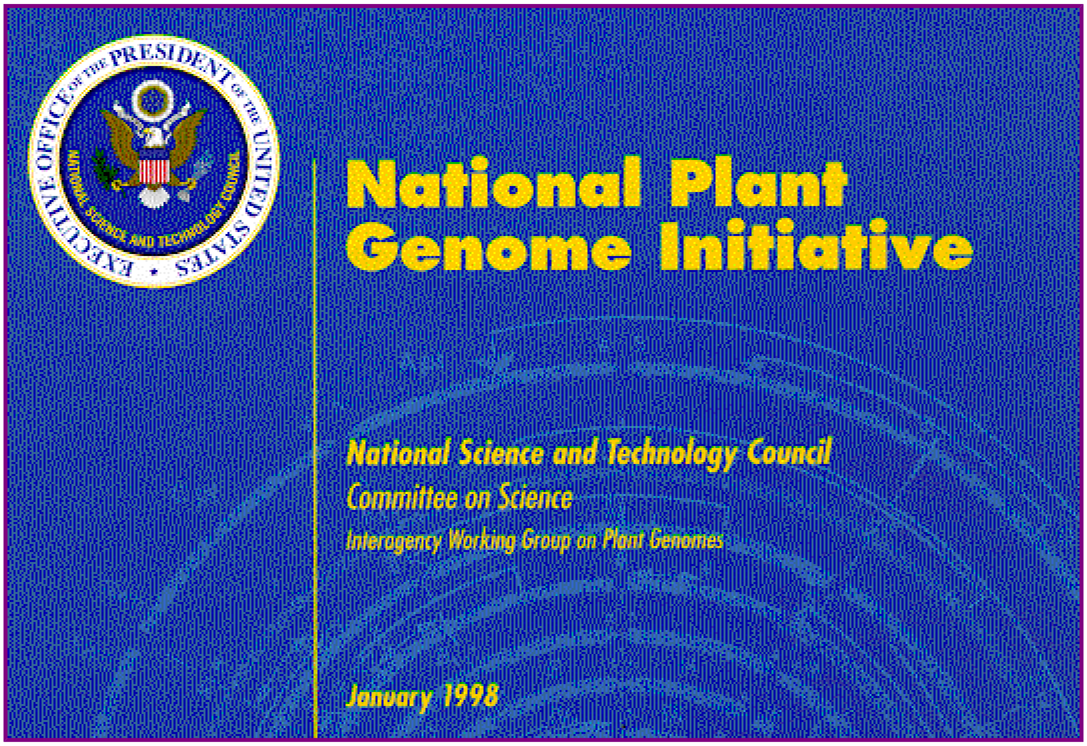

[About the National Science and Technology Council](#)
[About the Office of Science and Technology Policy](#)

Note: This document does not represent the final determinant in an overall Administration budget decision-making process. The programs presented in this report will have to compete for resources against many other high-priority Federal programs. If these programs compete successfully, they will be reflected in future Administration budgets.

Cover Illustration: Syntenic map of oats, triticeae, maize, sorghum, sugarcane, foxtail millet, and rice indicating close relationships among the genomes of grass species. Courtesy of Dr. M. Gale of John Innes Center, Norwich, United Kingdom.

Interagency Working Group on Plant Genomes
Committee on Science
National Science and Technology Council

Ronald L. Phillips (Chair)
Chief Scientist
National Research Initiative Competitive Grants Program
U.S. Department of Agriculture
(and Regents' Professor, University of Minnesota)

Mary E. Clutter
Assistant Director for Biological Sciences
National Science Foundation

Francis Collins
(Represented by Elke Jordan)
Director
National Human Genome Research Institute

Eileen Kennedy
Acting Deputy Under Secretary
Research, Education, and Economics
U.S. Department of Agriculture

Patricia Dehmer
(Represented by Greg Dilworth)
Associate Director
Office of Energy Research
Department of Energy

Clifford Gabriel
Deputy to the Associate Director
Office of Science and Technology Policy

National Institutes of Health

Catherine Woteki
Acting Under Secretary
Research, Education, and Economics
U.S. Department of Agriculture

Floyd Horn
Administrator
Agricultural Research Service
U.S. Department of Agriculture

Rachel Levinson
Assistant Director for Life Sciences
Office of Science and Technology Policy

Adrienne Erbach
Program Examiner
Office of Management and Budget

Acknowledgments

The IWG on Plant Genomes was assisted greatly by James Tavares, Office of Energy Research; James Edwards, Machi Dilworth, and Keelin Kuipers, National Science Foundation; Judy St. John, Agricultural Research Service; and Sally Rockey and Ed Kaleikau, Cooperative State Research Education, and Extension Service.

