Genetically Engineered Crops: Experiences and Prospects
Findings and Recommendations

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Chapter	Section Heading	Finding or Recommendation
Chapter 4	Effects of Genetically Engineered Traits versus Conventional Plant Breeding on Yield	**Finding:** The nation-wide data on maize, cotton, or soybean in the United States do not show a significant signature of genetic-engineering technology on the rate of yield increase. This does not mean that such increases will not be realized in the future or that current GE traits are not beneficial to farmers.
Chapter 4	Effects of Genetically Engineered Traits versus Conventional Plant Breeding on Yield	**Recommendation:** To assess whether and how much current and future GE traits themselves contribute to overall farm yield changes, research should be conducted that isolates effects of the diverse environmental and genetic factors that contribute to yield.
Chapter 4	Yield Effects of Genetically Engineered Insect Resistance	**Finding:** Although results are variable, *Bt* traits available in commercial crops from introduction in 1996 to 2015 have in many locations contributed to a statistically significant reduction in the gap between actual yield and potential yield when targeted insect pests caused substantial damage to non-GE varieties and synthetic chemicals did not provide practical control.
Chapter 4	Yield Effects of Genetically Engineered Insect Resistance	**Finding:** In areas of the United States where adoption of *Bt* maize or *Bt* cotton is high, there is statistical evidence that insect-pest populations are reduced regionally, and the reductions benefit both adopters and nonadopters of *Bt* crops.
Chapter 4	Yield Effects of Genetically Engineered Insect Resistance	**Finding:** In surveys of farmers' fields, differences in yield between *Bt* and non-*Bt* varieties may be due to differences between the farmers who do and who do not plant the *Bt* varieties. These differences could inflate the apparent yield advantage of the *Bt* varieties if *Bt*-adopting farmers on the average have other production advantages over non-*Bt*–adopting farmers.
Chapter 4	Yield Effects of Genetically Engineered Insect Resistance	**Finding:** In experimental plots, the difference in yield between *Bt* and non-*Bt* varieties is sometimes demonstrated to be due to decreased insect damage to the *Bt* variety, but in cases in which comparisons are not between true isolines, differences may be due to other characteristics of the *Bt* varieties or to a combination of crop variety and decreased insect-pest damage. These differences could confound the estimation of the apparent yield advantage of the *Bt* varieties.

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Chapter 4	Yield Effects of Genetically Engineered Insect Resistance	**Recommendation:** In future experimental and survey studies that compare crop varieties with IR traits with those without the traits, it is important to assess how much of the difference in yield is due to decreased insect damage and how much may be due to other factors.
Chapter 4	Changes in Insecticide Use Due to Insect-Resistant Crops	**Finding:** In all cases examined, use of *Bt* crop varieties reduced application of synthetic insecticides in those fields. In some cases, the use of *Bt* crop varieties has also been associated with reduced use of insecticides in fields with non-*Bt* varieties of the crop and other crops.
Chapter 4	Resistance Evolution and Resistance Management in *Bt* Crops	**Finding:** The high dose/refuge strategy for delaying evolution of resistance to *Bt* toxins appears to have been successful, but deployment of crops with intermediate levels of *Bt* toxins and small refuges has sometimes resulted in the evolution of resistance in insect pests that erodes the benefits of the *Bt* crops.
Chapter 4	Resistance Evolution and Resistance Management in *Bt* Crops	**Finding:** The widespread deployment of crops with *Bt* toxins has decreased some insect-pest populations to the point where it is economically realistic to increase plantings of crop varieties without a *Bt* toxin that targets these pests. Planting varieties without *Bt* under those circumstances would delay evolution of resistance further.
Chapter 4	Resistance Evolution and Resistance Management in *Bt* Crops	**Recommendation:** Given the theoretical and empirical evidence supporting the use of the high dose/refuge strategy to delay the evolution of resistance, development of crop varieties without a high dose of one or more toxins should be discouraged and planting of appropriate refuges should be incentivized.
Chapter 4	Resistance Evolution and Resistance Management in *Bt* Crops	**Recommendation:** Seed producers should be encouraged to provide farmers with high-yielding crop varieties that only have the pest resistance traits that are economically and evolutionarily appropriate for their region and farming situation.
Chapter 4	Yield Effects of Genetically Engineered Herbicide Resistance	**Finding:** HR crops contribute to greater yield where weed control is improved because of the specific herbicides that can be used in conjunction with the HR crop.
Chapter 4	Changes in Herbicide Use Due to Herbicide-Resistant Crops	**Finding:** The use of HR crops sometimes initially correlated with decreases in total amount of herbicide applied per hectare of crop per year, but the decreases have not generally been sustained. However, such simple determination of whether total kilograms of herbicide used per hectare per year has gone up or down is not useful for assessing changes in human or environmental risks.

