engineering innovations turn out to have no concrete and measurable negative consequences at all, some of a religious frame of mind might consider the very act of altering DNA to produce a human good to be immoral, obscene, or blasphemous. These concerns are often raised in a religious context, with discussants referring to religious scriptures as the basis for moral discussion. For example, the Christian and Jewish book of Genesis has a story of God creating humans in God's image and God creating the other animals and the plants for humanity's use. Does this imply that God's role is to be the creator, and humans should leave creation in God's hands and not attempt to fundamentally alter life forms? If so, what about the selective breeding humans have carried out for thousands of years? On the other hand, if humans are created in God's image, and God is a creator of life, then is not one of the fundamental essences of humanity its ability to make or modify life? Because God rested after six days of creation, however, perhaps the creation story suggests there is also a time to stop creating.

The advent of the age of genetic engineering has stirred up a hornet's nest of concerns about the new technology. Some of these concerns are practical and utilitarian. Some are ethical, and some are religious in nature. Regardless of whether one approves of genetic engineering, it is doubtless here to stay. The knowledge has been so widely disseminated that it is unlikely any government, group of governments, or international organizations could eliminate it or prevent it from being used by someone, somewhere. The genie is out of the bottle, and it is impossible to force him back in, it appears. Humans will need to ensure that they are developing their ethical considerations about genetic engineering as quickly and profoundly as scientists are making discoveries and developing their methods if they wish to find acceptable approaches before changes are thrust upon them, rather than be forced to deal with ethical crises after they have arisen.

See also Chemical and Biological Warfare; Cloning; Eugenics; Genetically Modified Organisms; Human Genome Project.

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Edward White

GENETICALLY MODIFIED ORGANISMS

Genetically modified plants, microbes, and animals have been a source of controversy since the development of genetic engineering techniques in the 1970s, intensifying with the growth of the life sciences industry in the 1990s. A wide range of critics, from scientists to religious leaders to antiglobalization activists, have challenged the development of genetically modified organisms (GMOs). Controversies over GMOs have revolved around their environmental impacts, effects on human health, ethical implications, and links to patterns of corporate globalization.

A GMO is a plant, microbe, or animal whose genetic material has been intentionally altered through genetic engineering. Other terms often used in place of "genetically modified" are *transgenic* or *genetically engineered* (GE). Genetic engineering refers to a highly sophisticated set of techniques for directly manipulating an organism's DNA, the genetic information within every cell that allows living things to function, grow, and reproduce. Segments of DNA that are known to produce a certain trait or function are commonly called genes. Genetic engineering techniques enable scientists to move genes from one species to another. This creates genetic combinations that would never have occurred in nature, giving the recipient organism characteristics associated with the newly introduced gene. For example, by moving a gene from a firefly to a tobacco plant, scientists created plants that glow in the dark.

Humans have been intentionally changing the genetic properties of animals and plants for centuries, through standard breeding techniques (selection, crossbreeding, hybridization) and the more recent use of radiation or chemicals to create random mutations, some of which turn out to be useful. In this broad sense, many of the most useful plants, animals, and microbes are "genetically modified."

The techniques used to produce GMOs are novel, however. To produce a GMO, scientists first find and isolate the section of DNA in an organism that includes the gene for the desired trait and cut it out of the DNA molecule. Then they move the gene into the DNA of the organism (in the cell's nucleus) that they wish to modify. Today, the most common ways that this is done include the following: using biological vectors such as plasmids (parts of bacteria) and viruses to carry foreign genes into cells; injecting genetic material containing the new gene into the recipient cell with a fine-tipped glass needle; using chemicals or electric current to create pores or holes in the cell membrane to allow entry of the new genes; and the so-called gene gun, which shoots microscopic metal particles, coated with genes, into a cell.

After the gene is inserted, the cell is grown into an adult organism. Because none of the techniques can control exactly where or how many copies of the inserted gene are incorporated into the organism's DNA, it takes a great deal of experimentation to ensure that the new gene produces the desired trait without disrupting other cellular processes.