Table of Contents

National Plant Genome Initiative
Executive Summary

The Need for a National Plant Genome Initiative: Recent scientific advances made through our nation's investments (private and public sector) in studying DNA structure and function in humans and model organisms have resulted in a new biological paradigm for understanding the traits of organisms. Through the National Plant Genome Initiative (NPGI), this paradigm can be extended to improving the useful properties of plants that are important to humanity. Solutions to many of our nation's greatest challenges can be met through the application of plant-based technologies. For example, the revitalization of rural America will come from a more robust agricultural sector; reductions in greenhouse gasses can be achieved from the production of plant biofuels for energy; chemically contaminated sites can be rehabilitated economically using selected plants; and worldwide malnutrition can be greatly reduced through the development of higher yielding and more nutritious crops that can be grown on marginal soil.

The Initiative's Goals: The long-term goal is to understand the structure and function of genes in plants important to agriculture, environmental management, energy, and health. Reaching this goal will require a sustained commitment from the Federal government working in collaboration with other nations and with the private sector. The Initiative's short-term goals, to be achieved over the next five years, focus on building a plant genome research infrastructure by:

- completing the sequencing of the model plant species *Arabidopsis*;
- participating in an international effort to sequence rice;
- developing the biological tools (e.g., physical maps, ESTs, mutants) to study complex plant genomes (e.g., corn, wheat, soybean, cotton);
- increasing our knowledge of gene structure and function of important plant processes;
- developing the appropriate data handling and analysis capabilities; and
- ensuring this new information will be accessible to the broader community of plant biologists (e.g., growers, breeders, physiologists, biotechnologists) and maximizing the training opportunities that will arise from the Initiative.

The Initiative's Operating Principles:

- The Initiative should be viewed as a long-term project, governed by a plan that will be updated periodically.
- All resources, including data, software, germplasm, and other biological materials should be openly accessible to all.
- The Federal portion of the Initiative should be coordinated by an NSTC interagency working group with USDA, NSF, DOE, NIH, OSTP, and OMB representation.
- All awards should be made on a competitive basis with peer review.
- Partnerships with the private sector and with other nations are vital for success.

Funding: To accomplish the five-year goals of the NPGI, at least $320 million could be used by the Federal government in a targeted manner to leverage existing plant genome activities in the public and private sectors. Current estimates of cost could be decreased with advances in technology.

National Plant Genome Initiative
Final Report
January 1998

The Interagency Working Group (IWG) for Plant Genomes was appointed on May 16, 1997, by Dr. John Gibbons, Assistant to the President for Science and Technology, in response to a request from the Senate VA, HUD and Independent Agencies Appropriations Subcommittee (see Appendix A). The charge was to identify science-based priorities for a national plant genome initiative and to plan for a collaborative interagency approach to address these priorities. The IWG consisted of representatives from the Department of Agriculture (USDA), National Science Foundation (NSF), National Institutes of Health (NIH), Department of Energy (DOE), Office of Science and Technology Policy (OSTP), and the Office of Management and Budget (OMB). The National Science and Technology Council (NSTC) Committee on Science provided oversight for the IWG.

Over the past eight months, the IWG has benefited from the deliberations of several scientific meetings related to plant genome research (see discussion of these meetings in Appendix B). These meetings with scientists in the field of genomics research provided valuable insights that assisted the IWG in responding to its charge and verified the wide interest in and support for a coherent Federal program in plant genomics. The IWG also convened informal meetings with representatives of three groups interested in a plant genome initiative: agribusiness, academia and crop producers.

Why a National Plant Genome Initiative?

The major challenges facing mankind in the 21st Century are the need for increased food and fiber production, a cleaner environment, and renewable chemical and energy resources. Plant-based technologies can play a major role in meeting each of these challenges. In order to reap the benefits of plant-based technologies, however, we must greatly expand our understanding of numerous fundamental aspects of plant biology and how these relate to desirable economic or environmental genetic traits. Therefore, the IWG recommends the development of the National Plant Genome Initiative (NPGI) as described in this report.

