**Genetically modified organisms**

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A **genetically modified organism** (**GMO**) is any organism whose [genetic](http://en.wikipedia.org/wiki/Gene) material has been altered using [genetic engineering](http://en.wikipedia.org/wiki/Genetic_engineering) techniques. GMOs are the source of [genetically modified foods](http://en.wikipedia.org/wiki/Genetically_modified_food) and are also widely used in scientific research and to produce goods other than food. The term GMO is very close to the [technical legal term](http://en.wikipedia.org/wiki/Technical_terminology), 'living modified organism', defined in the [Cartagena Protocol on Biosafety](http://en.wikipedia.org/wiki/Cartagena_Protocol_on_Biosafety), which regulates international trade in living GMOs (specifically, "any living organism that possesses a novel combination of genetic material obtained through the use of modern biotechnology") Production

Genetic modification involves the mutation, insertion, or deletion of genes. Inserted genes usually come from a different species in a form of [horizontal gene-transfer](http://en.wikipedia.org/wiki/Horizontal_gene_transfer). In nature this can occur when exogenous DNA penetrates the [cell membrane](http://en.wikipedia.org/wiki/Cell_membrane) for any reason. To do this artificially may require:

* attaching the genes to a [virus](http://en.wikipedia.org/wiki/Virus)
* physically inserting the extra DNA into the nucleus of the intended host with a very small syringe
* with the use of [electroporation](http://en.wikipedia.org/wiki/Electroporation" \o "Electroporation) (that is, introducing DNA from one organism into the cell of another by use of an electric pulse)
* with very small particles fired from a [gene gun](http://en.wikipedia.org/wiki/Gene_gun).

Other methods exploit natural forms of gene transfer, such as the ability of *[Agrobacterium](http://en.wikipedia.org/wiki/Agrobacterium" \o "Agrobacterium)* to transfer genetic material to plants. or the ability of [lentiviruses](http://en.wikipedia.org/wiki/Lentivirus" \o "Lentivirus) to transfer genes to animal cells.

**History**

Humans have [domesticated](http://en.wikipedia.org/wiki/Domestication) plants and animals since around 12,000 BCE, using [selective breeding](http://en.wikipedia.org/wiki/Selective_breeding) or artificial selection (as contrasted with [natural selection](http://en.wikipedia.org/wiki/Natural_selection)). The process of [selective breeding](http://en.wikipedia.org/wiki/Selective_breeding), in which organisms with desired [traits](http://en.wikipedia.org/wiki/Phenotypic_trait) (and thus with the desired [genes](http://en.wikipedia.org/wiki/Genes)) are used to breed the next generation and organisms lacking the trait are not bred, is the oldest form of genetic modification by humans. When [nucleic acid sequences](http://en.wikipedia.org/wiki/Nucleic_acid_sequence) are combined in a laboratory, the resulting DNA is called [recombinant DNA](http://en.wikipedia.org/wiki/Recombinant_DNA). Recombinant DNA may contain [oligonucleotides](http://en.wikipedia.org/wiki/Oligonucleotides" \o "Oligonucleotides) from the same or similar species, in which case it is called "[cisgenic](http://en.wikipedia.org/wiki/Cisgenesis" \o "Cisgenesis)", or may contain oligonucleotides from different organisms that could not naturally interbreed, in which case it is called "[transgenic](http://en.wikipedia.org/wiki/Transgenesis)". Recombinant DNA may also contain [synthetic](http://en.wikipedia.org/wiki/Artificial_gene_synthesis) sequences.

The first recombinant DNA molecules were produced by [Paul Berg](http://en.wikipedia.org/wiki/Paul_Berg) in 1972. [Genetic engineering](http://en.wikipedia.org/wiki/Genetic_engineering), the direct manipulation of genes using [biotechnology](http://en.wikipedia.org/wiki/Biotechnology), was first accomplished by [Herbert Boyer](http://en.wikipedia.org/wiki/Herbert_Boyer) and [Stanley Cohen](http://en.wikipedia.org/wiki/Stanley_Cohen_(biochemist)) in 1973. Whereas selective breeding depends on naturally occurring genetic variation within a population or species, genetic engineering can involve the intentional introduction of genes from different species. Advances have allowed scientists to manipulate, remove, and add genes to a variety of different organisms to induce a range of different traits. From 1976 the technology became commercialized, with companies producing and selling genetically modified foods and medicines.