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Chapter 4	Changes in Herbicide Use Due to Herbicide-Resistant Crops	**Recommendation:** Researchers should be discouraged from publishing data that simply compares total kilograms of herbicide used per hectare per year because such data can mislead readers.
Chapter 4	Changes in Herbicide Use Due to Herbicide-Resistant Crops	**Finding:** Both for insect pests and weeds, there is evidence that some species have increased in abundance as IR and HR crops have become widely planted. However, in only a few cases have the increases posed an agronomic problem.
Chapter 4	Resistance Evolution and Resistance Management for Herbicide-Resistant Crops	**Finding:** Weed resistance to glyphosate is a problem and could be delayed by the use of resistance-management tactics especially in cropping systems and regions where weeds have not yet been exposed to continuous glyphosate applications.
Chapter 4	Resistance Evolution and Resistance Management for Herbicide-Resistant Crops	**Recommendation:** To delay evolution of resistance to herbicides in places where GE crops with multiple HR traits are grown, integrated weed-management approaches beyond simply spraying mixtures of herbicides are needed. This will require effective extension programs and incentives for farmers.
Chapter 4	Resistance Evolution and Resistance Management for Herbicide-Resistant Crops	**Recommendation:** Although multiple strategies can be used to delay weed resistance, there is insufficient empirical evidence to determine which strategy is expected to be most effective in a given cropping system. Therefore, research at the laboratory and farm level should be funded to improve resistance-management strategies.
Chapter 4	Effects of Genetically Engineered Crops on Biodiversity on Farms	**Finding:** Planting of *Bt* varieties of crops tends to result in higher insect biodiversity than planting of similar varieties without the *Bt* trait that are treated with synthetic insecticides.
Chapter 4	Effects of Genetically Engineered Crops on Biodiversity on Farms	**Finding:** In the United States, farmers' fields with glyphosate-resistant GE crops sprayed with glyphosate have similar or more weed biodiversity than fields with non-GE crop varieties.
Chapter 4	Effects of Genetically Engineered Crops on Biodiversity on Farms	**Finding:** Since 1987, there has been a decrease in diversity of crops grown in the United States—particularly in the Midwest—and a decrease in frequency of rotation of crops. Studies could not be found that tested for a cause–effect relationship between GE crops and this pattern. Changes in commodity prices might also be responsible for this pattern.

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Chapter 4	Effects of Genetically Engineered Crops on Biodiversity on Farms	**Finding:** Although the number of available crop varieties declined in the 20th century, there is evidence that genetic diversity among major crop varieties has not declined in the late 20th and early 21st centuries since the introduction and widespread adoption of GE crops in some countries.
Chapter 4	Dispersal of Genes from Genetically Engineered Crops to Wild Species	**Finding:** Although gene flow has occurred, no examples have demonstrated an adverse environmental effect of gene flow from a GE crop to a wild, related plant species.
Chapter 4	Herbicide-Resistant Crops, Reduced Tillage, and Ecosystem Processes	**Finding:** Both GE crops and the percentage of cropping area farmed with no-till and reduced-till practices have increased over the last two decades. However, cause and effect are difficult to determine.
Chapter 5	Endogenous Toxins in Plants	**Finding:** Crop plants naturally produce an array of chemicals that protect against herbivores and pathogens. Some of these chemicals can be toxic to humans when consumed in large amounts.
Chapter 5	Substantial Equivalence of Genetically Engineered and Non–Genetically Engineered Crops	**Finding:** The concept of substantial equivalence can aid in the identification of potential safety and nutritional issues related to intended and unintended changes in GE crops and conventionally bred crops.
Chapter 5	Substantial Equivalence of Genetically Engineered and Non–Genetically Engineered Crops	**Finding:** Conventional breeding and genetic engineering can cause unintended changes in the presence and concentrations of secondary metabolites.
Chapter 5	Regulatory Testing of Crops Resistant to Glyphosate and 2,4-D and of the New Uses of the Herbicides Themselves	**Finding:** U.S. regulatory assessment of GE herbicide-resistant crops is conducted by USDA, and by FDA when the crop can be consumed, while the herbicides are assessed by EPA when there are new potential exposures.
Chapter 5	Regulatory Testing of Crops Resistant to Glyphosate and 2,4-D and of the New Uses of the Herbicides Themselves	**Finding:** When mixtures of herbicides are used on a new GE crop, EPA assesses the interaction of the mixture as compared to the individual herbicidal compounds.
Chapter 5	Animal Testing	**Finding:** The current animal-testing protocols based on OECD guidelines for the testing of chemicals use small samples and have limited statistical power; therefore they may not detect existing differences between GE and non-GE crops or may produce statistically significant results that are not biologically meaningful.