Genetic engineering has been used to produce a wide variety of GMOs. Following are some examples:

- Animals: Genetically modified (GM) animals, especially mice, are used in medical research, particularly for testing new treatments for human disease. Mosquitoes have been genetically engineered in hopes of slowing

the spread of malaria. Farm animals, such as goats and chickens, have been engineered to produce useful substances for making medicines. Salmon DNA has been modified to make the fish grow faster. Pet zebra fish have been modified to have a fluorescent glow.

- Microbes: GM microbes (single-celled organisms) are in use in the production of therapeutic medicines and novel GM vaccines. Research is underway to engineer microbes to clean up toxic pollution. GM microbes are being tested for use in the prevention of plant diseases.
- Plants: Scientists have experimented with a wide variety of GM food plants, but only soybeans, corn, and canola are grown in significant quantities. These and a small number of other crops (e.g., papaya, rice, squash) are engineered to prevent plant disease, resist pests, or enable weed control. Some food crops have been engineered to produce pharmaceutical and industrial compounds, often called "molecular farming" or "pharming." Other, nonfood plants have also been genetically engineered, such as trees, cotton, grass, and alfalfa.

The research and development of GMOs and other forms of biotechnology have occurred in both universities and corporations. The earliest technologies and techniques were developed by professors in university laboratories. In 1973 Stanley Cohen (Stanford University) and Herbert Boyer (University of California, San Francisco) developed recombinant DNA (rDNA) technology, which made genetic engineering possible.

Although the line between "basic" and "applied" research has always been fuzzy, GMO research has all but eliminated such distinctions. The first release of a GMO into the environment resulted directly from a discovery by Stephen Lindow, a plant pathologist at the University of California–Berkeley. His "ice-minus bacteria," a GM microorganism that could be sprayed on strawberry fields to resist frost damage, was tested by Advanced Genetic Sciences (a private company)

UNIVERSITY–INDUSTRY PARTNERSHIPS

Biotechnology firms have begun to invest heavily in university research programs. Such university–industry partnerships have been quite controversial. In one example, the Novartis Agricultural Discovery Institute (a private corporation) and the Department of Plant and Microbial Biology at University of California–Berkeley formed a research partnership in 1998. Supporters of the agreement praised the ability of a public university to leverage private assets for the public good during a time of decreasing governmental support of research and celebrated the opportunity for university researchers to access proprietary genetic databases. Meanwhile, critics warned of conflicts of interest, loss of autonomy of a public institution, and research trajectories biased in the direction of profit-making. An independent scholarly evaluation of the agreement by Lawrence Busch and colleagues at Michigan State University found that neither the greatest hopes nor the greatest fears were realized but recommended against holding up such partnerships as models for other universities to mimic.

in 1986 amid great controversy. In many cases, university professors have spun off their own companies to market and develop practical uses for their biotechnology inventions. Herbert Boyer, for example, cofounded Genentech (NYSE ticker symbol: DNA) in 1976, a biotechnology company that produced the first approved rDNA drug, human insulin, in 1982. Such entrepreneurial behavior by academics has become common, if not expected, but has also attracted criticism from those who mourn what some have called the "commercialization of the university."

The early 1990s witnessed a growth of "life science" companies—transnational conglomerations of corporations that produced and sold agricultural chemicals, seeds (GM and conventional), drugs, and other genetic technologies related to medicine. Many of these companies began as pharmaceutical companies or as producers of agricultural chemicals, especially pesticides (e.g., Monsanto, Syngenta). Companies combined and consolidated in the hope of taking advantage of economic and technological efficiencies, and they attempted to integrate research, development, and marketing practices. By the late 1990s, however, many life science companies had begun to spin off their agricultural divisions because of concerns about profit margins and the turbulent market for GM crops and food. Today there are a mixture of large transnational firms and smaller boutique firms, the latter often founded by former or current university researchers.

The biotechnology industry is represented by lobby groups including the Biotechnology Industry Organization (BIO) and CropLife International. There are also a variety of organizations that advocate for continued research and deployment of GMOs, such as the AgBioWorld Foundation and the International Service for the Acquisition of Agri-Biotech Applications (ISAAA).

GMOs SLIPPING THROUGH THE REGULATORY CRACKS?

