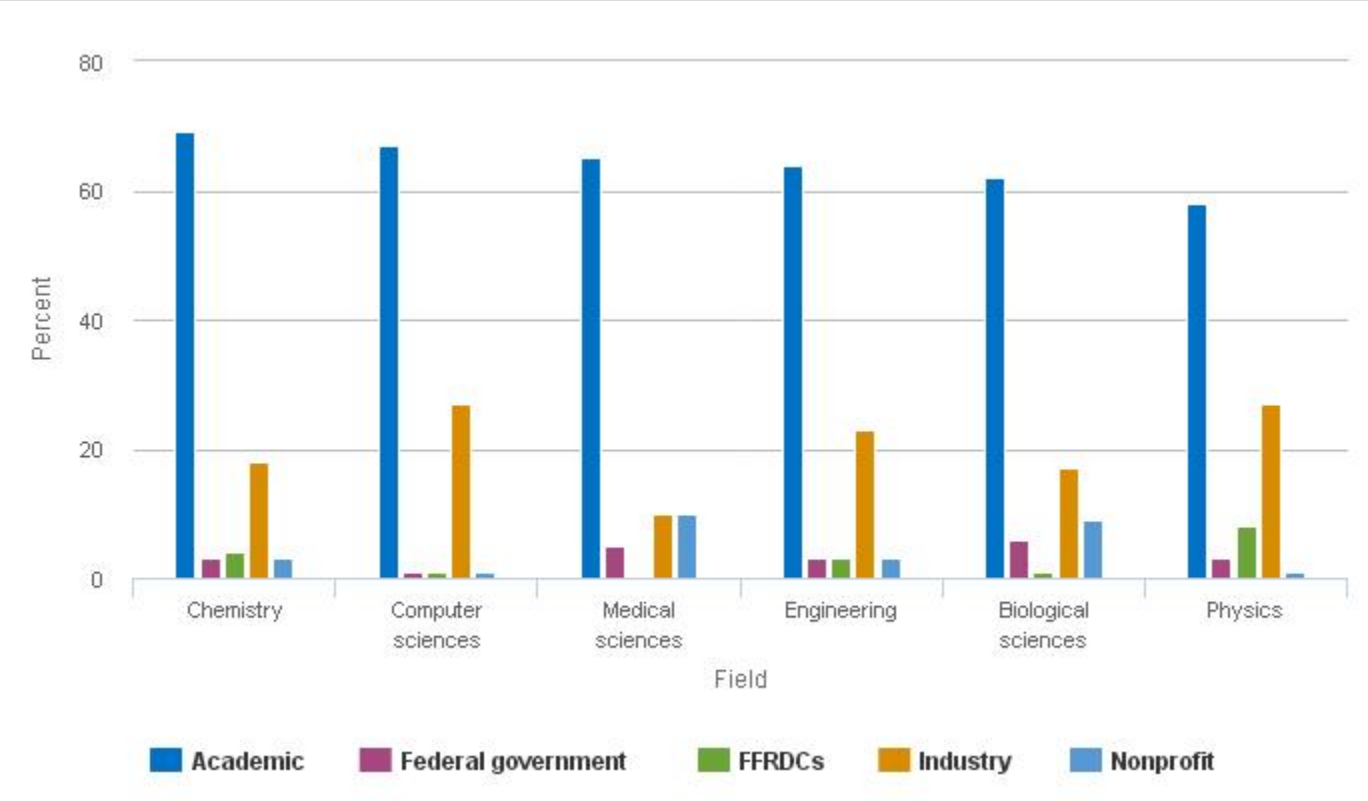
SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; LexisNexis and U.S. Patent and Trademark Office patent data; Elsevier, Scopus abstract and citation database (www.scopus.com). See appendix table 5-65.

Science and Engineering Indicators 2016

Consistent with its large share of all S&E publications and citations overall, the academic sector receives the majority of U.S. citations in patents (Appendix Table 5-65). Articles from other sectors receive far fewer citations in patents, but this varies by field (Figure 5-36). After academia, industry articles capture the next-largest share of citations overall, with particularly high citations in computer sciences (27%), physics (27%), and engineering (23%). In medical sciences, industry and nonprofit articles each account for 10% of patent citations. Compared with other fields, federal government S&E articles receive the largest number of citations in biological sciences (6%), and FFRDCs receive the largest number of citations in physics (8%).