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Chapter 5	Animal Testing	**Finding:** In addition to experimental data, long-term data on the health and feed-conversion efficiency of livestock that span a period before and after introduction of GE crops show no adverse effects on these measures associated with introduction of GE feed. Such data test for correlations that are relevant to assessment of human health effects, but they do not examine cause and effect.
Chapter 5	Animal Testing	**Recommendation:** Before an animal test is conducted, it is important to justify the size of a difference between treatments in each measurement that will be considered biologically relevant.
Chapter 5	Animal Testing	**Recommendation:** A power analysis for each characteristic based on standard deviations in treatments in previous tests with the animal species should be done whenever possible to increase the probability of detecting differences that would be considered biologically relevant.
Chapter 5	Animal Testing	**Recommendation:** In cases in which early published studies produced equivocal results regarding health effects of a GE crop, follow-up experimentation using trusted research protocols, personnel, and publication outlets should be used to decrease uncertainty and increase the legitimacy of regulatory decisions.
Chapter 5	Animal Testing	**Recommendation:** Public funding in the United States should be provided for independent follow-up studies when equivocal results are found in reasonably designed initial or preliminary experimental tests.
Chapter 5	Compositional Analysis of Genetically Engineered Crops	**Finding:** Statistically significant differences in nutrient and chemical composition have been found between GE and non-GE plants by using traditional methods of compositional analysis, but the difference have been considered to fall within the range of naturally occurring variation found in currently available non-GE crops.
Chapter 5	Composition of Processed Genetically Engineered Foods	**Finding:** The amount of GE protein and DNA in food ingredients can depend on the specific type of processing; some foods contain no detectable protein and little DNA. In a few countries that have mandatory labeling of GE foods, that is taken into account, and food without detectable GE DNA or GE protein is not labeled.

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Chapter 5	Newer Methods for Assessing Substantial Equivalence	**Finding:** In most cases examined, the differences found in comparisons of transcriptomes, proteomes, and metabolomes in GE and non-GE plants have been small relative to the naturally occurring variation found in conventionally bred crop cultivars due to genetics and environment.
Chapter 5	Newer Methods for Assessing Substantial Equivalence	**Finding:** If an unexpected change in composition beyond the natural range of variation in conventional crop cultivars were present in a GE crop, -omics approaches would be more likely to find the difference than current methods.
Chapter 5	Newer Methods for Assessing Substantial Equivalence	**Finding:** Differences in composition found by using -omics methods do not, on their own, indicate a safety problem.
Chapter 5	Food Allergenicity Testing and Prediction	**Finding:** For crops with endogenous allergens, knowing the range of allergen concentrations in a broad set of cultivars grown in a variety of environments is helpful, but it is most important to know whether adding a GE crop to the food supply will change the general exposure of humans to the allergens.
Chapter 5	Food Allergenicity Testing and Prediction	**Finding:** Because testing for allergenicity before commercialization could miss allergens to which the population had not previously been exposed, post-commercialization allergen testing would be useful in ensuring that consumers are not exposed to allergens, but such testing would be difficult to conduct.
Chapter 5	Food Allergenicity Testing and Prediction	**Finding:** There is a substantial population of persons who have higher than usual stomach pH, so tests of digestibility of proteins in simulated acidic gastric fluids may not be relevant to this population.
Chapter 5	Cancer Incidence	**Finding:** The incidence of a variety of cancer types in the United States has changed over time, but the changes do not appear to be associated with the switch to consumption of GE foods. Furthermore, patterns of change in cancer incidence in the United States are generally similar to those in the United Kingdom and Europe, where diets contain much lower amounts of food derived from GE crops. The data do not support the assertion that cancer rates have increased because of consumption of products of GE crops.
Chapter 5	Cancer Incidence	**Finding:** There is significant disagreement among expert committees on the potential harm that could be caused by the use of glyphosate on GE crops and in other applications. In determining the risk from glyphosate and formulations that include glyphosate, analyses must take into account both marginal exposure and potential harm.