The complete genetic makeup of any organism is known as its genome. The study of genomes, also known as genomics, consists of mapping, sequencing, and analyzing genomes to determine the function of genes. Information and knowledge gained from genomics will be used to improve the useful traits of plants through genetic engineering and new breeding strategies. Genomics has already had significant impact in agriculture with genetically-engineered plants comprising ten percent of the current U.S. corn crop. Similar, or greater, acreage of genetically engineered crops are anticipated for cotton and soybean. However, the total number of plant traits that have been genetically engineered is few, reflecting the limitations in our knowledge of fundamental plant processes. Fortunately, the genes that code for plant traits and processes appear to be nearly identical across a wide range of species. New technologies to exploit this finding are being developed constantly. Thus the time from fundamental discoveries about plant genomes to the final application of that information is relatively rapid.

The study of plant genomes is providing growing evidence of the value of comparative genomic analysis. Comparative genomics uses genetic information gleaned from one species to help decipher that of another. For example, comparative genomics can be used to help determine gene content and order, patterns of gene expression during development, or how a particular gene has been conserved throughout evolution from the simplest to higher organisms. The ability to determine the physical organization and expression patterns of genes from many plant species will allow the best leveraging of available resources through comparative genome analysis.

Initiative Goal and Objectives

Goal Statement

The ultimate goal of genomics is to understand the structure and function of every gene in an organism. With the intent of exploiting that knowledge for the betterment of society, the NPGI will pursue this goal by focusing on plant species important to agriculture, environment, energy and health. This increased emphasis on the plant genome will radically change fundamental plant science research and its application to agriculture, forestry, energy, and the environment, as well as to the production of pharmaceuticals and other plant-based industrial chemicals and materials.

Scientific Objectives

Genomics research can be divided into three components: 1) structural genomics—studies of the structure and organization of genomes; 2) functional genomics—studies that relate genome structure and organization to plant function at the cellular, organismal or evolutionary level; and 3) application of the genomic information and knowledge for development of improved plants and novel plant-based products for human uses. The plan recommended in this report focuses on the first two components as most relevant to the Federal investment and provides linkages to the third component.

- **Sequencing the *Arabidopsis thaliana* and Rice Genomes**

The IWG supports the sequencing of the entire genomes of *Arabidopsis* as part of the NSF, USDA, and DOE *Arabidopsis* Genome Sequencing Project, which is coordinated with the multinational *Arabidopsis thaliana* Genome Research Project, and rice in collaboration with the Rice Genome Program of Japan and other countries. Compared to other higher plants, the genomes of *Arabidopsis* and rice are small, making whole genome sequencing of these two plants a readily achievable goal. *Arabidopsis* and rice can become reference or model genomes for two major classifications of plants, dicots and monocots, respectively. (A comparison of the genome size of several economically important plants to *Arabidopsis* and rice can be found in Table 1.) It is anticipated that the genomes of *Arabidopsis* and rice could be completed in the years 2000 and 2004, respectively, with sufficient funding. This goal of the NPGI would facilitate international collaboration and result in data being readily available to U.S. scientists.

Table 1. Plant genome size comparisons to illustrate relative degrees of difficulty in sequencing species other than rice and *Arabidopsis*.

Relative Genome Sizes (Compared to rice)		Relative Genome Sizes (Compared to *Arabidopsis*)	
Arabidopsis	0.34	*Arabidopsis*	1.00
	1.00	Rice	2.97
Rice	1.74	Sorghum	5.17
Sorghum	2.21	Tomato	6.55
Tomato	5.81	Corn	17.24
Corn	11.40	Barley	33.79
Barley		Wheat	110.34
Wheat	37.22		

• Structural Genomics

Structural genomics research involves elucidating the structure and organization of genomes. Research in this area could include the production, mapping, and sequencing of expressed sequence tags (ESTs) from a number of plant species and the construction of physical maps (cloned and ordered segments of the genome). Therefore, a primary step for the NPGI would be to develop physical maps for key plant species, including corn and other economically important species. In addition, it would be extremely useful to have approximately 200,000 ESTs available for 10-12 species, such as corn, soybean, wheat, barley, sorghum, cotton, tomato and pine. A few "exotic" (non-economically significant) species should also be considered in order to search for useful genes not present or expressed in economically important plants.