Figure 5-36

Citation of U.S. S&E articles in U.S. patents, by selected S&E field and article author sector: 2014



FFRDC = federally funded research and development center.

NOTES: Fields with less than 5% in 2014 are omitted. Citations where the sector is unknown sectors are not shown. Citations to state and local government S&E articles are also not shown.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; LexisNexis and U.S. Patent and Trademark Office patent data; Elsevier, Scopus abstract and citation database (www.scopus.com). See appendix table 5-65.

Science and Engineering Indicators 2016

Clean energy and energy conservation and related technologies—including biofuels, solar, wind, nuclear, energy efficiency, pollution prevention, smart grid, and carbon sequestration—are closely linked to scientific R&D. With growing attention being given to climate change, this area has become a policy focus in the United States and other countries. These developing technology areas span four broad S&E fields—engineering, chemistry, physics, and biological sciences—indicating a wide base of S&E knowledge. Thus, performance in these technology areas is also an indicator of the capacity of the U.S. S&E enterprise to address large-scale challenges. The prior two editions of *Science and Engineering Indicators* have reported on the number of patents with potential application in these technologies.

Chapter 6 of this volume presents extensive data on the patents in four technology areas related to clean energy—alternative energy, pollution mitigation, smart grid, and energy storage—including the nationality of their inventors. (See chapter 6, "Industry, Technology, and the Global Marketplace," section Patenting of Clean Energy and Pollution Control Technologies) This section reports on the citations in those patents to the S&E literature,

using those citations to indicate the linkages between S&E R&D and the potential for practical use of the results of those R&D projects in new inventions and technologies. The citation data are based on patents issued between 2011 and 2014. See sidebar Identifying Clean Energy and Pollution Control Patents.

U.S. patents in these four areas of clean energy technology account for 3.4% of all utility patents issued in 2014 (Appendix Table 5-64 and Appendix Table 5-66). As is the case with U.S. utility patents overall, patents in clean energy technology areas have consistently cited more foreign literature than U.S. literature, with 60% for foreign citations in 2014, compared to 39% for U.S. citations (Appendix Table 5-66).[iv] Within citations to U.S. literature, articles authored by the academic sector accounted for the most citations (63%) among U.S. sectors in 2014. Industry and FFRDCs were the next largest, accounting for 13% and 12% of citations, respectively.

These four categories of energy and environment–related patents show somewhat different patterns of reliance on S&E literature. For alternative energy patents, engineering makes up the largest share (31%), but chemistry and physics each make up more than one-fifth of citations. For energy storage patents, over half of all citations are to chemistry articles. Pollution mitigation citations are dominated by chemistry (33%) and engineering (30%), with geosciences and biological sciences accounting for more than 10% each. Smart grid patents draw overwhelmingly from engineering (68%), with additional shares from computer sciences (15%) and physics (12%) (Table 5-30).

Using patent citations as an indicator, the data show that engineering research contributes heavily to invention in all areas of green technology and that chemistry contributes to each area, with the exception of smart grid. Physics, biological sciences, and geoscience research (which in this taxonomy includes environmental sciences) are all prominent in each area of energy and environment–related technology.

[iv] The remaining 1% cannot be assigned to a country.

Identifying Clean Energy and Pollution Control Patents

The technology areas used for identifying clean energy and pollution control patents are the same ones used in *Science and Engineering Indicators 2012* and *Science and Engineering Indicators 2014* (see Table 5-D, below). However, the methodology used for matching the patents to technology areas has been modified for *Science and Engineering Indicators 2016* to adapt to new data sources. The S&E fields cited by these patents are shown in Table 5-30.

Table 5-D Categories of Energy- and Environment-Related Patents

Categories of Energy- and Environment-Related Patents

Alternative energy	Energy storage	Smart grid	Pollution mitigation
Bioenergy	Batteries	Advanced components	Recycling
Geothermal	Flywheels	Sensing and measurement	Air
Nuclear	Superconducting magnetic energy systems	Advanced control methods	Solid waste

Categories of Energy- and Environment-Related Patents

Alternative energy	Energy storage	Smart grid	Pollution mitigation
Solar	Ultracapacitors	Improved interfaces and decision support	Water
Wave/tidal /ocean	Hydrogen production and storage	Integrated communications	Environmental remediation
Wind	Thermal energy storage		Cleaner coal
Electric/hybrid vehicles	Compressed air		Carbon and greenhouse gas storage and capture
Fuel cells			

SOURCE: D'Amato T, Hamilton K, Hill D, Identifying clean energy supply and pollution control patents, Working Paper, National Science Foundation, National Center for Science and Engineering Statistics (2015), http://www.nsf.gov/statistics/2015/ncses15200/, accessed 20 October 2015.