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Chapter 5	Kidney Disease	**Finding:** The available data on prevalence of chronic kidney disease in the United States show a 2 percent increase from 1988 to 2004, but the increase does not appear to be attributable to consumption of GE foods.
Chapter 5	Obesity	**Finding:** The committee found no published evidence to support the hypothesis that the consumption of GE foods has caused higher U.S. rates of obesity or type II diabetes.
Chapter 5	Gastrointestinal Tract Diseases	**Finding:** The committee could find no published evidence supporting the hypothesis that GE foods generate unique gene or protein fragments that would affect the body.
Chapter 5	Celiac Disease	**Finding:** Celiac disease detection began increasing in the United States before the introduction of GE crops and the increased use of glyphosate. It appears to have increased similarly in the United Kingdom, where GE foods are not typically consumed and glyphosate use did not increase. The data are not robust, but they do not show a major difference in the rate of increase in incidence of celiac disease between the two countries.
Chapter 5	Food Allergies	**Finding:** The committee did not find a relationship between consumption of GE foods and the increase in prevalence of food allergies.
Chapter 5	Autism Spectrum Disorder	**Finding:** The similarity in patterns of increase in autism spectrum disorder in children in the United States, where GE foods are commonly eaten, and the United Kingdom, where GE foods are rarely eaten, does not support the hypothesis of a link between eating GE foods and prevalence of autism spectrum disorder.
Chapter 5	Gastrointestinal Tract Microbiota	**Finding:** On the basis of available evidence, the committee determined that the small perturbations found in the gut microbiota of animals fed foods derived from GE crops are not expected to cause health problems. A better understanding of this subject is likely as the methods for identifying and quantifying gut microorganisms mature.
Chapter 5	Horizontal Gene Transfer to Gut Microorganisms or Animal Somatic Cells	**Finding:** On the basis of its understanding of the process required for horizontal gene transfer from plants to animals and data on GE organisms, the committee concludes that horizontal gene transfer from GE crops or conventional crops to humans does not pose a substantial health risk.
Chapter 5	Transfer of Transgenic Material across the Gut Barrier into Animal Organs	**Finding:** Experiments have found that Cry1Ab fragments but not intact *Bt* genes can pass into organs and that these fragments present concerns no different than other genes that are in commonly consumed non-GE foods and that pass into organs as fragments.

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Chapter 5	Transfer of Transgenic Material across the Gut Barrier into Animal Organs	**Finding:** There is no evidence that *Bt* transgenes or proteins have been found in the milk of ruminants. Therefore, the committee finds that there should be no exposure to *Bt* transgenes or proteins from consuming dairy products.
Chapter 5	Overall Finding on Purported Adverse Effects on Human Health of Foods Derived from GE Crops	On the basis of detailed examination of comparisons of currently commercialized GE with non-GE foods in compositional analysis, acute and chronic animal toxicity tests, long-term data on health of livestock fed GE foods, and human epidemiological data, the committee found no differences that implicate a higher risk to human health from GE foods than from their non-GE counterparts.
Chapter 5	Improved Micronutrient Content	**Finding:** Experimental results with non-GE crop varieties that have increased concentrations of micronutrients demonstrate that both GE and non-GE crops with these traits could have favorable effects on the health of millions of people, and projects aimed at providing these crops are at various stages of completion and testing.
Chapter 5	Altering Oil Composition	**Finding:** Crops with altered oil composition might improve human health, but this will depend on the specific alterations, how the crops yield, and how the products of the crops are used.
Chapter 5	Genetically Engineered Foods with Lower Concentrations of Toxins	**Finding:** It is possible that GE crops that would result in improved health by lowering exposure of humans to plant-produced toxins in foods could be developed, but there is insufficient information to assess the possibility. However, GE plants that indirectly or directly reduce fungal-toxin production and intake would offer substantial benefits to some of the world's poorest populations, which have the highest dietary intake of food-associated fungal toxins.
Chapter 5	Health Effects of Farmer Exposure to Insecticides and Herbicides	**Finding:** There is evidence that use of *Bt* cotton in developing countries is associated with reduced insecticide poisonings. However, there is a need for more rigorous survey data addressing the shortcoming of existing studies.
Chapter 5	Health Effects of Farmer Exposure to Insecticides and Herbicides	**Finding:** A major government-sponsored prospective study of farm-worker health in the United States does not show any significant increases in cancer or other health problems that are due to use of glyphosate.