**Uses**

GMOs are used in biological and medical research, production of [pharmaceutical drugs](http://en.wikipedia.org/wiki/Pharmaceutical_drug), experimental medicine (e.g. [gene therapy](http://en.wikipedia.org/wiki/Gene_therapy)), and agriculture (e.g. [**golden rice**](http://en.wikipedia.org/wiki/Golden_rice)**, resistance to** [**herbicides**](http://en.wikipedia.org/wiki/Herbicides)). The term "genetically modified organism" does not always imply, but can include, targeted insertions of genes from one [species](http://en.wikipedia.org/wiki/Species) into another. For example, a gene from a jellyfish, encoding a [fluorescent](http://en.wikipedia.org/wiki/Fluorescence) protein called [GFP](http://en.wikipedia.org/wiki/Green_fluorescent_protein), or green fluorescent protein, can be physically linked and thus [co-expressed](http://en.wikipedia.org/wiki/Gene_expression) with mammalian genes to identify the location of the protein encoded by the GFP-tagged gene in the mammalian cell. Such methods are useful tools for [biologists](http://en.wikipedia.org/wiki/Biologist) in many areas of research, including those who study the mechanisms of human and other diseases or fundamental biological processes in [eukaryotic](http://en.wikipedia.org/wiki/Eukaryote) or [prokaryotic](http://en.wikipedia.org/wiki/Prokaryote) cells.

**Microbes**

Bacteria were the first organisms to be modified in the laboratory, due to their simple genetics.

They continue to be important model organisms for experiments in genetic engineering. In the field of [synthetic biology](http://en.wikipedia.org/wiki/Synthetic_biology), they have been used to test various synthetic approaches, from synthesizing genomes to creating novel [nucleotides](http://en.wikipedia.org/wiki/Nucleotides).

These organisms are now used for several purposes, and are particularly important in producing large amounts of pure human [proteins](http://en.wikipedia.org/wiki/Protein) for use in medicine.

[Genetically modified bacteria](http://en.wikipedia.org/wiki/Genetically_modified_bacteria) are used to produce the protein [insulin](http://en.wikipedia.org/wiki/Insulin) to treat [diabetes](http://en.wikipedia.org/wiki/Diabetes). Similar bacteria have been used to produce biofuels, [clotting factors](http://en.wikipedia.org/wiki/Coagulation) to treat [haemophilia](http://en.wikipedia.org/wiki/Haemophilia), and [human growth hormone](http://en.wikipedia.org/wiki/Human_growth_hormone) to treat various forms of [dwarfism](http://en.wikipedia.org/wiki/Dwarfism).

In addition, various genetically engineered micro-organisms are routinely used as sources of [enzymes](http://en.wikipedia.org/wiki/Enzyme) for the manufacture of a variety of processed foods. These include [alpha-amylase](http://en.wikipedia.org/wiki/Alpha-amylase) from bacteria, which converts starch to simple sugars, [chymosin](http://en.wikipedia.org/wiki/Chymosin" \o "Chymosin) from bacteria or fungi, which clots milk protein for cheese making, and [pectin esterase](http://en.wikipedia.org/wiki/Pectinesterase) from fungi, which improves fruit juice clarity.

**Plants**

**Transgenic plants**

[](http://en.wikipedia.org/wiki/File:Btcornafrica.jpg)

Kenyans examining insect-resistant transgenic [Bt](http://en.wikipedia.org/wiki/Bacillus_thuringiensis) corn

Transgenic plants have been engineered for scientific research, to create new colours in plants, and to create different crops.

In research, plants are engineered to help discover the functions of certain genes. One way to do this is to [knock out](http://en.wikipedia.org/wiki/Gene_knockout) the gene of interest and see what [phenotype](http://en.wikipedia.org/wiki/Phenotype) develops. Another strategy is to attach the gene to a strong [promoter](http://en.wikipedia.org/wiki/Promoter_(biology)) and see what happens when it is over expressed. A common technique used to find out where the gene is expressed is to attach it to [GUS](http://en.wikipedia.org/wiki/GUS_reporter_system) or a similar [reporter gene](http://en.wikipedia.org/wiki/Reporter_gene) that allows visualisation of the location.