Science and Engineering Indicators 2016

Table 5-30 Patent citations to S&E articles, by selected patent technology area and article field: 2011–14

Technology/field	Citations (*n*)	Percent
Alternative energy	27,858	100.0
Engineering	8,608	30.9
Chemistry	7,236	26.0
Physics	6,017	21.6
Biological sciences	4,423	15.9
Geosciences	722	2.6
Agricultural sciences	614	2.2
All others	238	0.9
Energy storage	9,049	100.0
Chemistry	4,776	52.8
Engineering	2,536	28.0
Physics	898	9.9
Biological sciences	528	5.8
Geosciences	152	1.7
All others	159	1.8

Technology/field	Citations (*n*)	Percent
Pollution mitigation	8,999	100.0
Chemistry	2,971	33.0
Engineering	2,730	30.3
Geosciences	1,556	17.3
Biological sciences	985	10.9
Physics	336	3.7
Medical sciences	224	2.5
Agricultural sciences	156	1.7
All others	41	0.5
Smart grid	4,918	100.0
Engineering	3,318	67.5
Computer sciences	742	15.1
Physics	586	11.9
Chemistry	72	1.5
Biological sciences	72	1.5
Medical sciences	34	0.7
Geosciences	30	0.6
Social sciences	29	0.6
All others	35	0.7

NOTES: Article/citation counts are from the set of journals covered by Scopus. Articles are assigned to a sector on the basis of the institutional address(es) listed in the article. Articles/citations are credited on a fractional-count basis (i.e., for articles with collaborating institutions from multiple sectors, each sector receives fractional credit on the basis of the proportion of its participating institutions). Citation counts are based on an 11-year window with a 5-year lag (e.g., citations for 2012 are references in U.S. patents issued in 2012 to articles published in 1997–2007). Detail may not add to total because of rounding.

SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; LexisNexis and U.S. Patent and Trademark Office patent data; Elsevier, Scopus abstract and citation database (www.scopus.com).

Science and Engineering Indicators 2016

Academic Patenting

The Bayh-Dole Act (Patent and Trademark Act Amendments of 1980) gave colleges and universities a common legal framework for claiming ownership of income streams from patented discoveries that resulted from their federally funded research. Other countries implemented policies similar to the Bayh-Dole Act by the early 2000s, giving their academic institutions (rather than inventors or the government) ownership of patents resulting from government-funded research (Geuna and Rossi 2011). To facilitate the conversion of new knowledge produced in their laboratories to patent-protected public knowledge that potentially can be licensed by others or form the basis

for a startup firm, many U.S. research institutions established technology management/transfer offices (AUTM 2009).

