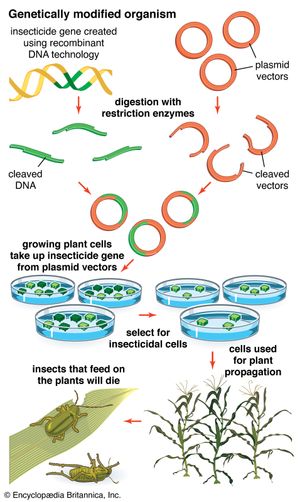
**Clemente**

**genetically modified organism (GMO)**

organism whose genome has been engineered in the laboratory in order to favour the expression of desired physiological traits or the generation of desired biological products. In [conventional](https://www.britannica.com/dictionary/conventional) [livestock](https://www.britannica.com/animal/livestock) production, crop farming, and even [pet](https://www.britannica.com/animal/pet) breeding, it has long been the practice to breed select individuals of a [species](https://www.britannica.com/science/species-taxon) in order to produce offspring that have desirable traits. In [genetic](https://www.britannica.com/science/genetics) modification, however, recombinant genetic technologies are employed to produce organisms whose genomes have been precisely altered at the molecular level, usually by the inclusion of [genes](https://www.britannica.com/science/gene) from unrelated species of organisms that code for traits that would not be obtained easily through conventional [selective breeding](https://www.britannica.com/science/selective-breeding).

[](https://cdn.britannica.com/44/117844-050-B0ECC780/methods-organisms-recombinant-DNA-technology.jpg)

[Genetically modified organisms](https://cdn.britannica.com/44/117844-050-B0ECC780/methods-organisms-recombinant-DNA-technology.jpg)

Scientific methods that include recombinant DNA technology are used to produce genetically modified organisms.

Genetically modified organisms (GMOs) are produced using scientific methods that include [recombinant DNA technology](https://www.britannica.com/science/recombinant-DNA-technology) and reproductive [cloning](https://www.britannica.com/science/cloning). In reproductive cloning, a [nucleus](https://www.britannica.com/science/nucleus-biology) is [extracted](https://www.britannica.com/dictionary/extracted) from a cell of the individual to be cloned and is inserted into the enucleated [cytoplasm](https://www.britannica.com/science/cytoplasm) of a host [egg](https://www.britannica.com/science/egg-biology) (an enucleated egg is an egg cell that has had its own nucleus removed). The process results in the generation of an offspring that is genetically identical to the donor individual. The first [animal](https://www.britannica.com/animal/animal) produced by means of this cloning technique with a nucleus from an adult donor cell (as opposed to a donor embryo) was a sheep named [Dolly](https://www.britannica.com/topic/Dolly-cloned-sheep), born in 1996. Since then a number of other animals, including [pigs](https://www.britannica.com/animal/pig-mammal-group), [horses](https://www.britannica.com/animal/horse), and [dogs](https://www.britannica.com/animal/dog), have been generated by reproductive cloning [technology](https://www.britannica.com/technology/technology). Recombinant DNA technology, on the other hand, involves the insertion of one or more individual genes from an organism of one species into the [DNA](https://www.britannica.com/science/DNA) (deoxyribonucleic acid) of another. Whole-genome replacement, involving the transplantation of one [bacterial](https://www.britannica.com/science/bacteria) genome into the “cell body,” or cytoplasm, of another microorganism, has been reported, although this technology is still limited to basic scientific applications.

GMOs produced through genetic technologies have become a part of everyday life, entering into society through agriculture, [medicine](https://www.britannica.com/science/medicine), research, and environmental management. However, while GMOs have benefited human society in many ways, some disadvantages exist; therefore, the production of GMOs remains a highly controversial topic in many parts of the world.

MONICA

GMOs in [agriculture](https://www.britannica.com/topic/agriculture)

[](https://cdn.britannica.com/61/131361-050-1A1D205E/corn.jpg)

[Genetically engineered corn (maize)](https://cdn.britannica.com/61/131361-050-1A1D205E/corn.jpg)A field of genetically engineered corn (maize).

[Genetically modified (GM) foods](https://www.britannica.com/topic/genetically-modified-food) were first approved for human [consumption](https://www.merriam-webster.com/dictionary/consumption) in the [United States](https://www.britannica.com/place/United-States) in 1994, and by 2014–15 about 90 percent of the [corn](https://www.britannica.com/plant/corn-plant), [cotton](https://www.britannica.com/topic/cotton-fibre-and-plant), and [soybeans](https://www.britannica.com/plant/soybean) planted in the United States were GM. By the end of 2014, GM crops covered nearly 1.8 million square kilometres (695,000 square miles) of land in more than two dozen countries worldwide. The majority of GM crops were grown in the Americas.

