

Science and Technology News, 2017

The following were some of the more newsworthy developments in science and technology in the past year.

Time Crystals

Crystals are typically a material with a special structure—the constituent atoms form a pattern that repeats throughout the material. In the Mar. 9, 2017, issue of *Nature*, two separate teams based at Harvard and the Univ. of Maryland reported success in creating a different sort of crystal: “time crystals,” whose constituents keep returning to the same configuration at regular intervals—that is, they display repetition across time. Time crystals represent a new state of matter, first proposed in 2012: a “nonequilibrium” state, involving a dynamic, quickly changing system. The two research teams used different approaches. One assembled a short chain of 10 ytterbium ions whose spins were “entangled”—or connected by quantum effects—with each other. When a laser was used on the ytterbium ions, they began flipping their spins at precise intervals. The other team used a diamond containing about 1 mil atomic-scale impurities, each having a spin. Microwave pulses were used to nudge the entangled impurity spins into periodically flipping. Just as a solid crystal is resistant to changes in its spatial structure, these time crystals showed a robust tendency to maintain their time periodicity.

Time crystals hold promise for practical application in such areas as quantum computing and precision measurement.

New Dinosaur Family Tree

When the dinosaur family tree was organized more than a century ago, information on dinosaur characteristics was more limited. Scientists focused on hip structure, dividing animals into two primary groups. Ornithischia contained “bird-hipped,” mostly herbivorous dinosaurs such as *Triceratops* and *Stegosaurus*. Saurischia contained “lizard-hipped” dinosaurs, including both meat-eating theropods, such as *Tyrannosaurus rex*, and giant long-tailed, long-necked plant-eating sauropods, such as *Brontosaurus*. As new species were discovered, they were patched into the tree, but not always easily. In particular, opinions differed as to where to put the carnivorous herrerasaurs. (Modern birds are descendants of “lizard-hipped” dinosaurs, further confusing classifications.)

British researchers in the Mar. 23, 2017, issue of *Nature* challenged the old classification of dinosaurs. The new study examined fossils of 74 species representing a variety of dinosaur types, looking for similarities and differences in 450 anatomical features. A computer program determined that the family tree that best fit the data made *T. rex* and *Stegosaurus* closer cousins: the carnivorous theropods and the ornithischia became subgroups of a new category: Ornithoscelida. A second heading, retaining the name Saurischia, included both herbivorous sauropods and meat-eating herrerasaurs. The new organization raises the possibility that dinosaurs may have originated around 247 mil years ago in what is now North America, rather than farther south as previously believed.

Artificial Womb

At present, only about half of infants born extremely prematurely—23-24 weeks into gestation—survive. Of those who do, about 90% suffer severe complications. Getting more time to develop in an “artificial womb” could radically increase chances for a healthy life, but creating one poses daunting challenges. It would need to ward off contamination and ensure that blood circulation, oxygen supply, and other basic needs were safely met. In the past, researchers’ best efforts found only partial, exceedingly short-lived success when tested on animals. But researchers from the Children’s Hospital of Philadelphia reported in *Nature Communications* Apr. 25, 2017, their success with a system that held premature lambs in “biobags” containing artificial amniotic fluid. The preterm lambs corresponded to human fetuses at about 23 weeks of gestation, and they were successfully incubated in infection-free artificial wombs for up to four weeks. Instead of a potentially stress-inducing external pump, the system relied on the animals’ own hearts to drive blood circulation. In June, Australian and Japanese researchers reported in the *American Journal of Obstetrics and Gynecology* that they had used a similar system to incubate lamb fetuses for a week.

Ancient Egyptian DNA, at Last

Ancient Egyptians left behind tombs, artifacts, and writing that provide a detailed picture of their culture. Learning about

their genetic history has been much harder, even though there is an abundance of ancient mummies to study. The region’s climate, humid conditions inside many tombs, and the strong chemicals involved in mummification have made it extremely difficult for usable DNA to survive. A small number of DNA analyses had been reported but were widely believed to have been contaminated by modern genetic material. Finally, in May 2017 an international team published in *Nature Communications* a successful analysis of DNA samples from 151 individuals who were buried between 1380 BCE and 425 CE in Abusir el-Meleq, south of Cairo. The researchers used sophisticated techniques to obtain mummies’ genetic materials and distinguish between ancient DNA and modern contaminants. Just three of the mummies studied yielded DNA genomes from the nuclei of body cells (particularly detailed genomes inherited from both parents). But 90 more individuals yielded usable samples of mitochondrial DNA, which passes from mother to child. Analysis showed the ancient Egyptians to be more closely related to peoples of the eastern Mediterranean/Middle East region, while Egyptians of today tend to derive roughly 8% more of their DNA from Africans south of the Sahara Desert.

