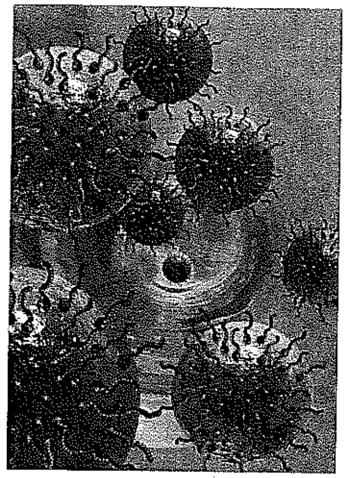

Chronology of Nanoscience

4th century C.E.
The Lycurgus Cup is crafted by Roman glassworkers, for use by very wealthy individuals (possibly members of the imperial family) in religious feasts. The cup's unusual color (green in reflected light, red in transmitted light) is due to colloidal gold nanoparticles embedded in the glass.

1590
Peter Bales produces a handwritten copy of the Bible "contained in a large English walnut." Isaac d'Israeli cites contemporary sources saying that this curiosity was seen "by many thousands."

circa 1600
Damascus steel swords are made that contain carbon nanotubes and cementite nanowires. These nanoparticles may have contributed to the extraordinary sharpness of damascene blades.

1665
Robert Hooke publishes the *Micrographia* on behalf of the Royal Society, containing microscopic observations of cells, pollen, insects, textiles, etc., as rendered exquisitely in illustrations produced by a group of anonymous artisans.

1726
Jonathan Swift publishes *Gulliver's Travels*, in which the main character visits both the land of Lilliput (where he is 12 times the size of the inhabitants) and Brobdingnag (where the inhabitants are 12 times the size of him). The novel is one of the earliest and most celebrated descriptions of life at radically different scales.

1757
Benjamin Franklin creates and observes a monolayer of oil on a farm pond. It is only in the 1890s that Agnes Pockels and Lord Rayleigh realize this experiment can be used to calculate the size of a single organic molecule.

1839
John Benjamin Dancer produces the first photographically demagnified image at 160:1 reduction. This is an important precursor to the photolithography technology used (~130 years later) in semiconductor manufacturing and nanofabrication.

1855
Paul Gustave Froment and N. Peters invent a micropantograph, capable of etching the "Lord's Prayer" in 1/35,6000 in^2 of glass (a 6,250:1 reduction).

1864

J.K. Wright, an ink-maker in Philadelphia, discovers a new way of manufacturing high-quality carbon black. This nanostructured material had been used since antiquity in making inks, but Wright's process makes it feasible to mass-produce carbon black as an additive to rubber. Large-scale production using the Wright process does not begin until World War I.

1891

Agnes Pockels publishes in *Nature* on her surface film balance, a precursor of the Langmuir-Blodgett trough.

1927

Clinton Davisson and Lester Germer, working at Bell Laboratories, demonstrate electron diffraction. Starting in the 1950s, a variant of their experiment—low-energy electron diffraction or LEED—becomes the key instrument in the new field of surface science, the study of the outermost atomic layers of a surface. Surface science provided a receptive audience for instruments such as the scanning tunneling microscope, and many LEED specialists moved in the late 1990s to work in nanoscience.

1931

Ernst Ruska builds the first electron microscope.

1935

Katherine Blodgett and Irving Langmuir show that a Langmuir-Blodgett trough can be used to compress monolayers of amphiphilic monolayers on water and then slide them, one layer at a time, onto a solid substrate.

1936

Subminiature vacuum tubes allow the first wearable, all-electronic hearing aids. The miniaturizing trend in vacuum tubes continues as they are incorporated into radios and proximity fuses during World War II. When commercial transistors are introduced they require several years to catch up to the level of miniaturization already found in vacuum tubes.

1941

Theodore Sturgeon's novella *Microcosmic God* describes a scientist who creates a microcosmic civilization able to evolve and innovate more rapidly than human society.

1942

Robert Heinlein publishes *Waldo*, a short story that mentions a way of manipulating matter at the scale of quantum phenomena using tiny robotic arms ("waldoes"). Ed Regis's book *Nano* cites this as an inspiration—direct or indirect is unknown—for Richard Feynman's talk of nanomanipulators in his 1959 "Plenty of Room at the Bottom" speech.