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Chapter 5	Increased Precision and Complexity of Genetic-Engineering Alterations	**Finding:** The precision of emerging genetic-engineering technologies should decrease some sources of unintended changes in the plants, thus simplifying food-safety testing. However, engineering involving major changes in metabolic pathways or insertion of multiple resistance genes will complicate the determination of food safety because changes in metabolic pathways are known to have unexpected effects on plant metabolites.
Chapter 5	Increased Diversity of Crops To Be Engineered	**Finding:** Some future GE crops will be designed to be substantially different from current crops and may not be as amenable to animal testing as currently marketed GE crops.
Chapter 5	Increased Diversity of Crops To Be Engineered	**Recommendation:** There is an urgent need for publicly funded research on novel molecular approaches for testing future products of genetic engineering so that accurate testing methods will be available when the new products are ready for commercialization.
Chapter 6	Income Effects	**Finding:** The available evidence indicates that GE soybean, cotton, and maize have generally had favorable outcomes in economic returns to producers who have adopted these crops, but there is high heterogeneity in outcomes. Earlier economic studies had data and methodological limitations, but there is progress in advancing methods and in the number of issues addressed in analyses beyond economics.
Chapter 6	Income Effects	**Finding:** In situations in which farmers have adopted GE crops, especially those with herbicide resistance, the committee finds that nonmonetary considerations are probably driving adoption of GE crops despite the absence of a readily identifiable economic benefit related to their production.
Chapter 6	Benefits to Small-Scale Farmers	**Finding:** GE maize, cotton, and soybean have provided economic benefits to some small-scale adopters of these crops in the early years of adoption. However, sustained gains will typically—but not necessarily—be expected in those situations in which farmers also had institutional support, such as access to credit, affordable inputs, extension services, and markets. Institutional factors potentially curtail economic benefits to small-scale farmers.
Chapter 6	Benefits to Small-Scale Farmers	**Finding:** VR papaya is an example of a GE crop that is conducive to adoption by small-scale farmers because it addresses an agronomic problem but does not require concomitant purchase of such inputs as pesticides. Other technologies currently in the R&D pipeline—such as insect, virus and fungus resistance and drought tolerance—are potential candidates to accomplish the same outcome especially if deployed in crops of interest to developing countries.

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Chapter 6	Benefits to Small-Scale Farmers	**Recommendation:** Investments in GE crop R&D may be just one potential strategy to solve agricultural production and food security problems because yield can be enhanced and stabilized by improving germplasm, environmental conditions, management practices, and socioeconomic and physical infrastructure. Policy-makers should determine the most cost-effective ways to distribute resources among those categories to improve production.
Chapter 6	Aspects of Farmer Knowledge	**Finding:** There is some evidence suggesting that farmers have insights helpful to regulators of GE crops but that regulators do not make use of this knowledge.
Chapter 6	Aspects of Farmer Knowledge	**Finding:** A few studies have suggested that HR and *Bt* crops contribute to farmer deskilling.
Chapter 6	Aspects of Farmer Knowledge	**Recommendation:** More research to ascertain how farmer knowledge can help to improve regulations should be conducted. Research is also needed to determine whether and to what degree genetic-engineering technology in general or specific GE traits contribute to farmer deskilling.
Chapter 6	Gender	**Finding:** GE crops with *Bt* and HR traits differentially affect men and women in the agricultural labor force, depending on the gendered division of labor for the specific crop and for particular localities.
Chapter 6	Gender	**Finding:** There is a small body of evidence that women's involvement in decision-making about planting new crop varieties and soil conservation has increased in farming households in general, including households that have adopted GE crops.
Chapter 6	Coexistence	**Finding:** Strict private standards mean that producers may meet government guidelines for adventitious presence but fail to meet private contract requirements.
Chapter 6	Coexistence	**Finding:** The question of who is economically responsible for adventitious presence is handled differently by different countries.
Chapter 6	Consumers' Acceptance and Marketplace Awareness	**Finding:** Consumers' willingness to pay for non-GE food is price-sensitive.
Chapter 6	Consumers' Acceptance and Marketplace Awareness	**Finding:** The economic effects of mandatory labeling of GE food at the consumer level are uncertain