New Light on Human Evolution

For decades, scientists believed the origin of *Homo sapiens*, the species to which modern humans belong, dated to East Africa roughly 200,000 years ago. Specifically, Ethiopia supplied the oldest known fossil specimens, dated at 160,000 years and 195,000 years in age. But findings by a multinational research team published in *Nature* June 7, 2017, painted a radically different picture: *Homo sapiens* may have originated far earlier and throughout the continent of Africa.

The researchers reported that remains uncovered at Jebel Irhoud in Morocco were dated to approximately 315,000 years ago and appeared to be closer to modern humans than to any other known human-type species, such as the Neanderthals. The fossils showed a mix of primitive and more recent anatomical features—for example, a face rather similar to ours with a more elongated skull (possibly indicating a difference in brain organization). The fossils may support speculation that the modern brain developed in *Homo sapiens* and not in some predecessor species.

Other scientists were more cautious about accepting the finds as *Homo sapiens*, and rather saw them as evidence that multiple different hominin species existed in Africa some 300,000 years ago. Providing further evidence, a report published online in *eLife* in May 2017 provided an age for fossils of the extinct species *Homo naledi* that were found in South Africa and originally described in 2015. The paper dated those remains to between 236,000 and 335,000 years ago.

Juno’s Jupiter & Cassini’s Saturn

NASA’s robotic spacecraft *Juno* continued to produce remarkable images and valuable scientific findings as it orbited the solar system’s biggest planet in 2017. Among the discoveries: both of Jupiter’s poles are covered with immense swirling storms, the planet’s magnetic field is stronger and more irregular than expected, and its auroras don’t seem to work like Earth’s. *Juno* was scheduled to deorbit and burn up in Jupiter’s atmosphere in early 2018.

Meanwhile, additional discoveries came from an older spacecraft, *Cassini*, which since 2004 had been exploring another gas giant, Saturn, along with some of Saturn’s moons and its spectacular rings. *Cassini* data showed that the moon Enceladus had, according to one project scientist, “almost all the ingredients to support life as we know it”—an ocean of liquid water under its icy crust, the right chemistry, and energy sources. (Astronomical observations suggest that similar conditions may exist on Jupiter’s moon Europa; there is also evidence for subsurface liquids on a few other moons around Jupiter and Saturn.) *Cassini*’s mission—a joint project of NASA, the European Space Agency, and Italy’s Agenzia Spaziale Italiana—ended Sept. 15, 2017, with the spacecraft’s disintegration in Saturn’s atmosphere, eliminating any chance of the spacecraft crashing into Enceladus or another moon, Titan, and contaminating life that might exist there.