Engineered crops can dramatically increase per area crop yields and, in some cases, reduce the use of chemical [insecticides](https://www.britannica.com/technology/insecticide). For example, the application of wide-spectrum insecticides declined in many areas growing plants, such as [potatoes](https://www.britannica.com/plant/potato), cotton, and corn, that were [endowed](https://www.britannica.com/dictionary/endowed) with a [gene](https://www.britannica.com/science/gene) from the [bacterium](https://www.britannica.com/science/bacteria) *Bacillus thuringiensis*, which produces a natural insecticide called [Bt toxin](https://www.britannica.com/science/Bt-toxin). Field studies conducted in India in which Bt cotton was compared with non-Bt cotton demonstrated a 30–80 percent increase in yield from the GM crop. This increase was attributed to marked improvement in the GM plants’ ability to overcome bollworm infestation, which was otherwise common. Studies of Bt cotton production in Arizona, U.S., demonstrated only small gains in yield—about 5 percent—with an estimated cost reduction of $25–$65 (USD) per acre owing to decreased [pesticide](https://www.britannica.com/technology/pesticide) applications. In China, where farmers first gained access to Bt cotton in 1997, the GM crop was initially successful. Farmers who had planted Bt cotton reduced their pesticide use by 50–80 percent and increased their earnings by as much as 36 percent. By 2004, however, farmers who had been growing Bt cotton for several years found that the benefits of the crop eroded as populations of secondary insect pests, such as mirids, increased. Farmers once again were forced to spray broad-spectrum pesticides throughout the [growing season](https://www.britannica.com/topic/growing-season), such that the average [revenue](https://www.britannica.com/dictionary/revenue) for Bt growers was 8 percent lower than that of farmers who grew conventional cotton. Meanwhile, Bt resistance had also evolved in field populations of major cotton pests, including both the [cotton bollworm](https://www.britannica.com/animal/corn-earworm) (*Helicoverpa armigera*) and the pink bollworm (*Pectinophora gossypiella*).

Other GM plants were engineered for resistance to a specific chemical [herbicide](https://www.britannica.com/science/herbicide), rather than resistance to a natural predator or pest. [Herbicide-resistant crops](https://www.britannica.com/science/herbicide-resistant-crop) (HRC) have been available since the mid-1980s; these crops enable effective chemical control of [weeds](https://www.britannica.com/plant/weed), since only the HRC plants can survive in fields treated with the corresponding herbicide. Many HRCs are resistant to glyphosate (Roundup), enabling liberal application of the chemical, which is highly effective against weeds. Such crops have been especially valuable for no-till farming, which helps prevent soil erosion. However, because HRCs encourage increased application of chemicals to the soil, rather than decreased application, they remain controversial with regard to their environmental impact. In addition, in order to reduce the risk of selecting for herbicide-resistant weeds, farmers must use multiple [diverse](https://www.merriam-webster.com/dictionary/diverse) weed-management strategies.

[](https://cdn.britannica.com/40/246540-050-F16365CF/Golden-rice-GMO-Vitamin-A.jpg)

[golden rice](https://cdn.britannica.com/40/246540-050-F16365CF/Golden-rice-GMO-Vitamin-A.jpg)

Genetically modified golden rice plants in cultivation.

Another example of a GM crop is [golden rice](https://www.britannica.com/technology/golden-rice), which originally was intended for Asia and was genetically modified to produce almost 20 times the beta-[carotene](https://www.britannica.com/science/carotene) of previous varieties. [Golden rice](https://www.britannica.com/technology/golden-rice) was created by modifying the rice genome to include a gene from the [daffodil](https://www.britannica.com/plant/daffodil) *Narcissus pseudonarcissus* that produces an [enzyme](https://www.britannica.com/science/enzyme) known as phyotene synthase and a gene from the bacterium *Erwinia uredovora* that produces an enzyme called phyotene desaturase. The introduction of these genes enabled beta-carotene, which is converted to [vitamin A](https://www.britannica.com/science/vitamin-A) in the human liver, to accumulate in the rice [endosperm](https://www.britannica.com/science/endosperm)—the [edible](https://www.britannica.com/dictionary/edible) part of the rice plant—thereby increasing the amount of beta-carotene available for vitamin A synthesis in the body. In 2004 the same researchers who developed the original golden rice plant improved upon the model, generating golden rice 2, which showed a 23-fold increase in carotenoid production.

Another form of modified rice was generated to help combat [iron](https://www.britannica.com/science/iron-chemical-element) deficiency, which impacts close to 30 percent of the world population. This GM crop was engineered by introducing into the rice genome a ferritin gene from the [common bean](https://www.britannica.com/plant/common-bean), *Phaseolus vulgaris*, that produces a [protein](https://www.britannica.com/science/protein) capable of binding iron, as well as a gene from the fungus [*Aspergillus fumigatus*](https://www.britannica.com/science/Aspergillus) that produces an enzyme capable of digesting [compounds](https://www.merriam-webster.com/dictionary/compounds) that increase iron bioavailability via digestion of phytate (an inhibitor of iron absorption). The iron-fortified GM rice was engineered to overexpress an existing rice gene that produces a cysteine-rich metallothioneinlike (metal-binding) protein that [enhances](https://www.merriam-webster.com/dictionary/enhances) iron absorption.

A variety of other crops modified to endure the weather extremes common in other parts of the globe are also in production.