1942

Sam Ruben invents the small mercury battery, primarily for use in military radios. It is quickly adapted for commercial applications such as hearing aids, kicking off a miniaturization trend in batteries that fueled the parallel miniaturization trend in vacuum tubes and transistors.

1947

Invention of the transistor at Bell Laboratories. Although the first transistors were macroscale objects, it soon became clear—especially with the introduction of integrated circuits in the 1950s—that their properties would improve as they got smaller.

1953

John von Neumann delivers the Vanuxem lectures at Princeton University, in which he describes his theory of cellular automata (CA). Since the 1980s, CA has been a favorite alternative to Boolean logic for computing, especially among proponents of molecular electronics and other exotic forms of microelectronics. Von Neumann also speculated on the properties of self-replicating machines, providing a scientific pedigree for later visions of molecular assemblers.

1953

The Committee on Vacuum Technique (CVT) has its first meeting. Four years later the CVT changes its name to the American Vacuum Society (AVS). From the late 1960s onward, the AVS becomes the home of a number of proto-nano communities: microfabrication, thin film processing, surface science, probe microscopy, etc.

1955

Single atoms are imaged at Pennsylvania State University by Kanwar Bahadur, a student in the lab of Erwin Müller, using a field ion microscope.

1956

Arthur von Hippel publishes an influential paper on "molecular engineering" (later an edited volume) arguing for a new approach to "build[ing] materials from their atoms and molecules for the purpose at hand." His ideas directly inspire the Westinghouse-USAF program in "molecular electronics." Ed Regis believes that Richard Feynman's 1959 "Plenty of Room at the Bottom" speech may have been influenced by the appearance of von Hippel's edited volume earlier that year.

1959

Richard Feynman delivers an after-dinner speech to the American Physical Society meeting in Pasadena, California. The speech ranges over a number of possibilities for the design and application of structures at what is now called the nanoscale. The speech is reprinted in a variety of popular media, usually with the title "There's Plenty of Room at the Bottom." However, most practicing scientists at the time assume Feynman was striving primarily to amuse, rather than inspire, and the speech is largely forgotten. The one exception is the microfabrication community, which takes Feynman's offer of a $1,000 prize for feats of nanolithography as a target to aim for.

1960

In the wake of Sputnik (first satellite launch by the Soviet Union), the Advanced Research Projects Agency founds the first three Interdisciplinary Laboratories (IDLs) at leading universities. A year later, eight more IDLs are added. These academic centers form the institutional core of the new discipline of materials science.

1965

Gordon Moore of Fairchild Semiconductor (later cofounder of Intel) publishes the observation that the number of components that could be placed on a commercial chip had been doubling approximately every year since 1959, and predicts that this rate would continue for the next 10 years at least. In the mid-1970s, Caltech physicist Carver Mead dubbed this "Moore's Law"—even as Moore modified the "law" to predict a doubling every two years rather than one.

1966

The film (and Isaac Asimov's novelization) *Fantastic Voyage* appears, depicting a journey of miniaturized scientists inside the ailing body of one of their colleagues. Often taken as a reference point for descriptions of nanomedicine starting in the 1990s.

1969

Jean-Marie Lehn, building on work of Charles Pedersen, synthesizes the first cryptands, three-dimensional crown ethers capable of enveloping a "guest" ion (i.e., burying it inside a molecular "crypt"). Lehn, Pedersen, and Donald Cram eventually win the Nobel Prize for founding the field of supramolecular chemistry, one of the constituent fields of nanotechnology. Caging guest atoms and molecules inside a molecular host has been an important subfield of fullerene research since the late 1980s.

1970

Alfred Cho and J.R. Arthur, both working at Bell Laboratories, introduce the technique of molecular beam epitaxy to the world. MBE enables the building up of very thin films for nanodevices such as quantum wells.

1970

Albert Crewe's group at the University of Chicago achieves atomic resolution with their scanning transmission electron microscope.

1971

Russell Young's Topografiner project is canceled at National Bureau of Standards. The Topografiner was a scanning field emission microscope that could operate in tunneling mode while stationary—i.e., it incorporated almost all the elements of the later scanning tunneling microscope (STM), but a bad vacuum chamber and electronics prevented it from scanning while in the tunneling mode. Young's protégé, Clayton Teague, later uses a similar apparatus to achieve the first unambiguous vacuum tunneling signature, but does not publish until after the announcement of the STM. Teague later becomes editor of *Nanotechnology* and director of the National Nanotechnology Coordination Office.