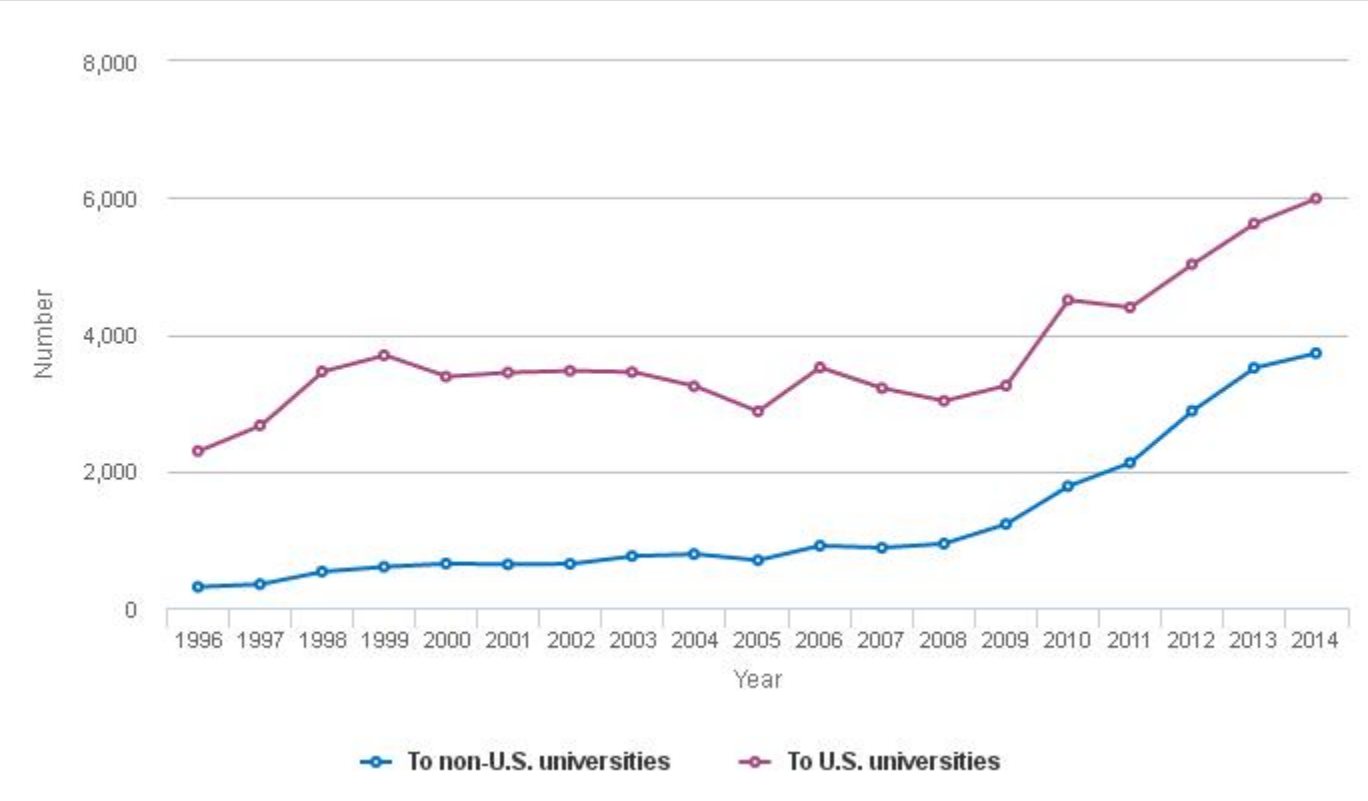
The following sections discuss overall trends in university patenting and related indicators through 2013 and 2014.

Trends and Patterns in Academic Patenting

The USPTO granted 9,716 patents to U.S. and foreign universities and colleges in 2014, 3.3% of USPTO patents granted to all U.S. and foreign inventors (Figure 5-37, Appendix Table 5-63). U.S. universities and colleges were granted 5,990 USPTO patents, with foreign universities receiving 3,726 patents. Patenting by both U.S. and foreign academic institutions has increased markedly since 2007. Although the number of U.S. academic patents continued to grow through 2014, the U.S. university and college share of all USPTO patents held constant around 2.0%. The share of U.S. patents from non-U.S universities increased from 0.3% in 1996 to 1.3% in 2014 (Figure 5-37, Appendix Table 5-63).

Figure 5-37

USPTO patents granted to U.S. and non-U.S. academic institutions: 1996–2014



USPTO = U.S. Patent and Trademark Office.

NOTE: Patents are credited on a fractional-count basis (i.e., for articles with collaborating institutions, each institutions receives fractional credit on the basis of the proportion of its participating institutions).