[](http://en.wikipedia.org/wiki/File:Blue_Rose_APPLAUSE.jpg)

Suntory "blue" rose

After thirteen years of collaborative research, an Australian company – [Florigene](http://en.wikipedia.org/wiki/Florigene" \o "Florigene), and a Japanese company – [Suntory](http://en.wikipedia.org/wiki/Suntory), created a [blue rose](http://en.wikipedia.org/wiki/Blue_rose)(actually lavender or mauve) in 2004. The genetic engineering involved three alterations – adding two genes, and interfering with another. One of the added genes was for the [blue plant pigment](http://en.wikipedia.org/wiki/Biological_pigment) [delphinidin](http://en.wikipedia.org/wiki/Delphinidin" \o "Delphinidin) cloned from the [pansy](http://en.wikipedia.org/wiki/Pansy). The researchers then used [RNA interference](http://en.wikipedia.org/wiki/RNA_interference) (RNAi) technology to depress all color production by endogenous genes by blocking a crucial protein in color production, called [dihydroflavonol 4-reductase)](http://en.wikipedia.org/wiki/Dihydrokaempferol_4-reductase" \o "Dihydrokaempferol 4-reductase) (DFR), and adding a variant of that protein that would not be blocked by the RNAi but that would allow the delphinidin to work. The roses are sold in Japan, the United States, and Canada. Florigene has also created and sells lavender-colored [carnations](http://en.wikipedia.org/wiki/Dianthus_caryophyllus#Colors) that are genetically engineered in a similar way.

Simple plants and plant cells have been genetically engineered for production of biopharmaceuticals in [bioreactors](http://en.wikipedia.org/wiki/Bioreactors) as opposed to cultivating plants in open fields. Work has been done with [duckweed](http://en.wikipedia.org/wiki/Lemna) *[Lemna minor](http://en.wikipedia.org/wiki/Lemna_minor" \o "Lemna minor)*, the [algae](http://en.wikipedia.org/wiki/Algae) *[Chlamydomonas reinhardtii](http://en.wikipedia.org/wiki/Chlamydomonas_reinhardtii" \o "Chlamydomonas reinhardtii)* and the [moss](http://en.wikipedia.org/wiki/Moss" \o "Moss)[*Physcomitrella patens*](http://en.wikipedia.org/wiki/Physcomitrella_patens). An Israeli company, Protalix, has developed a method to produce therapeutics in cultured transgenic carrot and tobacco cells. Protalix and its partner, Pfizer, received FDA approval to market its drug [Elelyso](http://en.wikipedia.org/wiki/Taliglucerase_alfa" \o "Taliglucerase alfa), a treatment for [Gaucher's disease](http://en.wikipedia.org/wiki/Gaucher%27s_disease" \o "Gaucher's disease), in 2012.

**Genetically modified crops**

In agriculture, currently marketed [genetically engineered crops](http://en.wikipedia.org/wiki/Genetically_engineered_crops) have [traits](http://en.wikipedia.org/wiki/Phenotypic_trait) such as resistance to pests, resistance to [herbicides](http://en.wikipedia.org/wiki/Herbicides), increased nutritional value, or production of valuable goods such as drugs ([pharming](http://en.wikipedia.org/wiki/Pharming_(genetics)" \o "Pharming (genetics))). Products under development include crops that are able to thrive in environmental conditions outside the species' native range or in changed conditions in their range (e.g. drought or salt resistance). Products that existed and have been withdrawn include those with extended product [shelf life](http://en.wikipedia.org/wiki/Shelf_life), such as the **Flavr-savr tomato**.

Since the first commercial cultivation of genetically modified plants in 1996, they have been modified to be tolerant to the herbicides [glufosinate](http://en.wikipedia.org/wiki/Glufosinate" \o "Glufosinate) and [glyphosate](http://en.wikipedia.org/wiki/Glyphosate" \o "Glyphosate), to be resistant to virus damage (as in [Ringspot virus](http://en.wikipedia.org/wiki/Papaya_ringspot_virus" \o "Papaya ringspot virus)-resistant GM papaya grown in Hawaii), and to produce the [Bt toxin](http://en.wikipedia.org/wiki/Bacillus_thuringiensis), an insecticide that is documented as non-toxic to mammals. Plants, including [algae](http://en.wikipedia.org/wiki/Algae_fuel), [jatropha](http://en.wikipedia.org/wiki/Jatropha" \o "Jatropha), [maize](http://en.wikipedia.org/wiki/Maize), and [poplars](http://en.wikipedia.org/wiki/Poplars), have been genetically modified for use in producing fuel, known as [biofuel](http://en.wikipedia.org/wiki/Biofuel" \o "Biofuel).