1972

Following the Mansfield Amendment, the ARPA Interdisciplinary Laboratories are transferred to the National Science Foundation and renamed Materials Research Laboratories (MRLs). Today known as the Materials Research Science and Engineering Centers (MRSECs), the MRSECs both directly facilitate a significant portion of U.S. nano research, as well as offer an institutional model for other kinds of academic nanocenters.

1974
The term *nano-technology* is coined by Norio Taniguchi in a paper for a precision engineering conference in Japan. Though Taniguchi's neologism is usually dismissed as having had no effect on the later development of nanotechnology, his paper is notable for having put in print an observation that was rapidly becoming obvious to microfabrication specialists at the time: that at the then-current rate of innovation in miniaturization techniques, it would soon be possible to build structures at the 1 to 100 nanometer scale, rather than the "submicron" regime of 100 to 1,000 nanometers.

1974
Ari Aviram, from IBM, and Mark Ratner, from New York University, publish an article on "molecular rectifiers." This becomes the kernel of revived interest in "molecular electronics"—i.e., the idea of replacing microelectronic components such as transistors with single (or small numbers of) molecules.

1975
The Japanese government, spurred by electron beam lithography advances at Bell Laboratories in the United States, announces a major program in VLSI (very large-scale integration) microelectronics. The program is run through MITI (Ministry of International Trade and Industry) and NTT (Nippon Telegraph and Telephone). In the United States, the Japanese VLSI program is seen as involving very close coordination among government, academic, and corporate institutions. As the Japanese share of the semiconductor industry starts to climb, calls mount to replicate the VLSI program in the United States.

1977
The National Science Foundation funds Cornell University to build the National Research and Resource Facility for Submicron Structures (usually called the National Submicron Facility). This facility—and its competitors at Massachusetts Institute of Technology, Stanford Unoiversity, Research Triangle Park, and elsewhere—pushes the forefront of microfabrication technology.

1977
Alan Heeger and Alan MacDiarmid (who first established a collaboration through the University of Pennsylvania's Materials Research Laboratory), and Hideki Shirakawa publish results of their work on conducting polymers. Conducting polymers soon becomes a focus for those interested in molecular electronics, and (more slowly) for those developing novel electronic devices such as solar cells and organic light-emitting diodes. Heeger and MacDiarmid both become influential figures in nanoscience after the three men are awarded the Nobel Prize in 2000.

1978
Fritz Vögtle and collaborators publish the first synthesis of a "dendrimer" (also known as a cascade molecule). These branched molecules can, like cryptands or fullerenes, envelop other atoms and molecules, potentially for applications such as drug delivery.

1979
Arthur C. Clarke publishes *Fountains of Paradise*, which features a "space elevator" running from the earth's surface to geostationary orbit. Though the book contains no mention of nanotechnology, it inspires interest in space elevators at the intersection of space- and nano-enthusiast groups. After the discovery of single-walled nanotubes, scientists such as Rick Smalley tout the space elevator as the ultimate application of these new materials.

1979
The Three Mile Island (TMI) nuclear power plant near Harrisburg, Pennsylvania, experiences a partial core meltdown, halting nuclear plant construction in the United States. The TMI accident spurs pioneering sociological investigation into the nature and perception of technological risk. For proponents of nanotechnology, nuclear power eventually becomes (in rather oversimplified form) an emblem of a technology that went from public acceptance to public rejection because of overstated promises and understated risks.

1980
The U.S. Congress passes the Bayh-Dole Act, making it easier for universities to patent inventions resulting from research funded by the federal government. Although universities had been increasingly patenting their fac-

ulty's research for several years prior, Bayh-Dole is conventionally thought to have spurred increased rates of academic entrepreneurialism. In fact, the greater stimulus probably came from the initial public offering, also in 1980, of Genentech, a biotech company cofounded by venture capitalist Robert Swanson and biochemist Herb Boyer. As Sally Smith-Hughes notes, the initial public offering (IPO) gave Boyer "a paper profit of $60 million on an initial investment of $500."