TECHNOLOGY

Computer Milestones

- 1623:** German mathematician Wilhelm Schickard developed the first mechanical calculator, capable of adding, subtracting, multiplying, and dividing.
- 1642:** French mathematician Blaise Pascal built the first of more than four dozen copies of an adding and subtracting machine that he invented.
- 1801:** French inventor Joseph Marie Jacquard demonstrated a new control system for looms. He “programmed” the loom, communicating desired weaving operations to the machine via patterns of holes in paper cards.
- 1833-71:** British mathematician and scientist Charles Babbage used the Jacquard punch-card system in his design for a sophisticated, programmable “Analytical Engine” that foreshadowed basic features of today’s computers. Babbage’s concept was beyond the capabilities of the technology of his time, and the machine remained unfinished at his death in 1871.
- 1889:** American engineer Herman Hollerith patented an electromechanical punch-card tabulating system that facilitated the handling of large amounts of statistical data and quickly found use in censuses in the U.S. and other countries.
- 1911:** Hollerith’s Tabulating Machine Company merged with two other enterprises to form the Computing-Tabulating-Recording Company, which was renamed the International Business Machines Corporation (IBM) in 1924.
- 1941:** German engineer Konrad Zuse completed the Z3, the first fully functional digital computer to be controlled by a program; the Z3 was not electronic—it was based on electrical switches called relays.
- 1942:** Iowa State Coll. physicist John Vincent Atanasoff and assistant Clifford Berry completed a working model of the first fully electronic computer using vacuum tubes, which could operate much more quickly than relays; the rudimentary machine was not programmable.
- 1943:** IBM and Harvard professor Howard Aiken completed the first large-scale automatic digital computer, the Mark I, a relay-based machine 55 ft long and 8 ft high. British scientists built the Colossus, an electronic computer for breaking German codes during World War II.
- 1946:** ENIAC (Electronic Numerical Integrator and Computer), a 30-ton room-sized electronic computer with more than 18,000 vacuum tubes, was completed by physicist John Mauchly and engineer J. Presper Eckert at the Univ. of Pennsylvania for the U.S. Army. ENIAC could be programmed to do different tasks, but cables had to be plugged in, and switches had to be set by hand.
- 1951:** Eckert and Mauchly’s UNIVAC (Universal Automatic Computer) became the first commercially available computer in the U.S. Its first customer was the Census Bureau. CBS-TV used a UNIVAC in 1952 to predict presidential election results.
- 1959:** COBOL, a computer programming language designed for business use, first appeared, based on programming language innovations of American mathematician Grace Hopper.
- 1967:** American computer pioneer Doug Engelbart applied for a patent on the mouse.
- 1969-71:** The powerful Unix operating system was developed at Bell Laboratories; later versions became widely used on large computers and formed the basis for the Macintosh OS X operating system.
- 1971:** Intel released the 4004, the first commercial microprocessor (an entire computer processing unit on a chip).
- 1973:** The Alto computer, developed at Xerox’s Palo Alto Research Center, became operational, implementing many features of modern commercial personal computers, including a graphical user interface (GUI) featuring windows, icons, and pointers that could be manipulated by a mouse.
- 1975:** The first widely marketed personal computer (PC), the MITS Altair 8800, was introduced in kit form, with no keyboard, video display, or printer, for under \$400. Microsoft was founded by Americans Bill Gates and Paul Allen.
- 1976:** The first word-processing program for personal computers, Electric Pencil, was written. Apple Computer Company was founded by Americans Steven Jobs and Stephen Wozniak.
- 1977:** Apple introduced the Apple II; capable of displaying text and graphics in color, the machine enjoyed phenomenal success.
- 1981:** IBM unveiled its Personal Computer (IBM 5150), which used an operating system from Microsoft known as MS-DOS (Disk Operating System).
- 1984:** Apple introduced the first Macintosh. The easy-to-use Macintosh came with a proprietary operating system and was the first popular computer to have a GUI and a mouse.
- 1990:** Microsoft released Windows 3.0, the first workable version of its own GUI.
- 1991:** The Unix-like Linux operating system was invented by Helsinki Univ. student Linus Torvalds and made available for free.
- 1996:** The Palm Pilot, the first widely successful handheld computer and personal information manager, arrived.
- 1997:** The IBM computer Deep Blue beat Russian world chess champion Garry Kasparov in a 6-game match, 2-1, with 3 draws.
- 2001:** Apple introduced the Unix-based operating system OS X for the Macintosh.
- 2002:** The total number of personal computers, including desktop and laptop machines of all types, shipped by manufacturers since 1975 reached 1 bil.
- 2006:** Apple began using Intel microprocessors instead of the IBM PowerPC in its Macintosh computers.
- 2007:** Amazon launched the Kindle, a hardware/software system for displaying books electronically; the product line later included tablet computers.
- 2008:** Google released the Linux-based Android operating system for mobile devices.
- 2010:** Apple released the iPad tablet computer and sold more than 3 mil devices in the first 80 days.
- 2012:** Microsoft released Windows 8, featuring enhanced support for touchscreens and an interface with a grid of tiles displaying actively updated content and apps.
- 2015:** Microsoft released Windows 10, promising faster startup and improved security, along with features like a personal digital assistant and a new web browser, Microsoft Edge.
- 2016:** Univ. of Maryland scientists developed the first reprogrammable quantum computer; it used lasers to manipulate its five qubits, or bits of quantum information.

Nations With the Most Personal Computers in Use, 2016

Source: Computer Industry Almanac, year-end 2016

Rank	Nation	PCs in use (mil)	% of world total	Rank	Nation	PCs in use (mil)	% of world total
1.	China	420.9	17.05%	10.	Italy	57.6	2.33%
2.	U.S.	380.2	15.41	11.	South Korea	49.9	2.02
3.	India	138.1	5.60	12.	Mexico	46.6	1.89
4.	Japan	119.4	4.84	13.	Spain	38.1	1.55
5.	Russia	92.9	3.76	14.	Canada	37.0	1.50
6.	Germany	84.8	3.44	15.	Indonesia	27.8	1.13
7.	Brazil	72.7	2.94		Other countries	770.1	31.20
8.	United Kingdom	66.1	2.68		Worldwide	2,468	100.00
9.	France	65.9	2.67				