In the United States, three agencies are primarily responsible for regulating GMOs: the Department of Agriculture (USDA), the Environmental Protection Agency (EPA), and the Food and Drug Administration (FDA). The USDA evaluates the safety of growing GM plants—for instance, to see if GM crops will become weedy pests. The EPA deals with GMOs when they involve herbicides or pesticides that may have an impact on the environment and also reviews the risks of GM microorganisms. The FDA is responsible for the safety of animals, foods, and drugs created using genetic engineering. Some believe that the U.S. system of regulation of GMOs is not stringent enough. Food safety advocates often criticize the FDA because most GM foods are exempted from the FDA approval process. In certain cases, the U.S. government provides no regulatory oversight for GMOs. For example, the "GloFish," a GM zebra fish, has not been evaluated by any U.S. government agencies yet is now commercially available at pet stores across the United States. The USDA, EPA, and Fish and Wildlife Service all said that the GloFish was outside of their jurisdiction. The FDA considered the GloFish but ruled that it was not subject to regulation because it was not meant to be consumed.

Opposition to GMOs has emerged from many different sectors of society and has focused on various aspects and consequences of biotechnologies. The following list captures the breadth and some of the diversity of critique, although there are too many advocacy organizations to list here.

- Consumers (Consumers Union, Organic Consumers Association): Both as individuals and as organized groups, some consumers have opposed GM food by boycotting products and by participating in campaigns against politicians, biotechnology companies, and food distributors. Reasons include the lack of labeling of GM foods and ingredients (a consumer choice or right-to-know issue), health concerns (allergies, nutritional changes, unknown toxic effects), and distrust of the regulatory approval process (especially in the European Union).
- Organic farmers (Organic Trade Association, California Certified Organic Farmers): Organic agricultural products demand a premium that stems from special restrictions on how they are grown and processed. Under most organic certification programs (e.g., USDA organic), the presence of transgenic material above certain very low thresholds disqualifies the organic label. Organic farmers have therefore sustained economic losses because of transgenic contamination of their crops. Routes of contamination include pollen drift (from neighboring fields), contaminated seeds, and post-harvest mixing during transport, storage, or processing. Some conventional farmers have also opposed GM crops (especially rice) because significant agricultural markets in Asia and the European Union (EU) have refused to purchase grains (organic or conventional) contaminated with transgenic DNA.
- Antiglobalization groups (International Forum on Globalization, Global Exchange, Peoples' Global Action): Efforts to counter corporate globalization have frequently targeted transnational biotechnology companies—GM food became a kind of rallying cry at the infamous World Trade Organization protests in Seattle in 1999. Critics oppose the consolidation of seed companies, the loss of regional and national variety in food production and regulation, and the exploitation of human and natural resources for profit.
- Scientists (Union of Concerned Scientists, Ecological Society of America): Scientists critical of GMOs (more commonly ecologists than molecular biologists) tend to emphasize the uncertainties inherent in developing and deploying biotechnologies. They criticize the government's ability to properly regulate GMOs, highlight research that suggests unwanted health or environmental effects, and caution against unchecked university–industry relations.
- Environmental organizations (Greenpeace, Friends of the Earth): Controversy exists over the realized and potential benefits of GM crops. Critics emphasize the negative impacts, dispute the touted benefits, disparage the regulatory process as too lax and too cozy with industry, and point out that yesterday's pesticide companies are today's ag-biotech companies.

- Religious groups (United Church of Canada, Christian Ecology Link, Eco Kosher Network, Directors of the Realm Buddhist Association): Faith-based criticism of GMOs may stem from beliefs against tinkering with life at the genetic level ("playing God"), concerns about inserting genes from "taboo" foods into other foods, or social justice and environmental principles.
- Sustainable agriculture/food/development organizations (ETC Group, Food First/Institute for Food and Development Policy): These nongovernmental organizations (NGOs) bring together ethical, technological, cultural, political, environmental, and economic critiques of GMOs, often serving as clearinghouses of information and coordinating transnational campaigns.
- Indigenous peoples: Because many indigenous groups have remained stewards of eco-regions with exceptional biodiversity, scientists and biotechnology companies have sought their knowledge and their genetic resources ("bioprospecting"). At times, this has led to charges of exploitation and "biopiracy." In some cases, indigenous peoples have been vocal critics of GMOs that are perceived as "contaminating" sacred or traditional foods, as in a recent controversy over GM maize in Mexico.