ESCOPALAO

**GMOs in**[**medicine and research**](https://www.britannica.com/science/medical-research)

GMOs have emerged as one of the mainstays of biomedical research since the 1980s. For example, GM [animal](https://www.britannica.com/animal/animal) models of human [genetic diseases](https://www.britannica.com/science/human-genetic-disease) enabled researchers to test novel therapies and to explore the roles of candidate risk factors and modifiers of disease outcome. GM microbes, plants, and animals also revolutionized the production of complex [pharmaceuticals](https://www.britannica.com/technology/pharmaceutical) by enabling the generation of safer and cheaper [vaccines](https://www.britannica.com/science/vaccine) and therapeutics. Pharmaceutical products range from recombinant [hepatitis](https://www.britannica.com/science/hepatitis) B vaccine produced by GM baker’s [yeast](https://www.britannica.com/science/yeast-fungus) to injectable [insulin](https://www.britannica.com/science/insulin) (for diabetics) produced in GM *Escherichia coli* bacteria and to factor VIII (for hemophiliacs) and tissue plasminogen activator (tPA, for [heart attack](https://www.britannica.com/science/heart-attack) or [stroke](https://www.britannica.com/science/stroke-medical-condition) patients), both of which are produced in GM mammalian cells grown in laboratory [culture](https://www.merriam-webster.com/dictionary/culture). Furthermore, GM plants that produce “edible vaccines” are under development. An edible vaccine is an antigenic [protein](https://www.britannica.com/science/protein) that is produced in the consumable parts of a plant (e.g., fruit) and absorbed into the bloodstream when the parts are eaten. Once absorbed into the body, the protein stimulates the [immune system](https://www.britannica.com/science/immune-system) to produce antibodies against the pathogen from which the antigen was derived. Such vaccines could offer a safe, inexpensive, and painless way to provide vaccines, particularly in less-developed regions of the world, where the limited availability of refrigeration and [sterile](https://www.britannica.com/dictionary/sterile) needles has been problematic for some traditional vaccines. Novel [DNA](https://www.britannica.com/science/DNA) vaccines may be useful in the struggle to prevent diseases that have proved resistant to traditional vaccination approaches, including HIV/[AIDS](https://www.britannica.com/science/AIDS), [tuberculosis](https://www.britannica.com/science/tuberculosis), and [cancer](https://www.britannica.com/science/cancer-disease).

Genetic modification of [insects](https://www.britannica.com/animal/insect) has become an important area of research, especially in the struggle to prevent parasitic diseases. For example, GM [mosquitoes](https://www.britannica.com/animal/mosquito-insect) have been developed that express a small protein called SM1, which blocks entry of the [malaria](https://www.britannica.com/science/malaria) parasite, *Plasmodium*, into the mosquito’s gut. This results in the disruption of the parasite’s life cycle and renders the mosquito malaria-resistant. Introduction of these GM mosquitoes into the wild could help reduce [transmission](https://www.britannica.com/dictionary/transmission) of the malaria parasite. In another example, male *Aedes aegypti* mosquitoes engineered with a method known as the sterile insect technique transmit a [gene](https://www.britannica.com/science/gene) to their offspring that causes the offspring to die before becoming sexually mature. In field trials in a Brazil suburb, *A. aegypti* populations declined by 95 percent following the sustained release of sterile GM males.

Finally, genetic modification of humans via [gene therapy](https://www.britannica.com/science/gene-therapy) is becoming a treatment option for diseases ranging from rare [metabolic disorders](https://www.britannica.com/science/metabolic-disease) to cancer. Coupling [stem cell](https://www.britannica.com/science/stem-cell) [technology](https://www.britannica.com/technology/technology) with [recombinant DNA](https://www.britannica.com/science/recombinant-DNA-technology) methods allows stem cells derived from a patient to be modified in the laboratory to introduce a desired gene. For example, a normal beta-globin gene may be introduced into the DNA of [bone marrow](https://www.britannica.com/science/bone-marrow)-derived hematopoietic stem cells from a patient with [sickle cell anemia](https://www.britannica.com/science/sickle-cell-anemia); introduction of these GM [cells](https://www.britannica.com/science/cell-biology) into the patient could cure the disease without the need for a matched donor.

**TORALBA**

**Role of GMOs in**[**environmental**](https://www.britannica.com/science/environment)**management**

[[](https://www.britannica.com/video/Top-questions-answers-genetically-modified-organisms/-245665)](https://www.britannica.com/video/Top-questions-answers-genetically-modified-organisms/-245665)

Are genetically modified organisms safe?Questions and answers about genetically modified organisms.