Second- and third-generation GM crops are on the market and under development with improved nutrition profiles and increased yields or ability to thrive in difficult environments. GM oilseed crops on the market today offer improved oil profiles for processing or healthier edible oils. Other examples include:

* A genetically modified cassava with lower cyanogen glucosides and enhanced with protein and other nutrients.
* [Golden rice](http://en.wikipedia.org/wiki/Golden_rice), which was developed by the [International Rice Research Institute](http://en.wikipedia.org/wiki/International_Rice_Research_Institute) (IRRI) and has been discussed as a possible cure for Vitamin A deficiency.
* A vitamin-enriched corn derived from South African white corn variety.
* [Camelina sativa](http://en.wikipedia.org/wiki/Camelina_sativa) that accumulates high levels of oils similar to [fish oils](http://en.wikipedia.org/wiki/Fish_oils). For discussions of issues about GM crops and GM food, see the Controversies section below and the article on [genetically modified food controversies](http://en.wikipedia.org/wiki/Genetically_modified_food_controversies).

**Cisgenic plants**

[Cisgenesis](http://en.wikipedia.org/wiki/Cisgenesis), sometimes also called [intragenesis](http://en.wikipedia.org/wiki/Intragenesis" \o "Intragenesis), is a product designation for a category of genetically engineered plants. A variety of classification schemes have been proposed that order genetically modified organisms based on the nature of introduced genotypical changes rather than the process of genetic engineering.

While some genetically modified plants are developed by the introduction of a gene originating from distant, sexually incompatible species into the host genome, cisgenic plants contain genes that have been isolated either directly from the host species or from sexually compatible species. The new genes are introduced using recombinant DNA methods and gene transfer. Some scientists hope that the approval process of cisgenic plants might be simpler than that of proper transgenics  but it remains to be seen.

**Mammals**

[](http://en.wikipedia.org/wiki/File:ChimericMouseWithPups.jpg)

Some [chimeras](http://en.wikipedia.org/wiki/Chimera_(genetics)), like the blotched mouse shown, are created through genetic modification techniques like[gene targeting](http://en.wikipedia.org/wiki/Gene_targeting).

[Genetically modified mammals](http://en.wikipedia.org/wiki/Genetically_modified_mammals) are an important category of genetically modified organisms. [Ralph L. Brinster](http://en.wikipedia.org/wiki/Ralph_L._Brinster) and Richard Palmiter developed the techniques responsible for transgenic mice, rats, rabbits, sheep, and pigs in the early 1980s, and established many of the first transgenic models of human disease, including the first carcinoma caused by a transgene. The process of genetically engineering animals is a slow, tedious, and expensive process. However, new technologies are making genetic modifications easier and more precise.The first transgenic (genetically modified) animal was produced by injecting DNA into mouse embryos then implanting the embryos in female mice.

Genetically modified animals currently being developed can be placed into six different broad classes based on the intended purpose of the genetic modification:

1. to [research](http://en.wikipedia.org/wiki/Research) human diseases (for example, to develop animal models for these diseases);
2. to produce industrial or consumer products (fibres for multiple uses);
3. to produce products intended for human therapeutic use (pharmaceutical products or tissue for implantation);
4. to enrich or enhance the animals' interactions with humans (hypo-allergenic pets);
5. to enhance production or food quality traits (faster growing fish, pigs that digest food more efficiently);
6. to improve animal health (disease resistance)

**Research use**

Transgenic animals are used as experimental models to perform [phenotypic](http://en.wikipedia.org/wiki/Phenotype) and for testing in biomedical research. Genetically modified (genetically engineered) animals are becoming more vital to the discovery and development of cures and treatments for many serious diseases. By altering the DNA or transferring DNA to an animal, we can develop certain proteins that may be used in medical treatment. Stable expressions of human proteins have been developed in many animals, including sheep, pigs, and rats. Human-alpha-1-antitrypsin, which has been tested in sheep and is used in treating humans with this deficiency and transgenic pigs with human-histo-compatibility have been studied in the hopes that the organs will be suitable for transplant with less chances of rejection.