Ever since researchers first began to develop GMOs, governments around the world have had to decide whether and how to regulate them. Controversies around GMOs often refer to arguments about the definition, assessment, and management of risk. Promoters of GMOs tend to favor science-based risk assessments ("sound science"), whereas critics tend to advocate the precautionary principle.

Calls for science-based risk assessments often come from stakeholders who oppose increased regulation and want to see GM technologies developed and marketed. Specifically, they argue that before a technology should be regulated for possible risks, those risks must be demonstrated as scientifically real and quantifiable. Although the definition of "sound science" is itself controversial, proponents state that regulatory agencies such as the EPA and FDA have been too quick to regulate technologies without good evidence—arguing that such government interference not only creates financial disincentives for technological innovation but actually causes social harm by delaying or preventing important technologies from becoming available. Such a perspective views government regulation as a risk in itself.

By contrast, advocates of the precautionary principle stress the existence of scientific uncertainties associated with many modern environmental and health issues. They have proposed a framework for decision making that errs on the side of precaution ("better safe than sorry"). Major components include the following: (1) anticipate harm and prevent it; (2) place the burden of proof on polluters to provide evidence of safety, not on society to prove harm; (3) always examine alternative solutions; and (4) include affected parties in democratic governance of technologies. Critics argue that the precautionary principle is little more than a scientific disguise for antitechnology politics.

In line with a precautionary approach to regulation, some governments (England, for example) have focused on genetic engineering as a process that may

pose novel environmental or health risks. Other governments (for example, the United States and Canada) focus instead on the product, the GMO itself. Such countries generally do not single out GMOs for special regulation, beyond what is typical for other products. In addition, some governments have restricted the use of GMOs because of concerns about their social, economic, and ethical implications. Austria, for example, requires GMOs used in agriculture to be "socially sustainable."

International law also reflects controversy over regulating GMOs. The agreements of the World Trade Organization, the international body that develops and monitors ground rules for international trade, initially set out an approach similar to that of the United States. In 2000, however, more than 130 countries adopted an international agreement called the Cartagena Protocol on Biosafety, which promotes a precautionary approach to GMOs. This conflict has been a matter of much speculation and will likely feature in trade disputes over GM foods in the future.

Labeling of GM foods represents another contentious regulatory issue. Some governments take the position that if GMOs are found to be "substantially equivalent" to existing foods, they do not need to be labeled. In the United States, for example, food manufacturers may voluntarily label foods as "GMO-free," but there is no requirement to note when foods contain GMOs. The European Union and China, on the other hand, require foods made with GMOs to be labeled as such. In countries where labeling is required, there are typically fierce debates about tolerance levels for trace amounts of GMOs in foods meant to be GMO-free.

One dimension of the public debate about GMOs that is difficult to resolve is the question of whether it is morally, ethically, and culturally appropriate to manipulate the genetic makeup of living things. Some people respond with revulsion to the idea that scientists can move genes across species boundaries, putting fish genes into a strawberry, for instance. For some, this feeling stems from a philosophical belief that plants and animals have intrinsic value that should not be subordinated to human needs and desires. Unease with gene transfer may also be based on religious belief, such as the conviction that engineering living things is a form of playing God. But where is the line between divine responsibilities and human stewardship of the earth? Some religious leaders, such as the Vatican, have taken the position that if GMOs can be used to end world hunger and suffering, it is ethical to create them.

Evolutionary biologists point out that boundaries between species are not as rigid, distinct, and unchanging as critics of genetic engineering imply. All living things have some genes in common because of shared common ancestors. Furthermore, the movement of genes across species boundaries without sexual reproduction happens in a process called horizontal gene transfer, which requires no human intervention. Horizontal gene transfer has been found to be common among different species of bacteria and to occur between bacteria and some other organisms.

Regardless of the scientific assessment of the "naturalness" of genetic engineering, it is highly unlikely that all people will come to agreement on whether

it is right to create GMOs, and not only for religious reasons. Those with philosophical beliefs informed by deep ecology or commitment to animal rights are unlikely to be persuaded that genetic engineering is ethical. Furthermore, many indigenous peoples around the world understand nature in ways that do not correspond with Western scientific ideas.