• Functional Genomics

Functional genomics research involves identification of functions for gene sequences, including determining expression patterns for pathways or networks of genes under specific environmental conditions or during developmental stages. Genes obviously important to plant production and productivity, such as those coding for disease and stress resistance, seed development, grain-quality traits, and flowering time would be targeted by the NPGI. Also included would be those genes that regulate other genes (e.g., transcription factors, receptors, signaling factors); these are difficult to identify by classical means, but are much more accessible via genomic technologies.

• Technology Development

Continued technological development will be required in order to sustain rapid advances in plant genomics. In particular, technological advances are needed in such areas as: analytical methods for mapping genes for complex traits; novel methods for analysis of genome organization and its effect on biological function; cost-effective sequencing technologies; and procedures to analyze the total expression patterns of genes under specific conditions. Promising technological developments include DNA chips for the simultaneous analysis of expression patterns of thousands of genes and strategies for creating specific gene mutations for the rapid identification of gene function. Due to the sizable Federal investment in genomic technology by the Human Genome Project, the NPGI should focus on the development of technologies of specific use for plant genomics.

- **Distribution and Use of Genome Data and Resources**

The NPGI will generate extensive mapping and sequence data that must be analyzed and distributed. While much of the necessary computer software and databases have been and are being developed by the Human Genome Project, plant-specific tools and databases must also be developed. Along with the distribution of genomic data, resources such as reference sequences, libraries, and germplasm must also be developed, maintained, and distributed. Plant genome data should be integrated with data from other genome projects.

- **Outreach and Training**

The ultimate success of a plant genome initiative will be determined by its impact on fundamental plant biology research and on the application of this research. In order to ensure rapid transfer of genomic information and technologies to their end users, outreach activities should be an integral part of the overall plan for the NPGI. Examples of outreach include mini-courses on how to access and utilize the data, tools, and resources of plant genomics and workshops that bring together plant genome researchers with other plant biologists or breeders. The NPGI also offers excellent training opportunities for young scientists, including members of under-represented groups, to participate in the development and use of cutting-edge research technologies.

Scientists Discover a New Class of Genes

Researchers have discovered a new gene in *Arabidopsis*, a small plant related to the mustard family, that allows the plant to obtain iron from soil whenever it is starved for this essential nutrient. The discovery has important implications for both crop yields and human nutrition. More than a third of the world's soils are iron-deficient, compromising soil fertility. Iron deficiency is also the leading nutritional disorder in people worldwide. A better understanding of this gene and its precise function could lead to the creation of plants that are more efficient users of iron in soil and richer sources of iron in foods.

To find the new gene, researchers inserted pieces of DNA from *Arabidopsis* into mutant yeast cells known to lack the ability to survive in low-iron conditions. The only yeast cells that survived with little iron were the ones that had incorporated an *Arabidopsis* gene for a protein in the plant's roots that converts an unusable form of iron into one that can be taken up from the soil. The scientists showed that the same protein appears to draw the metal cadmium into cells as well. That property could prove useful to a new technique called phytoremediation, in which gene-altered plants are being used to remove toxic metals such as cadmium from contaminated soils.

When the researchers compared the gene's DNA sequence to those stored in a publicly-funded data bank containing sequences from hundreds of other organisms, they discovered several closely related sequences of unknown function in rice, yeast, worms and humans, suggesting that they may have discovered a new family of metal transport genes. The NPGI would accelerate this kind of work, leading to the possible identification and manipulation of this class of genes in economically important plants.

Management of a National Plant Genome Initiative

Operating Principles

* The National Plant Genome Initiative should be viewed as a long-term project, governed by a plan that will be updated periodically, based on assessment of success in reaching critical milestones and of the rapidly changing state of the art. (The end-user community should participate in the periodic updating of NPGI goals and objectives.)

* Research resources including data, software, germplasm and other biological materials should be made openly accessible as rapidly as possible.

* The National Plant Genome Initiative should be coordinated by an interagency working group composed of representatives from DOE, NIH, NSF, USDA, OSTP and OMB, operating under the aegis of the National Science and Technology Council (NSTC).

* All awards should be made on a competitive basis with peer review to ensure the highest scientific merit.

* International partnerships should be developed with each country financing its own program.

* Cooperation with the private sector should be encouraged.