Scientists have genetically engineered several organisms, including some mammals, to include [**green fluorescent protein**](http://en.wikipedia.org/wiki/Green_fluorescent_protein)**(GFP)** for medical research purposes ([Chalfie](http://en.wikipedia.org/wiki/Martin_Chalfie" \o "Martin Chalfie), [Shimoura](http://en.wikipedia.org/wiki/Osamu_Shimomura" \o "Osamu Shimomura), and [Tsien](http://en.wikipedia.org/wiki/Roger_Y._Tsien" \o "Roger Y. Tsien) were awarded the [Nobel prize](http://en.wikipedia.org/wiki/Nobel_Prize_in_Chemistry) in 2008 for GFP). For example fluorescent pigs have been bred in order to study [human organ transplants](http://en.wikipedia.org/wiki/Organ_transplantation), regenerating ocular [photoreceptor cells](http://en.wikipedia.org/wiki/Photoreceptor_cell), and other topics. In 2011 a Japanese-American Team created green-fluorescent cats in order to find therapies for [HIV/AIDS](http://en.wikipedia.org/wiki/HIV/AIDS) and other diseases as [Feline immunodeficiency virus](http://en.wikipedia.org/wiki/Feline_immunodeficiency_virus) (FIV) is related to HIV .In 2009, scientists in [Japan](http://en.wikipedia.org/wiki/Japan) announced that they had successfully transferred a gene into a [primate](http://en.wikipedia.org/wiki/Primate) species ([marmosets](http://en.wikipedia.org/wiki/Marmoset)) and produced a stable line of breeding transgenic primates for the first time. Their first research target for these marmosets was [Parkinson's disease](http://en.wikipedia.org/wiki/Parkinson%27s_disease), but they were also considering [Amyotrophic lateral sclerosis](http://en.wikipedia.org/wiki/Amyotrophic_lateral_sclerosis) and [Huntington's disease](http://en.wikipedia.org/wiki/Huntington%27s_disease).

**Producing human therapeutics**

Within the field known as [pharming](http://en.wikipedia.org/wiki/Pharming_(genetics)" \o "Pharming (genetics)), intensive research has been conducted to develop transgenic animals that produce biotherapeutics. On 6 February 2009, the [U.S. Food and Drug Administration](http://en.wikipedia.org/wiki/U.S._Food_and_Drug_Administration) approved the first human biological drug produced from such an animal, a [goat](http://en.wikipedia.org/wiki/Goat). The drug, [ATryn](http://en.wikipedia.org/wiki/ATryn" \o "ATryn), is an [anticoagulant](http://en.wikipedia.org/wiki/Anticoagulant) which reduces the probability of[blood clots](http://en.wikipedia.org/wiki/Blood_clot) during [surgery](http://en.wikipedia.org/wiki/Surgery) or [childbirth](http://en.wikipedia.org/wiki/Childbirth). It is extracted from the goat's milk.

**Production or food quality traits**

[Enviropig](http://en.wikipedia.org/wiki/Enviropig) was a genetically enhanced line of [Yorkshire pigs](http://en.wikipedia.org/wiki/Yorkshire_pig) in Canada created with the capability of digesting plant [phosphorus](http://en.wikipedia.org/wiki/Phosphorus) more efficiently than conventional Yorkshire pigs. The project ended in 2012. These pigs produced the enzyme [phytase](http://en.wikipedia.org/wiki/Phytase" \o "Phytase), which breaks down the indigestible phosphorus, in their saliva. The enzyme was introduced into the pig chromosome by pronuclear [microinjection](http://en.wikipedia.org/wiki/Microinjection). With this enzyme, the animal is able to digest cereal grain [phosphorus](http://en.wikipedia.org/wiki/Phosphorus). The use of these pigs would reduce the potential of water pollution since they excrete from 30 to 70.7% less phosphorus in manure depending upon the age and diet. The lower concentrations of phosphorus in [surface runoff](http://en.wikipedia.org/wiki/Surface_runoff) reduces [algal](http://en.wikipedia.org/wiki/Algae) growth, because phosphorus is the [limiting nutrient](http://en.wikipedia.org/wiki/Limiting_nutrient) for algae. Because algae consume large amounts of oxygen, it can result in dead zones for fish.