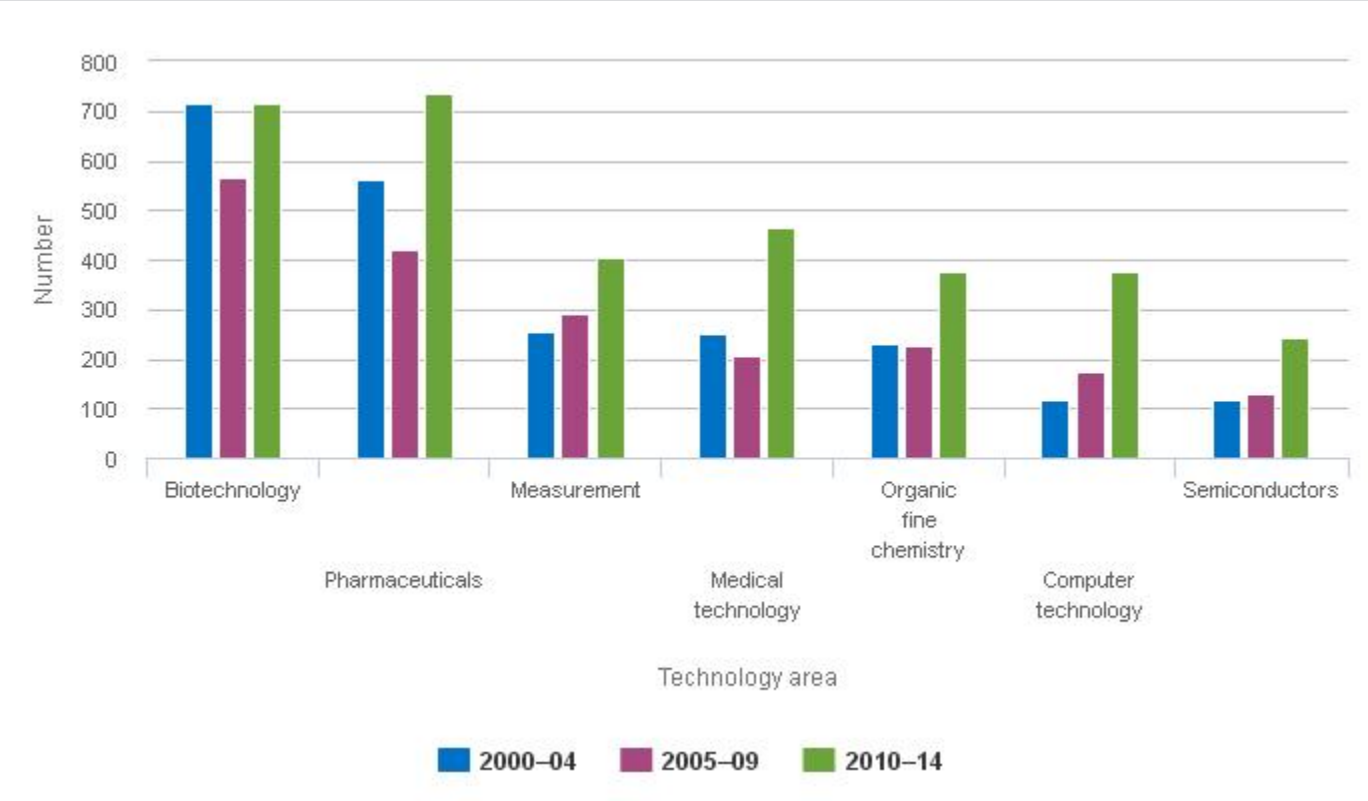
SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; U.S. Patent and Trademark data.

Science and Engineering Indicators 2016

Patenting data in *Science and Engineering Indicators 2016* are presented in 35 technical fields classified by the international patent classification used by the World Intellectual Property Organization (Appendix Table 5-67). Biotechnology patents accounted for the largest share (18.2%) of U.S. university patents between 1996 and 2014, followed by pharmaceuticals (15.1%) and measurement (7.8%) (Appendix Table 5-67). Biotechnology has been the largest technology area for U.S. academic patenting across the entire time period. Both biotechnology and pharmaceuticals, the next-largest technology area, had a declining number of patents between 2005 and 2009, but both have grown since 2010 (Figure 5-38). Biotechnology, medical technology, and organic fine chemistry share the rebounding pattern of pharmaceuticals since 2009. Computer technology and semiconductor patents rose across all three 5-year periods.

Figure 5-38

U.S. academic patents, by technology area: Selected 5-year averages, 2000–14



SOURCES: National Science Foundation, National Center for Science and Engineering Statistics; SRI International; Science-Metrix; LexisNexis and U.S. Patent and Trademark Office patent data; Elsevier, Scopus abstract and citation database (www.scopus.com). See appendix table 5-67.