Nations With Highest Percentage of Population Using the Internet, 2000-16

Source: © International Telecommunication Union; ranked by 2016 figures

Rank	Nation	2000	2005	2010	2011	2012	2013	2014	2015	2016
1.	Iceland	44.47%	87.00%	93.39%	94.82%	96.21%	96.55%	98.16%	98.20%	98.24%
2.	Liechtenstein	36.52	63.37	80.00	85.00	89.41	93.80	95.21	96.64	98.09
3.	Bahrain	6.15	21.30	55.00	77.00	88.00	90.00	90.50	93.48	98.00
4.	Andorra	10.54	37.61	81.00	81.00	86.43	94.00	95.90	96.91	97.93
5.	Luxembourg	22.89	70.00	90.62	90.03	91.95	93.78	94.67	97.33	97.49
6.	Norway	52.00	81.99	93.39	93.49	94.65	95.05	96.30	96.81	97.30
7.	Denmark	39.17	82.74	88.72	89.81	92.26	94.63	95.99	96.33	96.97
8.	Monaco	42.18	55.46	75.00	80.30	87.00	90.70	92.40	93.36	95.21
9.	United Kingdom	26.82	70.00	85.00	85.38	87.48	89.84	91.61	92.00	94.78
10.	Qatar	4.86	24.73	69.00	69.00	69.30	85.30	91.49	92.88	94.29
11.	South Korea	44.70	73.50	83.70	83.76	84.07	84.77	87.56	89.65	92.72
12.	Japan	29.99	66.92	78.21	79.05	79.50	88.22	89.11	91.06	92.00
13.	Sweden	45.69	84.83	90.00	92.77	93.18	94.78	92.52	90.61	91.51
14.	United Arab Emirates	23.63	40.00	68.00	78.00	85.00	88.00	90.40	90.50	90.60
15.	Netherlands	43.98	81.00	90.72	91.42	92.86	93.96	91.67	91.72	90.41
16.	Canada	51.30	71.66	80.30	83.00	83.00	85.80	87.12	88.47	89.84
17.	Germany	30.22	68.71	82.00	81.27	82.35	84.17	86.19	87.59	89.65
18.	Switzerland	47.10	70.10	83.90	85.19	85.20	86.34	87.40	87.48	89.41
19.	New Zealand	47.38	62.72	80.46	81.23	81.64	82.78	85.50	88.22	88.47
20.	Australia	46.76	63.00	76.00	79.49	79.00	83.45	84.00	84.56	88.24

Nations With the Most Internet Users, 2016

Source: Computer Industry Almanac, year-end 2016

Rank	Nation	Internet users (mil)	% of worldwide users	Rank	Nation	Internet users (mil)	% of worldwide users
1.	China	657.6	19.87%	10.	France	54.7	1.65%
2.	India	326.4	9.86	11.	Italy	50.8	1.54
3.	United States	289.5	8.75	12.	Mexico	50.8	1.53
4.	Brazil	123.0	3.72	13.	Turkey	43.9	1.33
5.	Japan	111.9	3.38	14.	South Korea	43.2	1.31
6.	Russia	90.0	2.72	15.	Egypt	41.0	1.24
7.	Indonesia	87.3	2.64				
8.	Germany	70.7	2.14		Other countries	1,213.0	36.67
9.	United Kingdom	54.9	1.66		World total	3,309.0	100.00

Most-Visited World Websites, 2017

Source: comScore, Inc.

Some websites represent an aggregation of commonly owned domain names; examples of popular domains within a group added in parentheses by World Almanac editors.

Rank	Website	Visitors ¹	Rank	Website	Visitors ¹
1.	Google sites (YouTube, Blogger)	1,178,803	11.	Wikimedia Foundation sites (Wikipedia)	317,769
2.	Microsoft sites (Bing, Xbox Live)	892,373	12.	iqiyi sites	241,739
3.	Facebook (Instagram)	723,595	13.	SINA Corp.	221,380
4.	Yahoo! sites (Flickr, Tumblr)	476,232	14.	Apple Inc. (iTunes)	219,488
5.	Qihoo.com sites	462,692	15.	NetEase.com Inc.	199,415
6.	Sohu.com Inc.	408,470	16.	CBS Interactive (CNET, ZDNet)	195,449
7.	Alibaba.com Corp.	394,969	17.	BitTorrent Network	183,910
8.	Baidu.com Inc.	389,925	18.	Dropbox sites	179,311
9.	Tencent Inc. (QQ)	371,854	19.	eBay	175,907
10.	Amazon sites (Zappos, Audible, IMDb)	340,849	20.	360buy Corp.	175,299

(1) Number of persons age 15 or older, in thousands, who visited a website from a desktop computer in any location at least once in June 2017.