[See all videos for this article](https://www.britannica.com/science/genetically-modified-organism/images-videos)

Another application of GMOs is in the management of [environmental issues](https://www.britannica.com/science/conservation-ecology). For example, some [bacteria](https://www.britannica.com/science/bacteria) can produce biodegradable [plastics](https://www.britannica.com/science/plastic), and the transfer of that ability to microbes that can be easily grown in the laboratory may enable the wide-scale “greening” of the plastics industry. In the early 1990s, [Zeneca](https://www.britannica.com/topic/Zeneca-Group-PLC), a British company, developed a microbially produced biodegradable plastic called Biopol (polyhydroxyalkanoate, or PHA). The plastic was made with the use of a GM bacterium, *Ralstonia eutropha*, to convert [glucose](https://www.britannica.com/science/glucose) and a variety of organic acids into a flexible [polymer](https://www.britannica.com/science/polymer). GMOs endowed with the bacterially encoded ability to metabolize [oil](https://www.britannica.com/science/oil-chemical-compound) and heavy [metals](https://www.britannica.com/science/metal-chemistry) may provide efficient bioremediation strategies.

BENAOJAN

**Sociopolitical relevance of GMOs**

While GMOs offer many potential benefits to society, the potential risks associated with them have fueled controversy, especially in the food industry. Many skeptics warn about the dangers that GM crops may pose to human health. For example, genetic manipulation may potentially alter the allergenic properties of crops. Whether some GM crops, such as [golden rice](https://www.britannica.com/technology/golden-rice), deliver on the promise of improved health benefits is also unclear. The release of GM mosquitoes and other GMOs into the [environment](https://www.merriam-webster.com/dictionary/environment) also raised concerns. More-established risks were associated with the potential spread of engineered crop genes to native flora and the possible [evolution](https://www.britannica.com/science/evolution-scientific-theory) of insecticide-resistant “superbugs.”

From the late 1990s, the [European Union](https://www.britannica.com/topic/European-Union) (EU) addressed such concerns by [implementing](https://www.merriam-webster.com/dictionary/implementing) strict GMO labeling laws. In the early 2000s, all GM foods and GM animal feeds in the EU were required to be labeled if they consisted of or contained GM products in a proportion greater than 0.9 percent. By contrast, in the United States, foods containing GM ingredients did not require special labeling, though the issue was hotly debated at national and state levels. Many opponents of GM products focused their arguments on unknown risks to food safety. However, despite the concerns of some consumer and health groups, especially in Europe, numerous scientific panels, including the U.S. [Food and Drug Administration](https://www.britannica.com/topic/Food-and-Drug-Administration), concluded that [consumption](https://www.merriam-webster.com/dictionary/consumption) of GM foods was safe, even in cases involving GM foods with genetic material from very distantly related organisms.

[[](https://www.britannica.com/video/CRISPR-society-medicine/-219151)](https://www.britannica.com/video/CRISPR-society-medicine/-219151)

The strict regulations on GM products in the EU have been a source of tension in agricultural trade. In the late 1990s, the EU declared a [moratorium](https://www.merriam-webster.com/dictionary/moratorium) on the import and use of GM crops. However, the ban—which led to trade disputes with other countries, particularly the [United States](https://www.britannica.com/place/United-States), where GM foods had been accepted openly—was considered unjustified by the [World Trade Organization](https://www.britannica.com/topic/World-Trade-Organization). In consequence, the EU [implemented](https://www.merriam-webster.com/dictionary/implemented) regulatory changes that allowed for the import of certain GM crops. Within Europe, however, only one GM crop, a type of insect-resistant corn (maize), was [cultivated](https://www.merriam-webster.com/dictionary/cultivated). Some countries, including certain African states, had likewise rejected GM products. Still other countries, such as Canada, China, [Argentina](https://www.britannica.com/place/Argentina), and Australia, had open policies on GM foods.

The use of GMOs in medicine and research has produced a [debate that is more philosophical](https://www.britannica.com/topic/medical-ethics) in nature. For example, while genetic researchers believe they are working to cure disease and [ameliorate](https://www.merriam-webster.com/dictionary/ameliorate) suffering, many people worry that current gene therapy approaches may one day be applied to produce “designer” children or to lengthen the natural human life span. Similar to many other technologies, gene therapy and the production and application of GMOs can be used to address and resolve complicated scientific, medical, and environmental issues, but they must be used wisely.

COMMERCIAL OR PALARO

**CLEMENTE**

**Biotechnology**

biotechnology, the use of [biology](https://www.britannica.com/science/biology) to solve problems and make useful products. The most prominent area of biotechnology is the production of therapeutic proteins and other drugs through [genetic engineering](https://www.britannica.com/science/genetic-engineering).

**History of biotechnology**

People have been harnessing biological processes to improve their [quality of life](https://www.britannica.com/topic/quality-of-life) for some 10,000 years, beginning with the first agricultural [communities](https://www.merriam-webster.com/dictionary/communities). Approximately 6,000 years ago, humans began to tap the biological processes of microorganisms in order to make bread, alcoholic beverages, and cheese and to preserve dairy products. But such processes are not what is meant today by *biotechnology*, a term first widely applied to the molecular and cellular technologies that began to emerge in the 1960s and ’70s. A fledgling “biotech” [industry](https://www.britannica.com/money/industry) began to coalesce in the mid- to late 1970s, led by [Genentech](https://www.britannica.com/topic/Genentech-Inc), a [pharmaceutical](https://www.britannica.com/technology/pharmaceutical) company established in 1976 by Robert A. Swanson and Herbert W. Boyer to commercialize the [recombinant DNA technology](https://www.britannica.com/science/recombinant-DNA-technology) pioneered by Boyer, [Paul Berg](https://www.britannica.com/biography/Paul-Berg), and Stanley N. Cohen. Early companies such as Genentech, Amgen, Biogen, Cetus, and Genex began by [manufacturing](https://www.britannica.com/technology/manufacturing) genetically engineered substances primarily for medical and environmental uses.