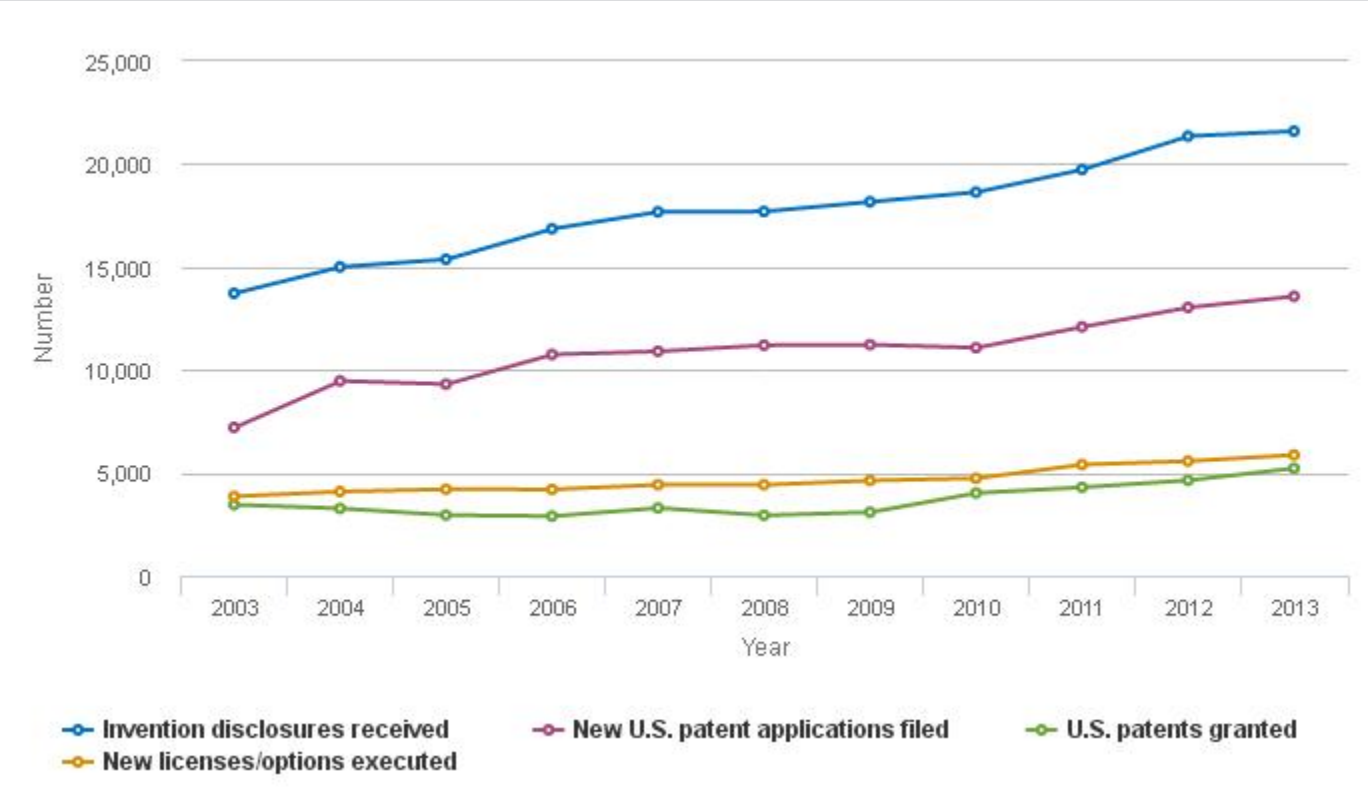
Science and Engineering Indicators 2016

Commercialization of U.S. Academic Patents

Universities commercialize their intellectual property by granting licenses to commercial firms and supporting startup firms formed by their faculty. Data from the Association of University Technology Managers (AUTM) indicate continuing growth in a number of such patent-related activities. Invention disclosures filed with university technology management/transfer offices describe prospective inventions and are submitted before a patent application is filed. These grew from 13,718 in 2003 to 21,596 in 2013 (notwithstanding small shifts in the number of institutions responding to the AUTM survey over the same period) (Figure 5-39). Likewise, new U.S. patent applications filed by AUTM university respondents also increased, nearly doubling from 7,203 in 2003 to 13,573 in 2013. U.S. patents awarded to AUTM respondents stayed flat between 2003 and 2009, rising to reach 5,220 in 2013 (see Appendix Table 5-68).

Figure 5-39

U.S. university patenting activities: 2003–13



SOURCE: Association of University Technology Managers (AUTM), AUTM Licensing Surveys: 2003–13. See appendix table 5-68.

Science and Engineering Indicators 2016

The top 201 patenting universities received 99% of the total patents granted to U.S. universities between 1996 and 2014 (Appendix Table 5-63). Among these institutions, 20 accounted for more than 50% of all patents granted to U.S. universities. (Some of these were multicampus systems, like the University of California and the University of Texas.) The University of California system received 10.2% of all U.S. patents granted to U.S. universities over the period, followed by Harvard, with 4.6%, and the Massachusetts Institute of Technology, with 4.2%.