In 2011, Chinese scientists generated [dairy cows](http://en.wikipedia.org/wiki/Dairy_cows) genetically engineered with genes from human beings in order to produce milk that would be the same as human breast milk.This could potentially benefit mothers who cannot produce breast milk but want their children to have breast milk rather than formula. Aside from milk production, the researchers claim these [transgenic](http://en.wikipedia.org/wiki/Transgenic) cows to be identical to regular cows. Two months later scientists from [Argentina](http://en.wikipedia.org/wiki/Argentina) presented Rosita, a [transgenic](http://en.wikipedia.org/wiki/Transgenic) cow incorporating two human genes, to produce milk with similar properties as human breast milk. In 2012, researchers from New Zealand also developed a genetically engineered cow that produced allergy-free milk.In 2006, a pig was engineered to produce [omega-3 fatty acids](http://en.wikipedia.org/wiki/Omega-3_fatty_acid) through the expression of a [roundworm](http://en.wikipedia.org/wiki/Roundworm) gene.Goats have been genetically engineered to produce milk with strong spiderweb-like silk proteins in their milk.

[Genetically modified fish](http://en.wikipedia.org/wiki/Genetically_modified_fish) have been developed with promoters driving an over-production of [growth hormone](http://en.wikipedia.org/wiki/Growth_hormone) for use in the [aquaculture](http://en.wikipedia.org/wiki/Aquaculture) industry to increase the speed of development and potentially reduce fishing pressure on wild stocks. Aqua Bounty, a biotechnology company working on bringing a GM salmon to market, claims that their GM Aqu Advantage salmon can mature in half the time it takes non-GM salmon and achieves twice the size. Aqua Bounty has applied for regulatory approval to market their GM salmon in the US. As of May 2012 the application was still pending. On 25 November 2013 Canada approved commercial scale production and export of GM Salmon eggs but they are not approved for human consumption in Canada.

**Human gene therapy**

[Gene therapy](http://en.wikipedia.org/wiki/Gene_therapy), uses [genetically modified viruses](http://en.wikipedia.org/wiki/Genetically_modified_virus) to deliver genes that can cure disease in humans. Although gene therapy is still relatively new, it has had some successes. It has been used to treat [genetic disorders](http://en.wikipedia.org/wiki/Genetic_disorder) such as [severe combined immunodeficiency](http://en.wikipedia.org/wiki/Severe_combined_immunodeficiency), and [Leber's congenital amaurosis](http://en.wikipedia.org/wiki/Adeno_associated_virus_and_gene_therapy_of_the_human_retina" \o "Adeno associated virus and gene therapy of the human retina). Treatments are also being developed for a range of other currently incurable diseases, such as [cystic fibrosis](http://en.wikipedia.org/wiki/Cystic_fibrosis), [sickle cell anemia](http://en.wikipedia.org/wiki/Sickle_cell_anemia), [Parkinson's disease](http://en.wikipedia.org/wiki/Parkinson%27s_disease), [cancer](http://en.wikipedia.org/wiki/Cancer), [diabetes](http://en.wikipedia.org/wiki/Diabetes), [heart disease](http://en.wikipedia.org/wiki/Heart_disease)and [muscular dystrophy](http://en.wikipedia.org/wiki/Muscular_dystrophy). Current gene therapy technology only targets the non-reproductive cells meaning that any changes introduced by the treatment can not be transmitted to the next generation. Gene therapy targeting the reproductive cells—so-called "Germ line Gene Therapy"—is very controversial and is unlikely to be developed in the near future.

**Insects**

**Fruit flies**

In biological research, transgenic fruit flies ([*Drosophila melanogaster*](http://en.wikipedia.org/wiki/Drosophila_melanogaster)) are [model organisms](http://en.wikipedia.org/wiki/Model_organism) used to study the effects of genetic changes on development. Fruit flies are often preferred over other animals due to their short life cycle, low maintenance requirements, and relatively simple genome compared to many [vertebrates](http://en.wikipedia.org/wiki/Vertebrates).