1981

Michael Isaacson and collaborators at Cornell University, using a variant of Albert Crewe's scanning transmission electron microscope, demonstrate the ability to write letters with a linewidth of 1.5 nanometers. Isaacson attempts to claim Richard Feynman's offer (made in the "Plenty of Room at the Bottom" speech) of $1,000 to anyone able to reproduce a page of text at 1:25,000 demagnification. At the time, Feynman is undergoing cancer treatment and Isaacson's request does not reach him. After Feynman's cancer goes into remission, the prize is claimed by Fabian Pease, of Stanford University, and his graduate student, Tom Newman, for engraving the opening page of *A Tale of Two Cities* in an area of 5.8 μm by 5.8 μm.

1981

Herbert Gleiter, a prominent materials scientist, proposes a new way of understanding the bulk properties of a matrix with embedded "ultrafine particles." By 1983, Gleiter and his collaborators coin the term *nanocrystals* to substitute for *ultrafine particles*. A few years later they coin the term *nanophase* or *nanostructured* materials to refer to the combination of matrix and nanocrystals. Though largely written out of standard histories of nano, Gleiter's terminology pervades the field and his network of collaborators were influential players in the formation of various national nanotechnology initiatives.

1983

Gerd Binnig, Heinrich Rohrer, and Christoph Gerber, working at the IBM Research Lab near Zurich, Switzerland, achieve atomic resolution of the silicon (111) 7x7 with their new invention, the scanning tunneling microscope (STM). The atomic structure of the silicon 7x7 is a prized mystery of surface science and, though the STM does not directly solve the mystery, its atomic resolution images quickly attract the attention of surface scientists and the 1986 Nobel Prize for Binnig and Rohrer.

1983

Richard Feynman revisits his 1959 speech in a talk at the Jet Propulsion Lab on "Infinitesimal Machinery." He reaffirms some of his predictions from 1959, cites a few that had already come true, and dispenses with a few that he has come to believe were misguided (especially the idea of "waldos" for nanomanipulation).

1985

CMOS (complementary metal-oxide-semiconductor) transistors overtake bipolar junction transistors for total market share. Two important implications for nano are that (A) since CMOS transistors only achieve high speed and economies of scale at very high levels of miniaturization, the popularity of CMOS pushes (and is pushed by) innovation in miniaturization; and (B) since West Coast firms such as Intel led the way in commercialization of (though not the initial research into) CMOS, their market share rises rapidly while bipolar-loyal firms such as IBM edge toward economic disaster.

1985

Greg Bear's *Blood Music* is published. The novel is often taken to be the first fully realized science fiction account of the "grey goo" scenario. Bear's book is notable also for its detailed description of research in a high-tech start-up company and the ways commercial interests and personal ambitions mix in science.

1985

Gerd Binnig and Christoph Gerber, of IBM, and Calvin Quate, of Stanford University, invent the atomic force microscope (AFM), a variant of the scanning tunneling microscope (STM). Compared to the STM, the AFM generally (though not always) has lower resolution, but has a wider range of applications because it is able to image insulating materials as well as conductors and semiconductors.

1985

Rick Smalley and Robert Curl, of Rice University, and Harry Kroto, of the University of Sussex, discover a third allotrope of carbon that they name buckminsterfullerene. The discovery brings widespread attention, but research into the exact nature of C60 is frustrated until 1990, when Wolfgang Krätschmer and Don Huffman showed that reasonable quantities of buckyballs could be generated with a simple arc discharge. This sets off a flurry of renewed interest in fullerenes, resulting eventually in Smalley, Curl, and Kroto winning the Nobel Prize.

1985
The National Science Foundation begins a new Engineering Research Centers program, based on academic campuses but designed to foster closer university-industry ties. The ERCs are modeled partly on the Materials Research Laboratories and the National Submicron Facility, and in turn provide a model for the Nanoscale Science and Engineering Centers. From this point on, commercialization of academic research becomes an increasingly important priority of federal science funding in the United States.

1986
The British government forms a National Initiative on Nanotechnology through its National Physical Laboratory. Two years later this expands into the LINK Nanotechnology Program to "bridge the gap between science and market place." Over the next 10 years, this program spends £23.6 million to fund 28 projects across 15 universities and 44 companies, including Unilever and GlaxoWellcome.

1986
K. Eric Drexler publishes *Engines of Creation: The Coming Age of Nanotechnology*, a speculative work imagining applications for "molecular assemblers" in a wide range of areas closely aligned with the futurist movement of the late 1970s and early 1980s—space travel, immortality, downloading of consciousness, transhumanism, and hypertext. That same year he and his then-wife Christine Peterson found the Foresight Institute in Palo Alto, California, to promote the assemblers idea.