AUTM data also provide counts of new startups formed and of operational startups still operating. The number of new startup companies formed continued to rise through the period from 2001 to 2013, reaching 759 in 2013. The number of past startups still operating was 3,948 in 2013 (Appendix Table 5-68). Licenses and options that generated revenues also increased over the period. Active licenses increased steadily from 18,845 in 2001 to 37,445 in 2013.

Although the maximization of royalty income is not the dominant objective of university technology management offices (Thursby, Jensen, and Thursby 2001), the 162 institutions that responded to the AUTM survey reported a total of $1.8 billion in net royalties from their patent holdings in 2013. This amount has grown from $754 million dollars in 2001 (Appendix Table 5-68).

Conclusion

The nation's universities and colleges play a key role in U.S. R&D by providing the following services:

- Educating and training S&E students in research practices and other advanced skills
- Performing a large share of the nation's basic research
- Building and operating world-class research facilities and supporting the national research cyberinfrastructure
- Producing intellectual output through published research articles and patents

Over the past several decades, academic expenditures on R&D have continued to increase, with slowing growth trends in recent years and no growth from 2013 to 2014. Although the federal government has long provided the majority of funding for academic S&E R&D, its share of total academic R&D funding has declined in recent years while the share paid for universities and colleges has increased. Other important sources of academic R&D funding are state and local governments, businesses, and nonprofit organizations.

Academic R&D expenditures have long been concentrated in a relatively small number of universities. For over 20 years, fewer than 12 schools each year have received about one-fifth of total academic R&D funding, about 20 schools have received close to one-third of this funding, and about 100 have received four-fifths of the total. (The identities of the universities in each group have varied over time.)

For decades, more than half of all academic R&D spending has been in the broad field of life sciences. Since the mid-1990s, about one-third of all U.S.-trained, academically employed S&E doctorate holders received their degree in life sciences. (In 2013, about 60% of their foreign-trained counterparts had doctorates in life sciences.) The dominance of life sciences is also seen in physical infrastructure, where two subfields of life sciences—biological sciences and biomedical sciences—account for the bulk of growth in research space and where the largest share of new university research construction has been undertaken to advance health and clinical sciences.

Academic R&D is increasingly collaborative and less field specific. R&D funds passed through universities to other universities or to nonacademic institutions have grown substantially over the past 15 years. There has also been growth in recent years in spending that cannot be classified within a single field. Spending on engineering R&D has outpaced growth in spending in the sciences in the aggregate.

The structure of academic employment of S&E doctorate holders within the nation's universities and colleges has undergone substantial changes over the past 20–30 years. Although full-time faculty positions in the professoriate continue to be the norm in academic employment, S&E doctorate holders are increasingly employed in part-time and nontenured positions. Since 1995, there has been a decrease in the percentage of doctorate holders with tenured positions even as the academic doctoral workforce has aged. The share of academic researchers receiving federal support, including early career S&E faculty, has declined since 1991. Funding success rates have declined at both NIH and NSF over the past decade. Shoring up support for early career academic faculty has received increasing policy attention in recent years.

Higher education has also experienced notable changes in demographic diversity. In particular, the share of academic doctoral positions held by white, male, native-born citizens has declined. Women represent a growing share of academic doctoral employment in S&E, as do the foreign born and foreign trained. The share of Asians or Pacific Islanders employed in the S&E academic doctoral workforce has grown dramatically over the past three decades, while the shares held by blacks, Hispanics, and American Indians or Alaska Natives have grown much more slowly; these latter groups remain underrepresented in the academic doctoral workforce.

Chapter 5. **Academic Research and Development**

There have been further shifts in the degree to which the academic doctoral workforce is focused on research activities versus teaching. Among full-time doctoral S&E faculty, there was a shift in priority from teaching to research from 1973 to 2003; since 2003, however, the shares of faculty who primarily teach and those who primarily conduct research have remained relatively stable. Of those in the academic doctoral workforce reporting research as their primary activity, two-thirds are employed at the nation's most research-intensive academic institutions. Those who primarily teach are more evenly distributed across academia.