**Mosquitoes**

In 2010, scientists created "malaria-resistant mosquitoes" in the laboratory The World Health Organization estimated that malaria killed almost one million people in 2008 Genetically modified male mosquitoes containing a lethal gene have been developed in order to combat the spread of [dengue fever](http://en.wikipedia.org/wiki/Dengue_fever), *[Aedes aegypti](http://en.wikipedia.org/wiki/Aedes_aegypti" \o "Aedes aegypti)* mosquitoes, the single most important carrier of dengue fever, were reduced by 80% in a 2010 trial of these GM mosquitoes in the Cayman Islands. Between 50 and 100 million people are affected by dengue fever every year and 40,000 people die from it.

**Bollworms** A strain of *Pectinophora gossypiella* ([Pink bollworm](http://en.wikipedia.org/wiki/Pink_bollworm)) has been [genetically engineered](http://en.wikipedia.org/wiki/Genetic_engineering) to express a [red fluorescent protein](http://en.wikipedia.org/wiki/Green_fluorescent_protein). This allows researchers to monitor bollworms that have been sterilized by radiation and released in order to reduce bollworm infestation. The strain has been field tested for over three years and has been approved for release.

**Aquatic life**

**Cnidarians**

[Cnidarians](http://en.wikipedia.org/wiki/Cnidarians) such as [*Hydra*](http://en.wikipedia.org/wiki/Hydra_(genus)) and the sea anemone *Nematostella vectensis* have become attractive [model organisms](http://en.wikipedia.org/wiki/Model_organism) to study the [evolution](http://en.wikipedia.org/wiki/Evolution) of [immunity](http://en.wikipedia.org/wiki/Immunity_(medical)) and certain developmental processes. An important technical breakthrough was the development of procedures for generation of stably transgenic hydras and sea anemones by embryo [microinjection](http://en.wikipedia.org/wiki/Microinjection).

**Fish**

GM fish are used for scientific research and as pets, and are being considered for use as food and as aquatic pollution sensors.

Genetically engineered fish are widely used in basic research in genetics and development. Two species of fish, [zebrafish](http://en.wikipedia.org/wiki/Zebrafish" \o "Zebrafish) and [medaka](http://en.wikipedia.org/wiki/Oryzias_latipes" \o "Oryzias latipes), are most commonly modified because they have optically clear chorions (shells), rapidly develop, and the 1-cell embryo is easy to see and microinject with transgenic DNA

The **[GloFish](http://en.wikipedia.org/wiki/GloFish" \o "GloFish)** is a patented brand of [genetically modified](http://en.wikipedia.org/wiki/Genetically_modified) (GM) fluorescent [zebrafish](http://en.wikipedia.org/wiki/Zebrafish" \o "Zebrafish) with bright red, green, and orange fluorescent color. Although not originally developed for the ornamental fish trade, it became the first genetically modified animal to become publicly available as a pet when it was introduced for sale in 2003. They were quickly banned for sale in California. [Genetically modified fish](http://en.wikipedia.org/wiki/Genetically_modified_fish) have been developed with promoters driving an over-production of "all fish" [growth hormone](http://en.wikipedia.org/wiki/Growth_hormone) for use in the [aquaculture](http://en.wikipedia.org/wiki/Aquaculture) industry to increase the speed of development and potentially reduce fishing pressure on wild stocks. This has resulted in dramatic growth enhancement in several species, including [salmon](http://en.wikipedia.org/wiki/Salmon),  and [tilapia](http://en.wikipedia.org/wiki/Tilapia). AquaBounty, a biotechnology company working on bringing a GM salmon to market, claims that their GM AquAdvantage salmon can mature in half the time it takes non-GM salmon and achieves twice the size. AquaBounty has applied for regulatory approval to market their GM salmon in the US. As of December 2012 the application was still pending.

Several academic groups have been developing GM zebrafish to detect aquatic pollution. The lab that originated the GloFish discussed above originally developed them to change color in the presence of pollutants, to be used as environmental sensors. A lab at University of Cincinnati has been developing GM zebrafish for the same purpose as has a lab at Tulane University.