1986
Japan overtakes the United States in worldwide semiconductor market share, leading to calls for the Ronald Reagan administration to pressure the Japanese government to fund more basic research. The market share crossover also spurs further U.S. government participation in the semiconductor industry through SEMATECH (formed the next year) and funding for academic centers in microfabrication and microelectronics research. After trading the lead through the early 1990s, by 1996 the United States once again edges Japan.

1986
The National Submicron Facility at Cornell changes its name, as part of a grant renewal, to the National Nanofabrication Facility. This reflects the fact that microfabrication techniques at the 100 to 1,000 nanometer scale are now routine, while the 1 to 100 nanometer regime is at the forefront of research.

1986
The National Science Foundation (NSF) establishes NSFNET, a computer network connecting its four new supercomputer centers (at Cornell University, University of California-San Diego, University of Illinois, and Carnegie Mellon/University of Pittsburgh) together. Regional subnetworks connected to academic computer science departments are also tied into the new network. NSFNET has two implications for nanotechnology: it leads to the NSF's role in privatizing the Internet, which aids its bid to be the lead institution of the NNI; and it establishes a model of networking academic centers that is deployed again in the National Nanofabrication Users Network, the Network for Nanotechnology in Society, and the Network for Computational Nanotechnology.

1988
Peter Grünberg and Albert Fert independently discover the phenomenon of giant magnetoresistance (GMR), for which they are awarded the Nobel Prize. Within a decade, IBM commercializes the effect for their hard-disk drives.

1989
Star Trek: The Next Generation introduces a plot line involving "nanites," small, self-replicating, possibly sentient, artificial beings. Nanotechnology is repeatedly deployed as a plot device in all ensuing Star Trek franchises.

1989
The Japanese government funds the Aono Atom Craft project, partly in response to U.S. calls for it to sponsor more basic research. This begins a major focus on nanoscale imaging and manipulation that, by the late 1990s, U.S. grant officers can point to as evidence that America may fall behind in nanoscience if more (and more coordinated) funding is not available.

1990
First meeting of the International Conference on Nanometer Scale Science and Technology (or NANO Conference), in conjunction with the Fifth International Conference on Scanning Tunneling Microscopy/Spectroscopy (or STM Conference). The NANO and STM meetings alternate every other year until 2006, when they are subsumed by the International Conference on Nanoscience + Technology (ICN+T). The NANO meeting was perhaps the first conference series explicitly focused on nanoscience, though it was quickly followed by other newly created nano conferences, as well as older series changing their names to accommodate nano research.

1990
The journal *Nanotechnology* is founded, initially publishing a mix of articles on precision engineering, probe microscopy, and Drexlerian speculations and simulations.

1990
Don Eigler and Erhard Schweizer, researchers at the IBM laboratory near San Jose, California, use a low-temperature scanning tunneling microscope to arrange 35 xenon atoms on a nickel surface to spell out the letters "I-B-M." Their employer seizes on the public relations possibilities of this discovery. Eigler's group goes on to do pioneering work in the study of quantum corrals and mirages, and builds some of the smallest conceivable logic elements out of cascades of carbon monoxide molecules.

1991
Ralph Merkle, one of the pioneers of public key encryption at Xerox PARC, coins the term *computational nanotechnology* to describe the use of computer simulation to design Drexler-type molecular machines. This becomes perhaps the most active area of research for adherents of Drexler's vision of assemblers, and almost certainly the area where Drexler's ideas have had the most direct influence on peer-reviewed scientific research.

1992
K. Eric Drexler testifies before the Senate Subcommittee on Science, Technology, and Space in a hearing convened by Senator (soon to be Vice President) Al Gore. Drexler's testimony likely had little direct effect on federal policy, but it may have aided grant officers such as Mihail Roco and James Murday in promoting their (quite different) vision of government funding for nano.

1992
The European Community begins the PHANTOMS (PHysics ANd Technology Of Mesoscale Systems) program to tie together research on traditional silicon microelectronics with exotic alternatives such as molecular electronics.