Top Web Browsers Worldwide, 2009-17

Source: StatCounter Global Stats, gs.statcounter.com

Browser	% of browser market				
	2009	2012	2014	2016	2017
Chrome	3.01%	33.81%	48.69%	62.38%	63.48%
Firefox	30.50	23.73	19.25	15.43	13.82
Internet Explorer	60.11	32.04	23.52	10.73	9.03
Safari	3.02	7.12	4.89	4.59	5.04
Edge	—	—	—	3.04	3.95
Opera	2.64	1.72	1.45	1.78	2.25

— = Not available. **Note:** Percent of desktop computer users accessing the web via a particular browser, for July of year shown.

Top Operating Systems Worldwide, 2009-17

Source: StatCounter Global Stats, gs.statcounter.com

Browser	% of OS market				
	2009	2012	2014	2016	2017
Android	0.02%	3.29%	16.38%	32.48%	41.24%
Windows	93.85	79.14	59.37	42.56	35.24
iOS	0.36	5.16	11.62	12.25	13.20
OS X	4.07	6.16	5.65	4.81	4.66
Unknown	0.37	0.55	1.35	4.00	2.99
Linux	0.76	0.75	1.19	0.96	0.77

Note: Percent of users accessing the web with a particular operating system (OS), for July of year shown. Includes desktop, tablet, and mobile devices' operating systems. In 2012, SymbianOS accounted for 1.49%, and Series 40 for 1.63%. In 2014, Series 40 accounted for 2.02%.

U.S. Internet Use by Selected Characteristics, 2013-16

Source: Pew Research Center

	% who are users			% who are users			% who are users	
	2013	2016		2013	2016		2013	2016
All adults	84%	88%						
Gender			Race/ethnicity			Annual household income		
Male	84	89	White, non-Hispanic. . .	85%	88%	Less than \$30,000 . . .	72%	79%
Female	84	86	Black, non-Hispanic. . .	79	85	\$30,000-\$49,999 . . .	86	90
Age			Hispanic	80	88	\$50,000-\$74,999 . . .	93	95
18-29	97	99				\$75,000 or more	97	98
30-49	92	96	Education			Geography		
50-64	81	87	No high school diploma	54	68	Urban	86	89
65+	56	64	High school graduate	75	81	Suburban	85	90
			Some college	92	94	Rural	78	81
			College graduate	96	98			

Note: Percent of U.S. adults, age 18 and over, who use the internet, email, or access the internet via a mobile device. Data for each year based on a pooled analysis of all surveys conducted during that year. Hispanic data includes only those surveys incorporating Spanish-language interviews.

Most-Visited U.S. Websites, 2017

Source: comScore, Inc.; comScore qSearch

Some websites represent an aggregation of commonly owned domain names; examples of popular domains within a group as of June 2017 added in parentheses by World Almanac editors.

All U.S. Sites			Email			
Rank	Website	Visitors ¹	Rank	Website	Visitors ¹	
1.	Google sites (YouTube, Blogger)	241,433	1.	Google Gmail	133,506	
2.	Facebook (Instagram)	203,915	2.	Yahoo! Mail	69,365	
3.	Yahoo! sites (Flickr, Rivals.com, Tumblr)	185,557	3.	Outlook (Outlook.com)	32,287	
4.	Microsoft sites (Bing, Xbox Live)	183,814	4.	Outlook Web (primarily Outlook.office.com) . . .	13,598	
5.	Amazon sites	180,032	5.	AOL Email	11,620	
6.	Comcast NBCUniversal	155,300	Social Networking Sites			
7.	AOL Inc. (Moviefone, Huffington Post)	154,532	Rank	Website	Visitors¹	
8.	CBS Interactive (CNET, ZDNet)	148,043	1.	Facebook and Messenger	201,987	
9.	Apple Inc. (iTunes)	140,939	2.	Instagram	121,460	
10.	Turner Digital	131,159	3.	Twitter	110,291	
11.	Time Inc. network	127,272	4.	LinkedIn	103,118	
12.	The Weather Company	110,486	5.	Snapchat	95,298	
13.	Twitter	110,291	6.	Pinterest	86,167	
14.	USA Today network	109,915	7.	Google+	46,169	
15.	Hearst	104,290	8.	Reddit	42,382	
			9.	Tumblr	35,409	
			10.	Goodreads	15,176	
Blog Sites			Video Sites			
Rank	Website	Visitors¹	Rank	Website²	Visitors¹	
1.	WordPress.com	59,301	1.	Google sites (YouTube)	142,607	
2.	Blogger	38,017	2.	Facebook	70,336	
3.	Outbrain.com	24,238	3.	Yahoo! sites (Flickr)	46,350	
4.	Eater sites	16,353	4.	Comcast NBCUniversal	45,512	
5.	Twentytwowords.com	12,640	5.	Microsoft sites	41,526	
Search and Navigation			6.	CBS Interactive	40,069	
Rank	Website	Searches (mil)	% of searches	7.	BroadbandTV	38,421
1.	Google sites	9,675	63.1%	8.	Vimeo	36,197
2.	Microsoft sites (Bing)	3,533	23.0	9.	Vevo	35,579
3.	Yahoo! sites	1,810	11.8	10.	Warner Music	34,966
4.	Ask Network	204	1.3			
5.	AOL Inc.	118	0.8			