**Regulation** The regulation of genetic engineering concerns the approaches taken by governments to assess and manage the risks associated with the use of [genetic engineering](http://en.wikipedia.org/wiki/Genetic_engineering) technology and the development and release of genetically modified organisms (GMO), including [genetically modified crops](http://en.wikipedia.org/wiki/Genetically_modified_crops) and [genetically modified fish](http://en.wikipedia.org/wiki/Genetically_modified_fish). There are differences in the regulation of GMOs between countries, with some of the most marked differences occurring between the USA and Europe. Regulation varies in a given country depending on the intended use of the products of the genetic engineering. For example, a crop not intended for food use is generally not reviewed by authorities responsible for food safety.The European Union differentiates between approval for cultivation within the EU and approval for import and processing. While only a few GMOs have been approved for cultivation in the EU a number of GMOs have been approved for import and processing. The cultivation of GMOs has triggered a debate about coexistence of GM and nonGM crops. Depending on the coexistence regulations, incentives for cultivation of GM crops differ.

**Controversy**

There is controversy over GMOs, especially with regard to their use in producing food. The dispute involves buyers, biotechnology companies, governmental regulators, non-governmental organizations, and scientists. The key areas of controversy related to [GMO food](http://en.wikipedia.org/wiki/Genetically_modified_food) are whether GM food should be labeled, the role of government regulators, the effect of GM crops on health and the environment, the effect on pesticide resistance, the impact of GM crops for farmers, and the role of GM crops in feeding the world population.

There is broad [scientific consensus](http://en.wikipedia.org/wiki/Scientific_consensus) that food on the market derived from GM crops poses no greater risk than conventional food. No reports of ill effects have been proven in the human population from ingesting GM food. Although labeling of GMO products in the marketplace is required in many countries, it is not required in the United States and no distinction between marketed GMO and non-GMO foods is recognized by the US FDA. In a May 2014 article in [The Economist](http://en.wikipedia.org/wiki/The_Economist) it was argued that, while GM foods could potentially help feed 842 million malnourished people globally, laws such as those being considered by Vermont's governor, Peter Shumlin, to require labeling of foods containing genetically modified ingredients, could have the unintended consequence of interrupting the benign process of spreading GM technologies to impoverished countries that suffer with [food security](http://en.wikipedia.org/wiki/Food_security) problems.

Opponents of genetically modified food such as the advocacy groups [Organic Consumers Association](http://en.wikipedia.org/wiki/Organic_Consumers_Association), the [Union of Concerned Scientists](http://en.wikipedia.org/wiki/Union_of_Concerned_Scientists) and [Greenpeace](http://en.wikipedia.org/wiki/Greenpeace) claim risks have not been adequately identified and managed, and they have questioned the objectivity of regulatory authorities. Some health groups say there are unanswered questions regarding the potential long-term impact on human health from food derived from GMOs, and propose mandatory labeling or a moratorium on such products. Concerns include contamination of the non-genetically modified food supply effects of GMOs on the environment and nature, the rigor of the regulatory process, and consolidation of control of the food supply in companies that make and sell GMOs.

**Recognition of the originators of GM crops**

On 19 June 2013 the leaders of the three research teams that first applied genetic engineering to crops, [Robert Fraley](http://en.wikipedia.org/wiki/Robert_Fraley) of Monsanto; [Marc Van Montagu](http://en.wikipedia.org/wiki/Marc_Van_Montagu) of [Ghent University](http://en.wikipedia.org/wiki/Ghent_University) in[Belgium](http://en.wikipedia.org/wiki/Belgium) and founder of [Plant Genetic Systems](http://en.wikipedia.org/wiki/Plant_Genetic_Systems) and Crop Design; and [Mary-Dell Chilton](http://en.wikipedia.org/wiki/Mary-Dell_Chilton) of the [University of Washington](http://en.wikipedia.org/wiki/University_of_Washington) and [Washington University in St. Louis](http://en.wikipedia.org/wiki/Washington_University_in_St._Louis) and [Syngenta](http://en.wikipedia.org/wiki/Syngenta" \o "Syngenta), were awarded with the [World Food Prize](http://en.wikipedia.org/wiki/World_Food_Prize). The prize, of $250,000, is awarded to people who improve the "quality, quantity or availability" of food in the world. The three competing teams first presented their results in January 1983.