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Chapter 6	Constraints on Trade	**Finding:** Trade disruptions related to crops with GE traits due to asynchronous approvals and violations of tolerance thresholds are likely to continue to occur and to be expensive for exporting and importing countries
Chapter 6	Effects of Regulation on the Development and Introduction of New Genetically Engineered Crops	**Finding:** Regulations of GE crops inherently involve tradeoffs. They are necessary for biosafety and consumer confidence, but they also have economic and social costs that can slow innovation and deployment of beneficial products.
Chapter 6	Effects of Regulation on the Development and Introduction of New Genetically Engineered Crops	**Finding:** Estimates of the regulatory costs of GE crop development vary widely by study and by trait-crop combination.
Chapter 6	Effects of Regulation on the Development and Introduction of New Genetically Engineered Crops	**Recommendation:** A robust, consistent, and rigorous methodology should be developed to estimate the costs associated with taking a GE crop through the regulatory-approval process.
Chapter 6	Intellectual Property	**Finding:** There is disagreement in the literature as to whether patents facilitate or hinder university-industry knowledge-sharing, innovation, and the commercialization of useful goods, and utility patents on GE crop germplasm legally block research on a crop.
Chapter 6	Intellectual Property	**Finding:** Whether a patent is applied to conventionally bred or GE crops, institutions with substantial legal and financial resources are capable of securing patent protections that limit access by small farmers, marketers, and plant breeders who lack resources to pay licensing fees or to mount legal challenges.
Chapter 6	Intellectual Property	**Finding:** There is evidence that the portfolio of public institutions has shifted to mirror that of private firms more closely.
Chapter 6	Intellectual Property	**Recommendation:** More research should be done to document benefits of and challenges to existing intellectual-property protection for GE and conventionally bred crops.
Chapter 6	Intellectual Property	**Recommendation:** More research should be done to determine whether seed-market concentration is affecting GE seed prices and, if so, whether the effects are beneficial or detrimental to farmers.
Chapter 6	Intellectual Property	**Recommendation:** Research should be done on whether trait-stacking is leading to the sale of more expensive seeds than farmers need.

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Chapter 6	Intellectual Property	**Recommendation:** Public investment in basic research and investment in crops that do not offer strong market returns for private firms should be increased.
Chapter 6	Food Security	**Finding:** The ability of crops with GE traits to address food-security concerns will depend on the types of traits introduced and the social and economic contexts in which the traits are developed and diffused.
Chapter 7	Modern Plant-Breeding Methods	**Finding:** Conventional and GE plant-breeding approaches in the 21st century have been enabled by increased knowledge of plant genomes, the genetic basis of agronomic traits, and genomic technologies to genotype germplasm.
Chapter 7	Modern Plant-Breeding Methods	**Finding:** Continued improvements in genomic technologies and algorithm and software development in the coming decades will facilitate further improvements in the efficiency of plant breeding.
Chapter 7	Modern Plant-Breeding Methods	**Finding:** As genomic technologies increase in throughput and decrease in cost, thousands of genomes will be characterized per crop species.
Chapter 7	Commonly Used Genetic-Engineering Technologies	**Finding:** Construction of GE plants commonly relies on in vitro plant tissue culture that can result in unintended, somaclonally induced genetic change. Development of transformation methods that minimize or bypass tissue culture for all crop species would reduce the frequency of tissue-culture–induced somaclonal variation.
Chapter 7	Genome Editing	**Finding:** Exploitation of inherent biological processes—DNA binding-zinc finger proteins (ZFNs), pathogen-directed transcription of host genes (TALEs), and targeted degradation of DNA sequences (CRISPR/Cas)—now permit precise and versatile manipulation of DNA in plants.
Chapter 7	Future Applications of Genome Editing	**Finding:** Genome-editing methods can complement and extend contemporary methods of genetic improvement by modifying composition and expression of genes and by targeting insertion events.
Chapter 7	Future Applications of Genome Editing	**Finding:** Current genome-editing methods and reagents are improving rapidly in precision and efficiency.