Note: Search and navigation data are for desktop computer users only for searches from the properties' core search engines (as opposed to searches within, for example, YouTube or Gmail). (1) Number of persons age 2 and older, in thousands, who visited the media property (including website/apps) at least once from any U.S. location in June 2017. Mobile users under age 18 are not measured. (2) Excludes advertisement videos.

Most Popular U.S. Mobile Apps, 2017

Source: comScore, Inc.

Rank	App	Reach	Rank	App	Reach
1.	Facebook	75.7%	9.	Gmail	43.1%
2.	YouTube	67.2	10.	Pandora Radio	39.2
3.	Facebook Messenger	65.4	11.	Twitter	34.2
4.	Google Search	59.6	12.	Google Calendar	34.1
5.	Google Maps	56.4	13.	Apple Maps	29.6
6.	Google Play	49.0	14.	Apple Music ¹	29.0
7.	Instagram	46.8	15.	Amazon Mobile	27.7
8.	Snapchat	46.5			

Note: Reach is percentage of all U.S. smartphone mobile media users on iOS and Android platforms, age 18 or over, in June 2017. (1) All music activity within Apple's native music app, including streaming, radio, and users' downloaded music libraries.

ENVIRONMENT

U.S. Greenhouse Gas Emissions From Human Activities, 1990-2015

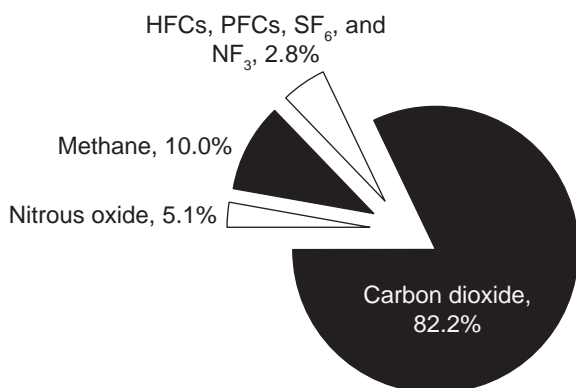
Source: U.S. Environmental Protection Agency

Gas and major source(s)	1990	2005	2011	2012	2013	2014	2015	% change, 1990-2015
Carbon dioxide (CO ₂)	5,123.0	6,131.8	5,569.5	5,362.1	5,514.0	5,565.5	5,411.4	5.6%
Fossil fuel combustion	4,740.3	5,746.9	5,227.1	5,024.6	5,156.5	5,202.3	5,049.8	6.5
Methane (CH ₄)	780.8	680.9	672.1	666.1	658.8	659.1	655.7	-16.0
Enteric fermentation	164.2	168.9	168.9	166.7	165.5	164.2	166.5	1.4
Natural gas systems ¹	194.1	159.7	154.5	156.2	159.2	162.5	162.4	-16.3
Landfills	179.6	134.3	119.0	120.8	116.7	116.6	115.7	-35.6
Manure management	37.2	56.3	63.0	65.6	63.3	62.9	66.3	78.2
Nitrous oxide (N ₂ O)	359.5	361.6	364.0	340.7	335.5	335.5	334.8	-6.9
Agricultural soil management	256.6	259.8	270.1	254.1	250.5	250.0	251.3	-2.1
Hydrofluorocarbons (HFCs), etc. ²	99.7	138.9	171.1	169.3	171.8	179.6	184.8	85.4
Total U.S. emissions	6,363.1	7,313.3	6,776.7	6,538.3	6,680.1	6,739.7	6,586.7	3.5
Net U.S. emissions³	5,543.5	6,582.3	6,027.6	5,784.5	5,917.1	5,978.3	5,827.7	5.1