[](https://cdn.britannica.com/46/206546-050-797ECAC4/Researcher-biological-samples-laboratory-purify-molecules-therapeutic-proteins.jpg)

[biotechnology](https://cdn.britannica.com/46/206546-050-797ECAC4/Researcher-biological-samples-laboratory-purify-molecules-therapeutic-proteins.jpg)A researcher processing biological samples in a laboratory to purify molecules for the production of therapeutic proteins.(more)

For more than a decade, the biotechnology industry was dominated by [recombinant](https://www.britannica.com/science/recombination-genetics) [DNA](https://www.britannica.com/science/DNA) [technology](https://www.britannica.com/technology/technology), or [genetic engineering](https://www.britannica.com/science/genetic-engineering). This technique consists of splicing the [gene](https://www.britannica.com/science/gene) for a useful [protein](https://www.britannica.com/science/protein) (often a human protein) into production cells—such as yeast, [bacteria](https://www.britannica.com/science/bacteria), or mammalian cells in culture—which then begin to produce the protein in volume. In the process of splicing a gene into a production [cell](https://www.britannica.com/science/cell-biology), a new organism is created. At first, biotechnology investors and researchers were uncertain about whether the courts would permit them to [acquire](https://www.britannica.com/dictionary/acquire) [patents](https://www.britannica.com/topic/patent) on organisms; after all, patents were not allowed on new organisms that happened to be discovered and identified in nature. But, in 1980, the [U.S. Supreme Court](https://www.britannica.com/topic/Supreme-Court-of-the-United-States), in the case of *Diamond* v. *Chakrabarty*, resolved the matter by ruling that “a live human-made microorganism is patentable subject matter.” This decision spawned a wave of new biotechnology firms and the infant industry’s first investment boom. In 1982 recombinant [insulin](https://www.britannica.com/science/insulin) became the first product made through genetic engineering to secure approval from the U.S. [Food and Drug Administration](https://www.britannica.com/topic/Food-and-Drug-Administration) (FDA). Since then, dozens of genetically engineered protein medications have been commercialized around the world, including recombinant versions of [growth hormone](https://www.britannica.com/science/growth-hormone), clotting factors, proteins for [stimulating](https://www.britannica.com/dictionary/stimulating) the production of red and white blood cells, [interferon](https://www.britannica.com/science/interferon)s, and clot-dissolving agents.

BENAOJAN

**Approaches and tools**

In the early years, the main achievement of biotechnology was the ability to produce naturally occurring therapeutic molecules in larger quantities than could be derived from conventional sources such as [plasma](https://www.britannica.com/science/plasma-biology), animal organs, and human cadavers. Recombinant proteins are also less likely to be contaminated with pathogens or to provoke allergic reactions. Today, biotechnology researchers seek to discover the root molecular causes of disease and to intervene precisely at that level. Sometimes this means producing therapeutic proteins that augment the body’s own supplies or that make up for genetic deficiencies, as in the first generation of biotech medications. (Gene therapy—insertion of genes [encoding](https://www.britannica.com/dictionary/encoding) a needed protein into a patient’s body or cells—is a related approach.)

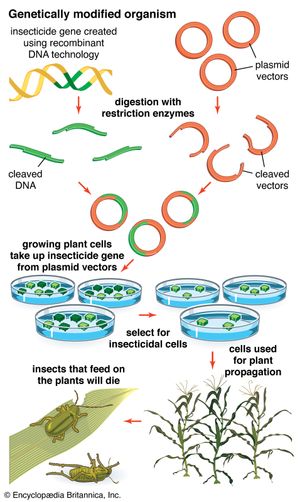
The biotechnology industry has also expanded its research into the development of traditional [pharmaceuticals](https://www.britannica.com/technology/pharmaceutical-industry) and [monoclonal antibodies](https://www.britannica.com/science/monoclonal-antibody) that stop the progress of a disease. Successful production of monoclonal antibodies was one of the most important techniques of biotechnology to emerge during the last quarter of the 20th century. The specificity of monoclonal antibodies and their availability in quantity have made it possible to devise sensitive assays for an enormous range of biologically important substances and to distinguish cells from one another by identifying previously unknown marker molecules on their surfaces. Such advances were made possible through the study of genes ([genomics](https://www.britannica.com/science/genomics)), the proteins that they [encode](https://www.britannica.com/dictionary/encode) (proteomics), and the larger biological pathways in which they act.