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Chapter 7	Detection of Genome Alterations Via -Omics Technologies	**Finding:** Application of -omics technologies has the potential to reveal the extent of modifications of the genome, the transcriptome, the epigenome, the proteome, and the metabolome that are attributable to conventional breeding, somaclonal variation, and genetic engineering. Full realization of the potential of -omics technologies to assess substantial equivalence would require the development of extensive species specific databases, such as the range of variation in the transcriptome, proteome, and metabolome in a number of genotypes grown in diverse environmental conditions. Although it is not yet technically feasible to develop extensive species-specific metabolome or proteome databases, genome sequencing and transcriptome characterization can be performed.
Chapter 7	Detection of Genome Alterations Via -Omics Technologies	**Recommendation:** To realize the potential of -omics technologies to assess intended and unintended effects of new crop varieties on human health and the environment and to improve the production and quality of crop plants, a more comprehensive knowledge base of plant biology at the systems level (DNA, RNA, protein, and metabolites) should be constructed for the range of variation inherent in both conventionally bred and genetically engineered crop species.
Chapter 8	Is Genetic Engineering Necessary to Deliver the Next Generation of Plant Traits?	**Finding**: New molecular tools are further blurring the distinction between genetic modifications made with conventional breeding and those made with genetic engineering.
Chapter 8	Is Genetic Engineering Necessary to Deliver the Next Generation of Plant Traits?	**Finding:** Treating genetic engineering and conventional breeding as competing approaches is a false dichotomy; more progress in crop improvement could be brought about by using both conventional breeding and genetic engineering than by using either alone.
Chapter 8	Is Genetic Engineering Necessary to Deliver the Next Generation of Plant Traits?	**Finding**: In some cases, genetic engineering is the only avenue for creating a particular trait. That should not undervalue the importance of conventional breeding in cases in which sufficient genetic variation is present in existing germplasm collections, especially when a trait is controlled by many genes.
Chapter 8	Tolerance of Biotic Stress	**Finding:** A better understanding of both the nature and regulation of inducible defense pathways coupled with emerging genetic-engineering technologies could enable manipulation of complex metabolic pathways for enhancing plant resistance to disease.
Chapter 8	Tolerance of Biotic Stress	**Finding**: Genetic engineering can be used to develop crop resistance to plant pathogens with potential to reduce losses for farmers in both developed and developing countries.

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Chapter 8	Tolerance of Biotic Stress	**Finding**: Several genetic-engineering approaches involving use of RNAi or exploitation of chemical ecological phenomena are becoming available for the control of insect pests. More research is required to address the sustainability of, and off-target effects arising from, RNAi approaches, and to learn how to adapt agroecological manipulation for crop protection.
Chapter 8	Tolerance of Abiotic Stress	**Finding**: Several approaches to engineering abiotic stress tolerance in plants are available, but, owing to the complexity of plant stress responses, more complex, temporally adjustable approaches than are now used will probably be necessary, particularly in the face of unpredictable climate change.
Chapter 8	Increasing Plant Yield and Efficiency of Production	**Finding**: Applications of genetic engineering that target basic plant processes, such as photosynthesis and nitrogen fixation, have the potential to result in greater yield gains or increased efficiency but will probably require complex genetic changes and therefore involve long-term projects.
Chapter 8	Increased Forage Quality	**Finding:** GE approaches to forage-quality improvement have potential to yield environmental benefits associated with reductions in greenhouse gases and manure.
Chapter 8	Improved Biofuel Feedstocks	**Finding**: Recent advances in understanding and overcoming biomass recalcitrance make it more likely that “second-generation” lignocellulosic biofuels will be developed commercially through either conventional breeding or genetic engineering.
Chapter 8	Introduced or Enhanced Nutritional Traits	**Finding:** Genetic engineering can enhance the ability to increase the nutritional quality and decrease antinutrients of crop plants.
Chapter 8	Future Genetically Engineered Crops, Sustainability, and Feeding the World	**Finding:** It is important to develop policy approaches that enable research on GE crops to assist in achieving sustainable intensification without diminishing resources available for the exploitation of proven existing technologies.
Chapter 8	Future Genetically Engineered Crops, Sustainability, and Feeding the World	**Finding**: Although emerging genetic-engineering technologies have the potential to assist in achieving a sustainable food system, broad and rigorous analyses will be necessary to determine the long-term health, environmental, social, and economic outcomes of adding specific crops and traits to an agroecosystem.
Chapter 8	Future Genetically Engineered Crops, Sustainability, and Feeding the World	**Finding:** Given the uncertainty about how much emerging genetic-engineering technologies will increase crop production, viewing such technologies as major contributors to feeding the world must be accompanied by careful caveats.