1992
The American Vacuum Society (AVS) founds its Nanometer-Scale Science and Technology Division, partly to reflect AVS's role in sponsoring (and publishing proceedings of) the NANO and STM meetings. The year before, AVS changes the subtitle of its *Journal of Vacuum Science and Technology B* from "Microelectronics Processing and Phenomena" to "Microelectronics and Nanometer Structures: Processing, Measurement, and Phenomena," but balks at starting a new journal which would have been named *JVST C: Nanometer Science.*

1992
The first National Technology Roadmap for Semiconductors formalizes the process of coordinating U.S. semiconductor manufacturers and their suppliers so as to bring miniaturization trends in microelectronics in line with Moore's Law. Starting in 1999, American firms are joined by counterparts worldwide and the NTRS becomes the International Technology Roadmap for Semiconductors.

1993
Donald Bethune, at IBM, and Sumio Iijima, at NEC, independently discover the single-walled carbon nanotube (CNTs). Though multi-walled CNTs had been known about, to some degree, for some time, it was Iijima's isolation of them in arc discharge soot in 1991 that focused scientific interest on what Mildred Dresselhaus terms "buckytubes." Single-walled tubes, however, promise significantly better mechanical and electrical properties than MWNTs, and it was only with Bethune and Iijima's discovery that fullerenes were seriously considered for applications such as molecular electronics.

1993
The U.S. Congress finally kills funding for the Superconducting Supercollider (SSC), a prized project of high-energy physicists. Congressional opposition to the SSC is buttressed by testimony of several prominent condensed

matter physicists who argue that high-energy research is in no way more elementary than other fields, and produces fewer technological benefits. At the same time that opposition to the SSC is building, funding for the Human Genome Project begins to grow—a fact often taken as emblematic of a reversal in the hierarchy of the physical and life sciences at the end of the Cold War. A decade later, the major opponent of the SSC in the House of Representatives, Sherwood Boehlert, is—with Mike Honda—the primary sponsor of the 21st Century Nanotechnology Research and Development Act.

1993

The Center for Nanoscale Science and Technology (CNST) is founded at Rice University, largely guided by the vision of Rick Smalley. CNST claims to be the "first nanotechnology center in the world." It becomes a model for later centers, and brings Smalley to the forefront of championing state and federal sponsorship of nanotechnology.

1994

Four-star Admiral David Jeremiah, vice chair of the Joint Chiefs of Staff, requests a presentation on nanotechnology research by the Office of Naval Research grant manager James Murday to the Pentagon's Joint Requirements Oversight Council. According to Ed Regis, Jeremiah had previously been briefed on nanotechnology by Eric Drexler. Murday's presentation leads eventually to his briefing the Secretary of Defense on nano research, and to his joining forces with the National Science Foundation's Mihail Roco to promote the National Nanotechnology Initiative.

1994

The National Nanofabrication Users Network is founded by the National Science Foundation, led by Cornell and Stanford universities, with initial participation by Howard University, Penn State, and University of California-Santa Barbara.

1995

Neal Stephenson's steampunk novel, *The Diamond Age, or a Young Lady's Illustrated Primer*, is published. It posits a future world in which Eric Drexler and Ralph Merkle are honored as the progenitors of the molecular assemblers on which the world's economy relies. *The Diamond Age* is published between the first two novels of Kathleen Ann Goonan's nano quartet, *Queen City Jazz and Mississippi Blues.* These also focus on a young woman's coming of age in a Drexlerian dystopia.

1996

AT&T spins off Bell Laboratories as Lucent Technologies, kicking off a decade-long extinguishing of what had almost certainly been the most important research laboratory in the United States. Given AT&T's contributions to the development of nanotechnology, federal grant officers in the late 1990s structure the National Nanotechnology Initiative partly to create academic centers that will fill the niche left by the disappearance of Bell Labs (and the more general decline of corporate long-term basic research).

1996

The Swiss government fronts 56 million francs (matched by industry) for a Priority Program on Micro- and Nanosystems Technologies. In 1999 this evolves into a National Center for of Competence in Research in Nanoscale Science at Basel University, which plays the same coordinating role for Swiss nano that the National Nanotechnology Initative will two years later in the United States.

1997

Mihail Roco, Evelyn Hu, and Richard Siegel organize a workshop under the auspices of the World Technology Evaluation Center to assess U.S. and worldwide work on "nanoparticles, nanostructured materials, and nanodevices." Roco quickly uses the workshop report as justification for forming an Interagency Working Group on Nanoscience, Engineering, and Technology within the National Science and Technology Council. This eventually serves as the institutional core of the National Nanotechnology Initiative.