Given the diversity and incompatibility of philosophical perspectives, should we bring ethics, morality, and cultural diversity into policy decisions, scientific research, and the regulation of GMOs? If so, how? Some have proposed that labeling GMOs would enable people with religious, cultural or other ethical objections to avoid GMOs. Others see widespread acceptance of GMOs as inevitable and judge philosophical opposition as little more than fear of technology. These issues often become sidelined in risk-centered debates about GMOs but remain at the heart of the controversy about this technology.

As the world's population continues to grow, many regions may face food shortages with increasing frequency and severity. A variety of groups, including the Food and Agriculture Organization of the United Nations, anticipate that genetic engineering will aid in reducing world hunger and malnutrition, for instance, by increasing the nutritional content of staple foods and increasing crop yields. Such claims have encountered scientific and political opposition. Critics point out that conventional plant-breeding programs have vastly improved crop yields without resorting to genetic engineering and that GMOs may create novel threats to food security, such as new environmental problems.

Whether or not GMOs will increase agricultural productivity, it is widely recognized that greater yields alone will not end world hunger. Food policy advocacy groups such as Food First point out that poverty and unequal distribution of food, not food shortage, are the root causes of most hunger around the world today. In the United States, where food is abundant and often goes to waste, 38 million people are "food insecure," meaning they find it financially difficult to put food on the table. Similarly, India is one of the world's largest rice exporters, despite the fact that over one-fifth of its own population chronically goes hungry.

GOLDEN RICE

For over 15 years, Swiss researchers have been developing "Golden Rice," a type of GM rice that contains increased levels of beta-carotene, which is converted by the human body into vitamin A. The aim of the research is to combat vitamin A deficiency (a significant cause of blindness among children in developing countries), yet the project has drawn criticism. Some critics see Golden Rice as a ploy to gain wider enthusiasm for GMOs rather than a genuine solution to widespread malnutrition. Advocates of sustainable agriculture argue that vitamin A deficiency could be ended if rice monocultures were replaced with diverse farming systems that included production of leafy green vegetables, sweet potatoes, and other sources of beta-carotene. Scientists also continue to investigate whether Golden Rice would provide sufficient levels of beta-carotene and whether Asian farmers and consumers would be willing to produce and eat the bright orange rice.

Distribution of GM crops as emergency food aid is also fraught with controversy. Facing famine in 2003, Zambia's government refused shipments of corn that contained GMOs, citing health worries and concerns that the grains, if planted, would contaminate local crop varieties. U.S. government officials blamed anti-GMO activists for scaring Zambian leaders into blocking much-needed food aid to starving people. A worldwide debate erupted about the right of poor nations to request non-GMO food aid and the possibility that pro-GMO nations such as the United States might use food aid as a political tool.

Patents are government guarantees that provide an inventor with exclusive rights to use, sell, manufacture, or otherwise profit from an invention for a designated time period, usually around 20 years. In the United States, GMOs and gene sequences are treated as inventions under the patent law. Laws on patenting GMOs vary around the world, however. Many legal issues are hotly debated, both in national courts and in international institutions such as the World Trade Organization and the United Nations Food and Agriculture Organization. Should one be able to patent a living thing, as though it were any other invention? Unlike other technologies, GMOs are alive and are usually able to reproduce. This raises novel questions. For instance, do patents extend to the offspring of a patented GMO?

Agricultural biotechnology companies stress that they need patents as a tool for collecting returns on investments in research and development. Patents ensure that farmers do not use GM seeds (collected from their own harvests) without paying for them. Monsanto Company, for instance, has claimed that its gene patents extend to multiple generations of plants that carry the gene. The biotechnology industry argues that the right to patent and profit from genes and GMOs stimulates innovation in the agricultural and medical fields. Without patents, they say, companies would have little incentive to invest millions of dollars in developing new products.

Complicating the issue, however, is evidence that biotechnology patents increasingly hinder scientific research. University and corporate scientists sometimes find their work hampered by a "patent thicket," when the genes and processes they wish to use have already been patented by multiple other entities. It can be costly and time-consuming to negotiate permissions to use the patented materials, slowing down research or causing it to be abandoned.