TORALBA

**Applications of biotechnology**

Biotechnology has numerous applications, particularly in [medicine](https://www.britannica.com/science/medicine) and agriculture. Examples include the use of biotechnology in merging biological information with computer [technology](https://www.britannica.com/technology/technology) ([bioinformatics](https://www.britannica.com/science/bioinformatics)), exploring the use of microscopic equipment that can enter the [human body](https://www.britannica.com/science/human-body) ([nanotechnology](https://www.britannica.com/technology/nanotechnology)), and possibly applying techniques of [stem cell](https://www.britannica.com/science/stem-cell) research and [cloning](https://www.britannica.com/science/cloning) to replace dead or defective cells and tissues ([regenerative medicine](https://www.britannica.com/science/regenerative-medicine)). Companies and academic laboratories [integrate](https://www.merriam-webster.com/dictionary/integrate) these [disparate](https://www.merriam-webster.com/dictionary/disparate) technologies in an effort to analyze downward into molecules and also to synthesize upward from [molecular biology](https://www.britannica.com/science/molecular-biology) toward chemical pathways, tissues, and organs.

In addition to being used in health care, biotechnology has proved helpful in refining industrial processes through the discovery and production of biological [enzymes](https://www.britannica.com/science/enzyme) that spark chemical reactions ([catalysts](https://www.britannica.com/science/catalyst)); for environmental cleanup, with enzymes that digest contaminants into harmless chemicals and then die after consuming the available “food supply”; and in agricultural production through [genetic engineering](https://www.britannica.com/science/genetic-engineering).

[](https://cdn.britannica.com/44/117844-050-B0ECC780/methods-organisms-recombinant-DNA-technology.jpg)

[Genetically modified organisms](https://cdn.britannica.com/44/117844-050-B0ECC780/methods-organisms-recombinant-DNA-technology.jpg)Scientific methods that include recombinant DNA technology are used to produce genetically modified organisms.(more)

[Agricultural](https://www.britannica.com/technology/agricultural-technology) applications of biotechnology have proved the most controversial. Some activists and consumer groups have called for bans on [genetically modified organisms](https://www.britannica.com/science/genetically-modified-organism) (GMOs) or for labeling laws to inform [consumers](https://www.britannica.com/dictionary/consumers) of the growing presence of GMOs in the [food](https://www.britannica.com/topic/food) supply. In the [United States](https://www.britannica.com/place/United-States), the introduction of GMOs into agriculture began in 1993, when the FDA approved bovine somatotropin (BST), a [growth hormone](https://www.britannica.com/science/growth-hormone) that boosts [milk](https://www.britannica.com/topic/milk) production in dairy cows. The next year, the FDA approved the first genetically modified whole food, a tomato engineered for a longer shelf life. Since then, regulatory approval in the United States, Europe, and elsewhere has been won by dozens of agricultural GMOs, including crops that produce their own pesticides and crops that survive the application of specific herbicides used to kill weeds.

Studies by the [United Nations](https://www.britannica.com/topic/United-Nations), the U.S. National Academy of Sciences, the [European Union](https://www.britannica.com/topic/European-Union), the [American Medical Association](https://www.britannica.com/topic/American-Medical-Association), U.S. regulatory agencies, and other organizations have found GMO foods to be safe, but [skeptics](https://www.britannica.com/dictionary/skeptics) contend that it is still too early to judge the long-term health and ecological effects of such crops. In the late 20th and early 21st centuries, the land area planted in genetically modified crops increased dramatically, from 1.7 million hectares (4.2 million acres) in 1996 to 180 million hectares (445 million acres) by 2014. By 2014–15 about 90 percent of the corn, cotton, and soybeans planted in the United States were genetically modified. The majority of genetically modified crops were grown in the Americas.

Overall, the revenues of U.S. and European biotechnology industries roughly doubled over the five-year period from 1996 through 2000. Rapid growth continued into the 21st century, fueled by the introduction of new products, particularly in health care. By 2020 the biotechnology market size was estimated at $752.88 billion globally, with new opportunities for growth [emerging](https://www.britannica.com/dictionary/emerging) in particular from government- and industry-driven efforts to accelerate [drug](https://www.britannica.com/science/drug-chemical-agent) development and product-approval processes.

MONICA

**genetic engineering**

**genetic engineering**, the artificial manipulation, modification, and recombination of [DNA](https://www.britannica.com/science/DNA) or other [nucleic acid](https://www.britannica.com/science/nucleic-acid) [molecules](https://www.britannica.com/science/molecule) in order to modify an [organism](https://www.britannica.com/science/multicellular-organism) or [population](https://www.britannica.com/science/population-biology-and-anthropology) of organisms. The term *genetic engineering* is generally used to refer to methods of [recombinant DNA technology](https://www.britannica.com/science/recombinant-DNA-technology), which emerged from basic research in microbial [genetics](https://www.britannica.com/science/genetics). The techniques employed in genetic engineering have led to the production of medically important products, including human [insulin](https://www.britannica.com/science/insulin), human [growth hormone](https://www.britannica.com/science/growth-hormone), and [hepatitis B](https://www.britannica.com/science/hepatitis-B) [vaccine](https://www.britannica.com/science/vaccine), as well as to the development of [genetically modified organisms](https://www.britannica.com/science/genetically-modified-organism) such as disease-resistant plants.