Note: Emissions given in terms of equivalent emissions of carbon dioxide (CO₂), using units of million metric tons of carbon dioxide equivalent (MMT CO₂ eq.). (1) Digestive process of ruminant animals, such as cattle and sheep, producing methane as a byproduct. (2) Includes HFCs, PFCs (perfluorocarbons), SF₆ (sulfur hexafluoride), and NF₃ (nitrogen trifluoride). (3) Total emissions minus the net sum of all emissions (i.e., sources) of greenhouse gases to the atmosphere plus removals of CO₂ (i.e., sinks or negative emissions) from the atmosphere.

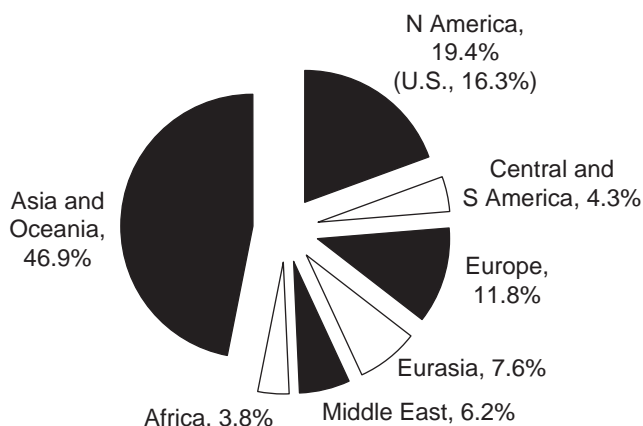
U.S. Greenhouse Gas Emissions, 2015

Source: U.S. Environmental Protection Agency



World Carbon Dioxide Emissions From the Use of Fossil Fuels, 2014

Source: U.S. Energy Information Administration



HFC = hydrofluorocarbon; PFC = perfluorocarbon; SF₆ = sulfur hexafluoride; NF₃ = nitrogen trifluoride. **Note:** Emissions sources are independently rounded; percentages may not add up to 100.

Top 20 Nations Producing Carbon Dioxide Emissions, 1980-2014

Source: Energy Information Administration, U.S. Dept. of Energy

(in million metric tons of carbon dioxide emitted from the consumption of energy; ranked by 2014 totals)

Country	1980	1990	2000	2005	2010	2013	2014	% change, 1980-2014	% change, 1990-2014
China	1,486	2,363	3,163	5,431	7,746	9,521	9,377	531.1%	296.8%
United States	4,680	4,981	5,829	6,026	5,642	5,455	5,508	17.7	10.6
India	263	529	874	1,093	1,614	1,822	1,895	621.9	258.0
Russia ¹	3,247	3,975	1,484	1,576	1,651	1,722	1,756	-45.9	-55.8
Japan	939	1,044	1,157	1,199	1,108	1,203	1,177	25.3	12.8
Germany ²	739	648	813	806	773	788	756	2.3	16.7
Iran	118	201	320	449	564	619	646	448.2	222.1
Korea, South	138	245	435	483	563	643	643	367.9	162.3
Canada	430	438	525	573	558	602	607	41.4	38.7
Saudi Arabia	177	208	291	401	511	550	576	225.4	176.4
Indonesia	85	158	264	314	411	514	548	546.0	247.1
Brazil	185	238	347	372	461	529	547	195.9	130.0
South Africa	225	324	386	425	461	473	472	109.5	45.8
United Kingdom	597	575	555	569	521	487	446	-25.3	-22.3
Mexico	239	300	379	395	437	437	436	82.6	45.2
Australia	191	261	335	373	387	382	378	97.5	44.7
Italy	371	410	442	463	416	359	343	-7.6	-16.5
France	482	364	399	411	378	356	329	-31.6	-9.5
Thailand	34	91	165	245	280	325	325	843.0	256.8
Turkey	75	152	231	250	292	305	317	322.4	108.9
World total³	18,401	21,731	23,643	27,841	31,157	33,707	33,733	83.3	55.2

(1) Numbers for 1980-90 are for the former Soviet Union. (2) Numbers for 1980-90 are for former West Germany. (3) Includes nations not listed.