Advocacy groups, such as the Council for Responsible Genetics, argue that patents on genes and GMOs make important products more expensive and less accessible. These critics worry that large corporations are gaining too much control over the world's living organisms, especially those that provide food. Some disagree with the idea that societies should depend on private companies to produce needed agricultural and medical innovations. Such research, they say, could be funded exclusively by public monies, be conducted at public institutions, and produce knowledge and technology freely available to anyone.

Furthermore, a wide variety of stakeholders, from religious groups to environmentalists, have reached the conclusion that "patenting life" is ethically and morally unacceptable. Patenting organisms and their DNA treats living beings and their parts as commodities to be exploited for profit. Some say this creates a slippery slope toward ownership and marketing of human bodies and body parts.

Many controversies over GMOs center on their perceived or predicted environmental impacts. Although both benefits and negative impacts have been realized, much of the debate also involves speculation about what might be possible or likely with further research and development.

With respect to GM crops, there are a variety of potential benefits. Crops that have been genetically engineered to produce their own pesticides (plant-incorporated protectants, or PIPs) eliminate human exposures to pesticides through hand or aerial spray treatments and may reduce the use of more environmentally harmful pesticides. Crops that have been genetically engineered with tolerance to a certain herbicide allow farmers to reduce soil tillage, a major cause of topsoil loss, because they can control weeds more easily throughout the crop's life cycle. If GMOs increase agricultural yields per unit of land area, less forested land will need to be converted to feed a growing population. Finally, some believe that GMOs represent a new source of biodiversity (albeit human-made).

The potential environmental harms of GM crops are also varied. PIPs may actually increase overall pesticide usage as target insect populations develop resistance. PIPs and herbicide-tolerant crops may create non-target effects (harm to other plants, insects, animals, and microorganisms in the agricultural environment). GM crops may crossbreed with weedy natural relatives, conferring their genetic superiority to a new population of "superweeds." GMOs may reproduce prolifically and crowd out other organisms—causing ecological damage or reducing biodiversity. Finally, because GMOs have tended to be developed for and marketed to users that follow industrial approaches to agriculture, the negative environmental impacts of monocultures and factory farming are reproduced.

With regard to GM microorganisms, proponents point to the potential for GMOs to safely metabolize toxic pollution. Critics emphasize the possibility of creating "living pollution," microorganisms that reproduce uncontrollably in the environment and wreak ecological havoc.

MONARCH BUTTERFLIES

Protesters dressed in butterfly costumes have become a regular sight at anti-GMO demonstrations. What is the story behind this ever-present symbol of anti-GMO activism? In 1999 John Losey and colleagues from Cornell University published a study that suggested that pollen from GM corn could be lethal to monarch butterflies. The corn in question had been genetically modified to express an insecticidal protein throughout the plant's tissues, including the pollen grains. The genetic material for this modification came from bacteria that are otherwise used to create a "natural" insecticide approved for use on organic farms. The GM corn thus represented both an attempt to extend a so-called organic method of crop protection to conventional agriculture (an environmental benefit) and a potential new threat to a beloved insect already threatened by human activities. Controversy erupted over the significance and validity of the Losey study, and the monarch butterfly remains symbolic of the controversy over the environmental pros and cons of GMOs.

GM animals also offer a mix of potential environmental harms and benefits. For example, GM salmon, which grow faster, could ease the pressure on wild salmon populations. On the other hand, if GM salmon escape captivity and breed in the wild, they could crowd out the diversity of salmon species that now exist.

No long-term scientific studies have been conducted to measure the health impacts of ingesting GMOs. As a result, there is an absence of evidence, which some proponents use as proof of GMOs' safety. Critics counter that "absence of evidence" cannot serve as "evidence of absence" and accuse biotechnology corporations and governments of conducting an uncontrolled experiment by allowing GMOs into the human diet. Several specific themes dominate the discussion:

- Substantial equivalence. If GMOs are "substantially equivalent" to their natural relatives, GMOs are no more or less safe to eat than conventional foods. Measuring substantial equivalence is itself controversial: Is measuring key nutrients sufficient? Do animal-feeding studies count? Must every transgenic "event" be tested, or just types of GMOs?
- Allergies. Because most human allergies are in response to proteins, and GMOs introduce novel proteins to the human diet (new sequences of DNA and new gene products in the form of proteins), GMOs may cause novel human allergies. On the other hand, some research has sought to genetically modify foods in order to remove proteins that cause widespread allergies (e.g., the Brazil nut).
- Horizontal gene transfer. Because microorganisms and bacteria often swap genetic material, the potential exists for bacteria in the human gut to acquire transgenic elements—DNA sequences that they would otherwise never encounter because of their non-food origin. Debate centers on the significance of such events and whether genetic material remains sufficiently intact in the digestive tract to cause problems.
- Antibiotic resistance. Antibiotic-resistant genes are often included in the genetic material that is added to a target organism. These DNA sequences serve as "markers," aiding in the selection of organisms that have actually taken up the novel genetic material (when an antibiotic is applied, only those cells that have been successfully genetically modified will survive). Some fear that the widespread production of organisms with antibiotic resistance and the potential for transfer of such traits to gut bacteria will foster resistance to antibiotics that are important to human or veterinary medicine.
- Unpredictable results. Because the insertion of genetic material is not precise, genetic engineering may alter the target DNA in unanticipated ways. Existing genes may be amplified or silenced, or novel functioning genes could be created. A controversial study by Stanley Ewen and Arpad Pusztai in 1999 suggested alarming and inexplicable health effects on rats fed GM potatoes, despite the fact that the transgenic trait was chosen for its nontoxic properties. Unfortunately, most data on the health safety of GMOs remains proprietary (privately owned by corporations) and unavailable to the public for review.

- Second-order effects. Even when GMOs are not ingested, they may have health consequences when used to produce food. For example, recombinant bovine growth hormone (rBGH) was approved for use in increasing the milk production of dairy cows. No transgenic material passes into the milk, but rBGH fosters udder inflammation and mastitis in cows. As a result, milk from cows treated with rBGH includes higher-than-average levels of pus and traces of antibiotics, both of which may have human health impacts.

Given that most GMOs retain their biological ability to reproduce with their conventional counterparts, there exist a number of reasons to segregate GMOs (to prevent mixing or interbreeding). First, some consumers prefer to eat food or buy products that are made without GMOs. Second, some farmers wish to avoid patented GM crops, for instance, in order to retain the right to save their own seeds. Third, there may be a need for non-GMO plants and animals in the future—for instance, if GM foods are found to cause long-term health problems and must be phased out. Fourth, it is essential that unauthorized GMOs or agricultural GMOs that produce inedible or medicinal compounds do not mix with or breed with organisms in the food supply.

For all of these reasons, the coexistence of GMOs and non-GMOs is a topic of heated debate around the world. There are a variety of possibilities for ensuring that GMOs and conventional organisms remain segregated. One possibility for the food industry is to use "identity preserved" (IP) production practices, which require farmers, buyers, and processors to take special precautions to keep GM plants segregated from other crops, such as using physical barriers between fields and using segregated transportation systems. Thus far, such efforts have proven unreliable, permitting, in some instances, unapproved transgenic varieties to enter the food supply. The biotechnology industry has advocated for standards that define acceptable levels of "adventitious presence"—the unintentional comingling of trace amounts of one type of seed, grain, or food product with another. Such standards would acknowledge the need to segregate GMOs from other crops but accept some mixing as unavoidable.

Critics of biotechnology, on the other hand, tend to see the mixing of GMOs with non-GMOs at any level as a kind of contamination or "biopollution," for which the manufacturers should be held legally liable. Because cross-pollination between crops and accidental mixture of seeds are difficult to eliminate entirely, critics sometimes argue that GMOs should simply be prohibited. For this reason, some communities, regions, and countries have declared themselves "GMO-free zones" in which no GMOs are released into the environment.