1998

The European Union imposes a ban on the import of new types of genetically modified foods. Though the ban is later lifted, U.S. proponents of nanotechnology look to this episode as the type of public skepticism that should be avoided for their field. Much of the funding for research on ethical, legal, and social implications (ELSI) of nano and nano environmental health and safety (EHS) is designed to avoid the kinds of controversies associated with genetically modified foods.

1999
Mihail Roco establishes the *Journal of Nanoparticle Research*, a venue for both technical and social scientific perspectives on nanotechnology. The same year, he presents his plan for a National Nanotechnology Initiative (NNI) to President Bill Clinton's Science Adviser, Neal Lane, and his Deputy Assistant for Technology and Economic Policy, Tom Kalil. Lane is Rick Smalley's former provost at Rice University, and Kalil is a former lobbyist for the semiconductor industry. Roco's proposal is accepted and the creation of the NNI is set in motion.

2000
The American Institute of Physics starts a *Virtual Journal of Nanoscale Science and Technology* to gather together nano research articles from its other journals.

2000
Wired magazine publishes "Why the Future Doesn't Need Us," by Bill Joy, cofounder of Sun Microsystems. In this opinion piece, Joy cites Drexlerian molecular assemblers as a clear example of the kind of technology that could pose an existential threat to humanity. Proponents of the National Nanotechnology Initiative mobilize leading scientists such as Rick Smalley to counter Joy and Drexler's arguments.

2000
President Bill Clinton announces the National Nanotechnology Initiative in a speech at Caltech, the site of Richard Feynman's "Plenty of Room at the Bottom" speech. With him on-stage are Gordon Moore, of Intel, and David Baltimore, president of Caltech.

2001
The American Chemical Society founds a new journal, *Nano Letters*, catering largely to an academic audience; Ardesta founds *Small Times*, aimed more at readers in industry.

2001
The National Science Foundation awards the first round of Nanoscale Science and Engineering Centers (NSEC), interdisciplinary academic centers modeled on the previous ERCs and MRSECs, but focused exclusively on various aspects of nanoscience and technology. Each NSEC is encouraged to promote education, outreach, and commercialization activities as well as ethical, legal, and social issues (ELSI) research. Notable nanoscience and society-focused NSECs include the Center for Biological and Environmental Nanotechnology at Rice University (in the first round).

2002
Michael Crichton publishes *Prey*. The novel follows Crichton's usual plot template (scientists trapped in a remote location face life-threatening intelligence of their own making but not under their control), with nanobots substituted as the villain. Crichton's gothic prose primarily scares proponents of the National Nanotechnology Initiative—ordinary readers' views of nanotechnology are largely unaffected.

2002
Nanobots replace radiation in the hero's origin story in the cinematic adaptation of *Spider-Man*. A similar substitution takes place in the following year's *The Hulk*.

2003
Eric Drexler and Rick Smalley debate the physical possibility of Drexler's molecular assemblers—and the advisability of discussing same in public—in *Chemical & Engineering News*, a widely read weekly for chemists and chemical engineers. While Smalley found Drexler's writings useful in promoting his own work in the early 1990s, he now declares that Drexler is "scaring our children."

2003
The 21st Century Nanotechnology Research and Development Act passes the U.S. Congress, formally authorizing the National Nanotechnology Initiative.

2003
Greenpeace UK issues a report by Huw Arnall, of Imperial College London, surveying the environmental implications of nanotechnology, artificial intelligence, and robotics. Though some industry nano organizations condemn the report for not being pro-nano enough, Arnall's tone is in fact agnostic to somewhat favorable.

2003
Most of the semiconductor industry converts to the 90 nanometer process node for manufacturing. The process node designation refers to the average half-pitch of

a memory cell—meaning that most structures manufactured by this process easily qualify as "nanotechnology" according to the NNI's definition. For most manufacturers, meeting the 90 nm node is accompanied by adoption of a 300 mm wafer and 193 nm wavelength of light used in photolithography.

2004
The National Nanofabrication Users Network grant comes to an end and the expanded (13-institution) group renames itself the National Nanotechnology Infrastructure Network. Facilities provide services to external users, continue pushing nanofabrication technique, and sponsor education, outreach, and social and ethical issues (SEI) research.