Atmospheric Concentration of Carbon Dioxide, 1744-2016

Source: Carbon Dioxide Information Analysis Center, U.S. Dept. of Energy; Earth System Research Laboratory, Natl. Oceanic and Atmospheric Admin., U.S. Dept. of Commerce

Year ¹	CO ₂ in ppm	Year ¹	CO ₂ in ppm	Year ¹	CO ₂ in ppm	Year ¹	CO ₂ in ppm	Year ¹	CO ₂ in ppm
1744	277	1878	290	1960	317	2005	380	2012	394
1791	280	1903	295	1970	326	2008	386	2013	397
1816	284	1915	301	1980	339	2009	387	2014	399
1843	287	1927	306	1990	354	2010	390	2015	401
1869	289	1943	308	2000	370	2011	392	2016	404

ppm = Parts per million. (1) Measurements for 1744-1943 were derived from a 200-m-deep ice core sample drilled near Siple Station in Antarctica in 1983-84. Measurements for 1960-2016 were taken directly from the atmosphere at Mauna Loa Observatory in Hawaii.

Emissions of Principal Air Pollutants in the U.S., 1970-2016

Source: Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency; in million tons

Pollutant	1970	1975	1980	1985	1990	1995	2000	2005	2010	2016
Carbon monoxide	204.0	188.4	185.4	176.8	154.2	126.8	114.5	88.5	73.8	59.0
Nitrogen oxides ¹	26.9	26.4	27.1	25.8	25.5	25.0	22.6	20.4	14.8	10.5
Particulate matter ²										
PM10	13.0	7.6	7.0	41.3	27.8	25.8	23.7	21.3	20.8	24.4
PM2.5	NA	NA	NA	NA	7.6	6.9	7.3	5.6	6.0	6.2
Sulfur dioxide	31.2	28.0	25.9	23.3	23.1	18.6	16.3	14.5	7.7	2.7
Volatile org. compounds ¹	34.7	30.8	31.1	27.4	24.1	22.0	17.5	17.8	17.8	15.9
Ammonia	NA	NA	NA	NA	4.3	4.7	4.9	3.9	4.3	3.9
Total³	309.8	281.2	276.5	294.6	266.6	229.8	206.8	172.0	145.2	122.6

NA = Not available. (1) Ozone, a major air pollutant and the primary constituent of smog, is not emitted directly to the air but is formed by sunlight acting on emissions of nitrogen oxides and volatile organic compounds. (2) PM10 = particulates 10 microns or smaller in diameter. PM2.5 = particulates 2.5 microns or smaller in diameter. (3) Totals are rounded, as are components of totals.

Sources of Air Pollutants in the U.S., 1970-2016

Source: Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency; in thousand tons

Carbon monoxide sources	1970	1975	1980	1985	1990	1995	2000	2005	2010	2016
Fuel combustion, elec. util. . . .	237	276	322	291	363	372	484	643	766	717
Industrial processes ¹	10,610	8,304	7,700	5,894	5,572	5,631	3,628	3,074	2,807	3,162
Transportation ²	174,602	167,884	160,512	153,216	131,702	107,755	92,239	64,729	43,595	30,861
Total carbon monoxide³	204,042	188,398	185,408	176,845	154,188	126,778	114,467	88,546	73,771	58,983
Nitrogen oxide sources										
Fuel combustion, elec. util. . . .	4,900	5,694	7,024	6,127	6,663	6,384	5,330	3,792	2,458	1,053
Industrial processes ¹	5,100	4,546	4,110	4,009	3,831	3,909	3,518	2,783	2,406	2,469
Transportation ²	15,276	15,029	14,846	14,508	13,373	12,989	12,561	12,613	9,016	6,021
Total nitrogen oxide³	26,882	26,378	27,080	25,757	25,527	24,955	22,598	20,355	14,846	10,489
Sulfur dioxide sources										
Fuel combustion, elec. util. . . .	17,398	18,268	17,469	16,272	15,909	12,080	11,396	10,404	5,696	1,185
Industrial processes ¹	11,661	7,993	6,725	5,597	5,402	4,945	3,516	2,721	1,447	1,154
Transportation ²	551	635	717	809	874	741	697	682	158	49
Total sulfur dioxide³	31,218	28,044	25,926	23,307	23,077	18,619	16,347	14,546	7,732	2,709

(1) Industrial fuel combustion, chemical and allied manufacturing, metals processing, and petroleum and other industrial sectors. (2) Highway and off-highway vehicles. (3) Numbers may not add up to totals because not all categories are listed.

Average Global Temperature and Atmospheric Carbon Dioxide, 1880-2016

Source: Goddard Institute for Space Studies, National Aeronautics and Space Administration, via Earth Policy Institute; National Centers for Environmental Information, National Oceanic and Atmospheric Admin. (NOAA), U.S. Dept. of Commerce