One possible technical solution to unwanted breeding between GMOs and their conventional relatives is to devise biological forms of containment. The biotechnology industry has suggested that Genetic Use Restriction Technologies (GURTs), known colloquially as "Terminator Technologies," may aid in controlling the reproduction of GM plants by halting GMO "volunteers" (plants that grow accidentally). GURTs make plants produce seeds that will not grow. Critics have mounted a largely successful worldwide campaign against Terminator Technology, calling attention to its original and central purpose: to

GMOs ON THE LOOSE

In August 2006, the U.S. Department of Agriculture (USDA) announced that an unapproved variety of GM rice (Liberty Link Rice 601), manufactured and tested by Bayer CropScience a number of years earlier but never approved for cultivation, had been discovered to be growing throughout the U.S. long-grain rice crop. Despite the USDA's attempts to reassure the public of the safety of the unapproved variety of rice, when it was found in food supplies around the world, major importers stopped buying rice from the United States, causing prices for American exports to plummet. Hundreds of U.S. farmers filed a class action lawsuit against Bayer. Although it remains unclear how, exactly, the GM rice got into the seed supply, one possible explanation that the company offered is that it became mixed with "foundation" seeds, used to develop seeds that are sold to farmers, at a Louisiana State University rice breeding station. Rice breeders there had collaborated on the field trials for the experimental rice. From there, it seems, the rice was reproduced, spreading throughout the food system.

force farmers to purchase fresh seeds every year. Other research efforts aim at controlling pollen flow, not seed growth. For instance, a number of EU research programs (Co-Extra, Transcontainer, and SIGMEA) are currently investigating ways to prevent GM canola flowers from opening; to use male-sterile plants to produce GM corn, sunflowers, and tomatoes; and to create transplastomic plants (GM plants whose pollen cannot transmit the transgenic modification).

Should there be more GM crops? Advocates of GMOs argue that currently marketed technologies (primarily herbicide-tolerant and pest-resistant corn, rice, and soy) represent mere prototypes for an expanding array of GMOs in agriculture. Three directions exist, with some progress in each area. First, genetic engineers could focus on incorporating traits that have a more direct benefit to consumers, such as increased nutrition, lower fat content, improved taste or smell, or reduced allergens. Second, existing technologies could be applied to more economically marginal crops, such as horticultural varieties and food crops important in the Global South. Third, traits could be developed that would drastically reduce existing constraints on agriculture, such as crops with increased salt and drought tolerance or non-legume crops that fix their own nitrogen. It remains to be seen how resources will be dedicated to these diverse research paths and who will benefit from the results.

Should there be GM animals? With animal cloning technology possible in more and more species, and some signs of acceptance of cloned animals for the production of meat in the United States, conventional breeding of livestock could veer toward genetic engineering. Scientists around the world are experimenting with genetic modification of animals raised for meat, and edible GM salmon are close to commercialization. GM pets may also be in the future, with one GM aquarium fish already commercially available.

Should there be GM "pharming"? Some companies are pursuing the development of GM crops that manufacture substances traditionally produced

by industrial processes. Two directions exist. First, if vaccines or medications can be genetically engineered into food crops, the cost and ease of delivery of such pharmaceuticals could decrease dramatically, especially in the global South (the developing world). Second, crops might be modified to produce industrial products, such as oils and plastics, making them less costly and less dependent on petroleum inputs. A California-based company, Ventria Biosciences, already has pharmaceutical rice in production in the United States. Animals are also being genetically engineered to produce drugs and vaccines in their milk or eggs, raising questions about the ethics of using animals as "drug factories."

Should there be GM humans? Genetic technologies have entered the mainstream in prenatal screening tests for genetic diseases, but the genetic modification of humans remains hypothetical and highly controversial. "Gene therapy" experiments have attempted to genetically modify the DNA of humans in order to correct a genetic deficiency. These experiments have remained inconclusive and have caused unpredicted results, including the death of an otherwise-healthy 18-year-old (Jesse Gelsinger). Even more controversial are calls for "designer babies," the genetic modification of sex cells (sperm and eggs) or embryos. Some advocate for such procedures only to correct genetic deficiencies, whereas others see attractive possibilities for increasing intelligence, improving physical performance, lengthening the life span, and choosing aesthetic attributes of one's offspring. Several outspoken scientists even predict (with optimism) that GM humans will become a culturally and reproductively separate species from our current "natural" condition. Critics not only doubt the biological possibility of such developments but also question the social and ethical impacts of embarking on a path toward such a "brave new world."

See also Agriculture; Ecology; Genetic Engineering; Gene Patenting; Organic Food; Pesticides; Precautionary Principle.

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GEOTHERMAL ENERGY

Geothermal energy is energy derived from beneath the surface of the earth. It takes two main forms, either the transfer of heat into some form of power