Agency Coordination and Responsibilities

Past and current interagency activities in plant biology research (USDA, NSF and DOE) and the

Arabidopsis Sequencing Project (NSF, USDA, DOE, and NIH) have evolved rational procedures for full collaboration between the respective agencies. These procedures allow the agencies to maintain faithfulness to each agency's mission and provide sufficient budgetary independence to permit full accountability. Joint program announcements, proposal peer review and technical management will be foremost among the characteristics of the interagency interactions. Coordination of these activities should be handled under the aegis of an NSTC interagency working group.

Opportunities for cooperation and coordination of research efforts must be taken in a context that acknowledges the responsibility of specific agencies to support their distinct missions. The development of the fundamental knowledge base in the plant sciences is central to the mission of the NSF. NSF's continued efforts in all of plant science will be critical in helping to build the needed linkages between gene sequence and gene function, which is the ultimate goal of any plant genome project.

The plant genomics mission of the USDA likely will be part of the broader program defined as the Food Genome Initiative, which includes agriculturally important plants, animals, and microbes used as sources of food, feed, and fiber. The new knowledge and technologies generated by the coordinated NPGI will be widely applicable for development of improved crops for traditional and new uses. The plant component of the Food Genome Initiative is envisioned as encompassing the USDA participation in the NPGI.

DOE's interest in plant genome research includes energy-related issues underlying the use of plants in the production of biomass, chemical feedstocks, and biodegradable environmentally- friendly materials. The DOE is also interested in opportunities to genetically improve the role of plants for mitigating environmental problems in soil, water, or the atmosphere. Dependent upon the addition of fiscal resources, the DOE is likely to build upon its strengths in the functional genomics of metabolic pathways. Since DOE is a major participant in the Human Genome Project, relevant technologies developed through this program will be transferred to support the goals of the NPGI.

The NIH will continue its activities promoting human health by investing in the underlying critical technologies through the Human Genome Project, and it will have strong interest in comparative genomics and the genetics of potential pharmaceuticals and nutritional factors of plant origin.

While USDA, NSF, DOE, and NIH have been identified as the key Federal agencies, other agencies will benefit from this research and may wish to participate in the proposed NSTC NPGI coordination working group.

The Genetic Assault on Plant Disease

The time-honored approach to breeding a disease-resistant plant variety--crossing a resistant strain with a disease-susceptible stock--can be hugely successful, but it also can take a decade or more. That timetable is being rapidly revised downward as scientists identify specific genes that confer disease-resistance and slip them into more vulnerable plants, carrying along the power to shrug off disease. Farmers hope these advances will help slash the billions of dollars they lose to crop disease each year (an estimated $9.1 billion will be lost in the United States in the current year), while reducing their reliance on the chemicals widely used to fight plant disease.

In their quest to learn what makes one plant variety more capable of fighting off disease than another, molecular plant geneticists are identifying and mapping the genes that allow plants to resist the four scourges of field crops: fungi, viruses, nematodes, and bacteria. Once a resistance gene is isolated, the researchers can begin to identify the proteins produced by genes that are thought to be early players in the defense game. The genes recognize the invading pathogen, which triggers the host to quickly respond with effective defense measures, often stopping the pathogen and bolstering the plant's resistance to later attacks by other pathogens.

The new molecular advances dovetail with years of research that have resulted in maps of thousands of genes that code for diverse traits. In the last two years, researchers learned, much to their surprise, that most genes for resistance to different bacterial, viral, and fungal pathogens have common sequence patterns, that is, they encode proteins that have similar structure and thus, may have similar functions. This finding suggests that the disease-resistance genes may share an underlying mechanism for specifying disease resistance in all plants. Their similarities mean basic research on one plant/pathogen system will apply to many other systems, and thus may save scientists years of effort in bolstering plants' innate abilities to resist disease. The finding may also speed development of novel strategies for conferring resistance to a broad variety of pathogens.

So far, researchers have isolated and cloned at least 15 disease-resistance genes. In 1994, they came a step closer to cross-species transfer when they successfully isolated and cloned the gene that fights tobacco mosaic virus, which afflicts not only tobacco, but more than 150 other kinds of plants including tomatoes, eggplants, and peppers. The virus causes vulnerable plants to form a mosaic of yellow and green splotches, and can stunt the plant's growth. Resistant plants, however, quickly kill the cells surrounding the intruding virus, so the infection cannot spread. When researchers placed the gene in tobacco plants highly susceptible to the tobacco mosaic virus, the plants shrugged off attack.