**Historical developments**

[[](https://www.britannica.com/video/Genetically-Modified-Humans-CRISPR-Cas-9-Explained/-280930)](https://www.britannica.com/video/Genetically-Modified-Humans-CRISPR-Cas-9-Explained/-280930)

genetically modified humansCRISPR and genetically modified humans.

The term *genetic engineering* initially referred to various techniques used for the modification or manipulation of organisms through the processes of [heredity](https://www.britannica.com/science/heredity-genetics) and [reproduction](https://www.britannica.com/science/reproduction-biology). As such, the term embraced both [artificial selection](https://www.britannica.com/science/selective-breeding) and all the interventions of biomedical techniques, among them [artificial insemination](https://www.britannica.com/science/artificial-insemination), [in vitro fertilization](https://www.britannica.com/science/in-vitro-fertilization) (e.g., “test-tube” babies), [cloning](https://www.britannica.com/science/cloning), and [gene](https://www.britannica.com/science/gene) manipulation. In the latter part of the 20th century, however, the term came to refer more specifically to methods of [recombinant DNA technology](https://www.britannica.com/science/recombinant-DNA-technology) (or [gene cloning](https://www.britannica.com/science/recombination-genetics)), in which DNA molecules from two or more sources are combined either within [cells](https://www.britannica.com/science/cell-biology) or in vitro and are then inserted into host organisms in which they are able to [propagate](https://www.merriam-webster.com/dictionary/propagate).

The possibility for [recombinant DNA](https://www.britannica.com/science/recombinant-DNA-technology) [technology](https://www.britannica.com/technology/technology) emerged with the discovery of [restriction enzymes](https://www.britannica.com/science/restriction-enzyme) in 1968 by Swiss microbiologist [Werner Arber](https://www.britannica.com/biography/Werner-Arber). The following year American microbiologist [Hamilton O. Smith](https://www.britannica.com/biography/Hamilton-O-Smith) purified so-called [type II restriction enzymes](https://www.britannica.com/science/type-II-restriction-enzyme), which were found to be essential to genetic engineering for their ability to [cleave](https://www.merriam-webster.com/dictionary/cleave) a specific site within the DNA (as opposed to type I restriction enzymes, which cleave DNA at random sites). Drawing on Smith’s work, American molecular biologist [Daniel Nathans](https://www.britannica.com/biography/Daniel-Nathans) helped advance the technique of DNA recombination in 1970–71 and demonstrated that type II enzymes could be useful in genetic studies. Genetic engineering based on recombination was pioneered in 1973 by American biochemists [Stanley N. Cohen](https://www.britannica.com/biography/Stanley-Cohen) and Herbert W. Boyer, who were among the first to cut DNA into fragments, rejoin different fragments, and insert the new genes into [*E. coli*](https://www.britannica.com/science/E-coli) [bacteria](https://www.britannica.com/science/bacteria), which then reproduced.

**CLEMENTE**

**Process and techniques**

[](https://cdn.britannica.com/73/269473-050-33CA6451/Vaccine-manufacturing-at-GlaxoSmithKline-facility-in-Wavre-Belgium.jpg)

[Vaccine development](https://cdn.britannica.com/73/269473-050-33CA6451/Vaccine-manufacturing-at-GlaxoSmithKline-facility-in-Wavre-Belgium.jpg)The generation of vaccines relies heavily on techniques in genetic engineering.

Most [recombinant DNA technology](https://www.britannica.com/science/recombinant-DNA-technology) involves the insertion of foreign genes into the [plasmids](https://www.britannica.com/science/plasmid) of common laboratory strains of [bacteria](https://www.britannica.com/science/bacteria). [Plasmids](https://www.britannica.com/science/plasmid) are small rings of DNA; they are not part of the bacterium’s [chromosome](https://www.britannica.com/science/chromosome) (the main [repository](https://www.britannica.com/dictionary/repository) of the organism’s genetic information). Nonetheless, they are capable of directing [protein](https://www.britannica.com/science/protein) synthesis, and, like chromosomal [DNA](https://www.britannica.com/science/DNA), they are reproduced and passed on to the bacterium’s progeny. Thus, by incorporating foreign DNA (for example, a mammalian [gene](https://www.britannica.com/science/gene)) into a bacterium, researchers can obtain an almost limitless number of copies of the inserted gene. Furthermore, if the inserted gene is operative (i.e., if it directs protein synthesis), the modified bacterium will produce the protein specified by the foreign DNA.

A subsequent generation of genetic engineering techniques that emerged in the early 21st century centred on [gene editing](https://www.britannica.com/science/gene-editing). Gene editing, based on a [technology](https://www.britannica.com/technology/technology) known as [CRISPR-Cas9](https://www.britannica.com/technology/CRISPR), allows researchers to customize a living organism’s genetic sequence by making very specific changes to its DNA. Gene editing has a wide array of applications, being used for the genetic modification of crop plants and livestock and of laboratory model organisms (e.g., mice).