2004
The Royal Society and Royal Academy of Engineering in Great Britain issue a report on "Nanoscience and Nanotechnologies: Opportunities and Uncertainties." The report comes at the same time as Prince Charles's skeptical public comments on nanotechnology—comments that the press misconstrues as having warned of a "Grey Goo" scenario. The report is notable for conducting, and recommending workshops in which scientists and members of the public can interact to better understand each other's views on nanotechnology.

2004
The U.S. Patent Office creates class 977, a cross-reference classification for nanotechnology patents. Patents are still categorized primarily by non-nano classifications, but are also placed in class 977 to group new nanotechnologies under a single umbrella cutting across the older classifications.

2005
The Network for Nanotechnology in Society (composed of centers at Arizona State University and University of California-Santa Barbara) are created, and the U.S. National Science Foundation announces the creation of the Nanoscale Informal Science Education Network.

2005
According to IBM CEO Sam Palmisano, this year marks the first time that annual worldwide production of transistors exceeds annual worldwide production of grains of rice!

2006
A German cleaning product, Magic Nano, is recalled after several dozen customers are hospitalized with breathing problems. The incident causes a spike in reporting on potential risks of nanotechnology, even though it is determined that the product's name is pure marketing—the product contains nothing that could qualify as nanotechnology. Fears that this incident would lead to widespread public opposition to nano appear to be unfounded, however.

2006
The Berkeley, California, city council passes an ordinance requiring that "all facilities [within the jurisdiction of the city] that manufacture or use manufactured nanoparticles shall submit a separate written disclosure of the current toxicology, to the extent known, and how the facility will safely handle, monitor, contain, dispose, track inventory, prevent release and mitigate such materials."

2007
Harvard University establishes a deal for Nano-Terra, a start-up cofounded by George Whitesides, to license more than 50 patents on research conducted in Whitesides Harvard laboratory. The deal is one of the largest patent portfolios ever transferred from a university to a start-up company. The portfolio largely covers Whitesides's work on soft (imprint) nanolithography.

2007
The U.S. Environmental Protection Agency rules that Samsung's SilverCare washing machines must be regulated as a pesticide because they release antimicrobial silver ions into their waste water. Though the ions are actually too small to count as nanotechnology (by the National Nanotechnology Initiative's definition), the ruling was called for by advocacy groups interested in nanotechnology regulation, and reported in the press as having implications for future commercialization of nanotechnology.

2007
A survey of members of the general public and leading nanoscientists by researchers at Arizona State University and the University of Wisconsin finds that, for the first time, scientists were more worried about an aspect of a high-technology than the public. In this case, nanoscientists were more pessimistic about risks to health

and environment from nanotechnology than the public. However, the public was much more worried than nanoscientists that nanotechnology could pose risks to employment, privacy, and national security.

2008
A well-publicized article by Scottish researchers appears in *Nature Nanotechnology* showing that mice exposed to solutions containing long (20 to 100 nm) bundles of multi-walled nanotubes had an increased likelihood of developing abdominal inflammations similar to those caused by asbestos as a precursor to mesothelioma.

2008
The National Science Foundation and Environmental Protection Agency found two Centers for Environmental Implications of Nanotechnology, centered at UCLA and Duke University, to study the fate and transport of engineered nanoparticles in the environment.

2009
Physicians and scientists from China's Capital University of Medical Sciences publish an article in *European Respiratory Journal* blaming severe lung disease (including two deaths) in seven women on nanoparticles they had inhaled while working at a Beijing factory. The report is vague as to the nature of the particles and the mechanism of injury, and the women were also exposed to a variety of toxic non-nano chemicals. The incident raises the profile of occupational safety questions in the growing nanotoxicology community, but does little to indicate which nanoparticles pose what kinds of risks, and whether industrial hygiene practices can lessen those risks.

2009
South Korean and American scientists announce that they have created the first "molecular transistor": a single organic molecule suspended between gold electrodes that responds to changes in input voltage in the same way as a solid-state transistor.

2010
A team of scientists from the University of New South Wales (UNSW) Centre for Quantum Computer Technology (CQCT), and the University of Wisconsin, Madison break into a new era of computing power by fabricating the world's smallest precision-built transistor. The transistor consists of a quantum dot of seven atoms in a single silicon crystal, and is said to be the world's first functioning electronic device created by deliberately placing individual atoms.

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