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Chapter 8	Future Genetically Engineered Crops, Sustainability, and Feeding the World	**Recommendation:** Balanced public investment in emerging genetic-engineering technologies and in a variety of other approaches should be made because it will be critical for decreasing the risk of global and local food shortages.
Chapter 9	Regulatory Systems for Genetically Engineered Crops	**Finding:** The diverse regulatory processes for products of genetic engineering mirror the broader social, political, legal, and cultural differences among countries.
Chapter 9	Regulatory Systems for Genetically Engineered Crops	**Finding:** Conflicts about trade and disagreements about regulatory models are likely to continue to be a part of the international landscape.
Chapter 9	The Role of Product Regulation Beyond Biosafety	**Finding:** Policy regarding GE crops has scientific, legal, and social dimensions, and not all issues can be answered by science alone. Indeed, conclusions about GE crops often depend on how stakeholders and decision-makers set priorities among and weigh different considerations and values.
Chapter 9	The Role of Product Regulation Beyond Biosafety	**Recommendation:** In addition to issues of product safety, socioeconomic issues that go beyond product safety are technology-governance issues that should be addressed by policy-makers, the private sector, and the public in a way that considers competing interests of various stakeholders and inherent tradeoffs.
Chapter 9	The Role of Expertise, Public Participation, and Transparency in Product Regulation	**Finding:** Transparency and public participation have been shown by research to be critically important for appropriate, sound, and credible governance of all aspects of the development, deployment, and use of GE crops.
Chapter 9	The Role of Expertise, Public Participation, and Transparency in Product Regulation	**Recommendation:** Regulating authorities should be particularly proactive in communicating information to the public about how emerging genetic-engineering technologies (including genome editing and synthetic biology) or their products might be regulated and about how new regulatory methodologies (such as the use of -omics technologies) might be used. They should also be proactive in seeking input from the public on these issues.
Chapter 9	The Role of Expertise, Public Participation, and Transparency in Product Regulation	**Recommendation:** In deciding what information to exclude from public disclosure as confidential business information or on other legal grounds, regulating authorities should bear in mind the importance of transparency, access to information, and public participation and ensure that exemptions are as narrow as possible.

Click the link below to find the report text about each finding or recommendation

Chapter 9	Post-Approval Environmental Monitoring	**Recommendation:** Regulatory agencies responsible for environmental risk should have the authority to impose continuing requirements and require environmental monitoring for unexpected effects after a GE crop has been approved for commercial release.
Chapter 9	Scope of Products Subject to Premarket Regulatory Safety Assessment	**Finding:** Not having government regulation of GE crops would be problematic for safety, trade, and other reasons and would erode public trust.
Chapter 9	Scope of Products Subject to Premarket Regulatory Safety Assessment	**Recommendation:** In determining whether a new plant variety should be subject to a premarket government approval for health and environmental safety, regulators should focus on the extent to which the characteristics of the plant variety (both intended and unintended) are likely to pose a risk to health or the environment on the basis of the novelty of traits, the extent of uncertainty regarding the severity of potential harm, and the potential for exposure regardless of the process by which the novel plant variety was bred.