The bibliometric data described in this chapter show U.S. research maintaining global strength in the life sciences, as demonstrated by publication output and citations. This focus is accompanied by academic patenting in biotechnology and pharmaceuticals. Overall, the United States remains the most influential individual nation in its contribution to S&E publications. This influence is based both on the overall size of its contribution and the relative impact, as measured by citations by S&E publications. In terms of S&E research quantity, but not impact, China is now on a par with the United States. Taking measures of quantity and impact into account, the United States maintains overall preeminence in S&E research output. However, growth trends in S&E publications reflect the spread of overall economic and social development across the world. Building from a higher base, the developed world, including the United States, the EU, and Japan, is growing more slowly in S&E publications.

In addition to the increased performance in the developing world, individual nations within the EU and the developed world have emerged as centers of research excellence, as demonstrated by their citations. Unlike the competition for finite resources, the creation of S&E publications adds to the knowledge base available for use worldwide, as international collaboration and citations attest. International research collaboration is increasing, reflecting traditional cross-country ties as well as new ones that stem from growing capabilities in the developing world. This international collaboration and the accompanying rise in international citations indicate that S&E knowledge is flowing with increasing ease across the world.

Glossary

Average of relative citations (ARC): The ARC is a citation measure normalized across fields of science and document types to correct for differences in the frequency and timing of citations. It is constructed from a relative citation that divides each publication's citation count by the average citation count of all publications in that subfield and document type in that same year. Then, for a given area of geography or sector, these relative citations for each publication are then averaged to create an ARC. An ARC value greater than 1.00 has more citations than average for subfield and year; an ARC value less than 1.00 has fewer citations.

Doctoral academic S&E workforce: Includes those with a research doctorate in science, engineering, or health who are employed in 2- or 4-year colleges or universities, including medical schools and university research institutes, in the following positions: full and associate professors (referred to as *senior faculty*); assistant professors (referred to as *junior faculty*); postdoctorates (postdocs); other full-time positions, such as instructors, lecturers, adjunct faculty, research associates, and administrators; and part-time positions of all kinds. Unless otherwise specified, these individuals earned their doctorate at a U.S. university or college.

European Union (EU): As of September 2015, the EU comprised 28 member nations: Austria, Belgium, Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, the Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, and the United Kingdom. Unless otherwise noted, Organisation for Economic Co-operation and Development data on the EU include all of these 28 members.

Federally funded research and development center (FFRDC): R&D organization exclusively or substantially financed by the federal government, either to meet particular R&D objectives or, in some instances, to provide major facilities at universities for research and associated training purposes. Each FFRDC is administered by an industrial firm, a university, or a nonprofit institution.

Fractional counting: Method of counting S&E publications in which credit for coauthored publications is divided among the collaborating institutions or countries based on the proportion of their participating authors.

Index of highly cited articles: A country's share of the top 1% most-cited S&E publications divided by the country's share of all relevant S&E publications. An index greater than 1.00 means that a country has a disproportionately higher share in highly cited publications; an index less than 1.00 means a lower share.

Index of international collaboration: A country's share of another country's internationally coauthored publications divided by the other country's share of all internationally coauthored publications. An index greater than 1.00 means that a country pair has a stronger-than-expected tendency to collaborate; an index less than 1.00 means a weaker-than-expected tendency to collaborate.

Net assignable square feet (NASF): Unit for measuring research space. NASF is the sum of all areas on all floors of a building assigned to, or available to be assigned to, an occupant for a specific use, such as research or instruction. NASF is measured from the inside face of walls.

Relative citation index: A country's share of another country's cited S&E publications divided by the other country's share of all cited S&E publications. An index of greater than 1.00 means that the country has a higher-than-expected tendency to cite the other country's S&E literature; an index less than 1.00 means a lower-than-expected tendency to cite the other country.

Research space: The budgeted and accounted for space used for sponsored R&D activities at academic institutions. Research space is the net assignable square feet of space in buildings within which research activities take place. Research facilities are located within buildings. A building is a roofed structure for permanent or temporary shelter of persons, animals, plants, materials, or equipment. Structures are included as research space if they are (1) attached to a foundation; (2) roofed; (3) serviced by a utility, exclusive of lighting; and (4) a source of significant maintenance and repair activities.

Underrepresented minority: Race and ethnic groups, including blacks, Hispanics, and American Indians or Alaska Natives, that are considered to be underrepresented in academic institutions.

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