The correction of genetic errors associated with disease in animals suggests that gene editing has potential applications in [gene therapy](https://www.britannica.com/science/gene-therapy) for humans. Gene therapy is the introduction of a normal gene into an individual’s genome in order to repair a [mutation](https://www.britannica.com/science/mutation-genetics) that causes a genetic disease. When a normal gene is inserted into a mutant [nucleus](https://www.britannica.com/science/nucleus-biology), it most likely will [integrate](https://www.merriam-webster.com/dictionary/integrate) into a chromosomal site different from the defective allele; although this may repair the mutation, a new mutation may result if the normal gene [integrates](https://www.merriam-webster.com/dictionary/integrates) into another functional gene. If the normal gene replaces the mutant [allele](https://www.britannica.com/science/allele), there is a chance that the transformed cells will proliferate and produce enough normal gene product for the entire body to be restored to the undiseased [phenotype](https://www.britannica.com/science/phenotype).

TORALBA

**Applications**

[](https://cdn.britannica.com/61/131361-050-1A1D205E/corn.jpg)

[Genetically engineered corn (maize)](https://cdn.britannica.com/61/131361-050-1A1D205E/corn.jpg)A field of genetically engineered corn (maize).

Genetic engineering has advanced the understanding of many theoretical and practical aspects of gene function and organization. Through recombinant DNA techniques, bacteria have been created that are capable of synthesizing human [insulin](https://www.britannica.com/science/insulin), human [growth hormone](https://www.britannica.com/science/growth-hormone), alpha [interferon](https://www.britannica.com/science/interferon), a [hepatitis B](https://www.britannica.com/science/hepatitis-B) [vaccine](https://www.britannica.com/science/vaccine), and other medically useful substances. Plants may be genetically adjusted to enable them to fix nitrogen, and [genetic diseases](https://www.britannica.com/science/human-genetic-disease) can possibly be corrected by replacing dysfunctional genes with normally functioning genes.

Genes for toxins that kill insects have been introduced in several species of plants, including corn and cotton. Bacterial genes that confer resistance to herbicides also have been introduced into crop plants. Other attempts at the genetic engineering of plants have aimed at improving the nutritional value of the plant.

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**Controversy and ethical issues**

In 1980 the “new” microorganisms created by recombinant DNA research were deemed [patentable](https://www.britannica.com/topic/patent), and in 1986 the [U.S. Department of Agriculture](https://www.britannica.com/topic/US-Department-of-Agriculture) approved the sale of the first living genetically altered organism—a [virus](https://www.britannica.com/science/virus), used as a pseudorabies vaccine, from which a single gene had been cut. Since then several hundred [patents](https://www.britannica.com/topic/patent) have been awarded for genetically altered bacteria and plants. Patents on genetically engineered and genetically modified organisms, particularly crops and other foods, however, were a [contentious](https://www.merriam-webster.com/dictionary/contentious) issue, and they remained so into the first part of the 21st century.

[](https://cdn.britannica.com/41/246541-050-8D5BA567/Golden-rice-GMO-Vitamin-A.jpg)

[golden rice](https://cdn.britannica.com/41/246541-050-8D5BA567/Golden-rice-GMO-Vitamin-A.jpg)

Grains of golden rice, a genetically modified rice (*Oryza sativa*) that contains beta-carotene.

Special concern has been focused on genetic engineering for fear that it might result in the introduction of unfavourable and possibly dangerous traits into microorganisms that were previously free of them—e.g., resistance to antibiotics, production of toxins, or a tendency to cause disease. Indeed, possibilities for misuse of genetic engineering were vast. In particular, there was significant concern about genetically modified organisms, especially modified crops, and their impacts on human and [environmental health](https://www.britannica.com/science/environmental-health). For example, genetic manipulation may potentially alter the allergenic properties of crops. In addition, whether some genetically modified crops, such as [golden rice](https://www.britannica.com/technology/golden-rice), deliver on the promise of improved health benefits was also unclear. The release of genetically modified mosquitoes and other modified organisms into the [environment](https://www.merriam-webster.com/dictionary/environment) also raised concerns.

In the 21st century, significant progress in the development of gene-editing tools brought new urgency to long-standing discussions about the [ethical](https://www.merriam-webster.com/dictionary/ethical) and social [implications](https://www.merriam-webster.com/dictionary/implications) surrounding the genetic engineering of humans. The application of gene editing in humans raised significant ethical concerns, particularly regarding its potential use to alter traits such as intelligence and beauty. More practically, some researchers attempted to use gene editing to alter genes in human sperm, which would enable the edited genes to be passed on to subsequent generations, while others sought to alter genes that increase the risk of certain types of cancer, with the aim of reducing cancer risk in offspring. The impacts of gene editing on [human genetics](https://www.britannica.com/science/human-genetics), however, were unknown, and regulations to guide its use were largely lacking.