Arabidopsis is known to produce a specific protein in response to both fungal and bacterial pathogens. Recently, scientists reported the identification of the gene encoding that protein. They found that when this gene is lost through mutation, several additional gene-based plant defense mechanisms are lost as well, thus supporting a hypothetical control function for the new gene that may extend to other plants, including tomato and barley.

International Coordination and Collaboration

With over 40 plant species of economic importance in the United States alone, it is clear that our nation–or any single nation–does not have the resources (financial or human) to launch a major genome project for each. Therefore, we must use our resources strategically, including establishing collaborations with scientists from other nations. Ideally, these collaborations should be among scientists rather than governments. Each participating scientist/laboratory should be supported by his or her own government under the terms and provisions of its own funding authority. However, in order to advance the project in a coordinated and efficient manner, all participating laboratories need to adhere to a common framework for participation. A key for success in international collaboration is open communication and free exchange of research results including data and experimental materials.

Fortunately we have excellent models on which to base future international plant genome projects. In particular, the *Arabidopsis thaliana* and the Human Genome Projects provide clear indications of how we should proceed in entering into international collaborations. Plans also are well underway for a new international rice genome project. Scientists met on September 23, 1997 in Singapore to begin development of an operational framework for this project. A steering committee was appointed consisting of representatives from Japan, China, Korea, European Union, and the United States. The Rockefeller Foundation will provide support to facilitate the work of the steering committee.

Interactions with the Private Sector

The large benefits of genomic science for both fundamental and applied research activities, combined with current laws and policies governing intellectual property rights and patenting, have prompted some companies to make substantial investments in plant genomics including DNA sequencing. It is believed that currently there are extensive collections of plant sequence data in the private sector. The traditionally highly cooperative interactions between the public and private research communities have permitted some public researchers access to this information with restrictions on future patent rights or open communication. The IWG’s discussions with representatives from four agribusiness firms indicated that motives for restricted access to the sequence data were to protect the companies’ investments in genomics and, therefore, their competitive advantage. However, these companies appeared to want extensive interaction with the public research community to leverage the private sector research investment. In particular, these four agribusiness firms were interested in establishing proprietary arrangements with public sector scientists in the area of functional genomics.

The IWG also met with representatives from various commodity and producer groups. In general, these groups were supportive of an extensive Federal role in plant genomics. These representatives expressed concern that support for genomics should not detract from other high priority projects. Such groups can play an important role in determining the expediency of particular applications and identifying areas in need of further research. In order to promote the development of specific applications, partnerships should be explored between Federally supported researchers and commodity or producer groups.

It is the responsibility of government funding agencies to ensure the continued advancement of fundamental plant science, which leads to a highly competitive environment for those industries and businesses directly or indirectly dependent on plants or plant production. Limitations in the availability of public funds have restricted the government's ability to support timely and extensive plant genome research. These limitations, combined with current patenting policies, have led to a significant investment by the private sector which now is unable to make the information freely available. While it is undesirable to duplicate private sector efforts, both philosophically and economically, the government must now act to provide critical data and research tools to the entire plant science community. Government officials, as representatives of the public research community, should continue to hold discussions with private industry in an effort to minimize current and future impediments to plant genome research.

Intellectual Property Rights

One legal issue that still requires considerable discussion concerns the intellectual property rights to genomic data. Increasing attention is being given to the nature of private sector involvement and its influence on biosciences research and development. Commercial entities founded on exploitation of the tools of biotechnology to manipulate life processes have proliferated over the past two decades, with significant holdings in the health, agricultural and, to a lesser degree, environmental sectors. Such companies have become major players in all phases of genomics, including plant genomics, with a particular focus on crops with the highest market value such as corn and soybeans, in the United States. Biotechnology companies face the challenge of a long product development cycle, making them particularly dependent on the ability to obtain enduring capital investment through the research, development, and manufacturing period preceding product marketing. A strong intellectual property portfolio is an attractive magnet to draw investors' attention to a young start-up firm, necessitating vigorous protection measures for this asset. International harmonization of patent laws will probably emphasize this role by encouraging the practice of filing patent applications early and often.

A number of agricultural biotechnology companies are engaged in the systematic sequencing of ESTs, focusing their efforts on the corn and soybean genomes with the intent to discover genes coding for proteins that are important for enhancing growth and development, disease and pest resistance, and desirable nutritional or other properties. There is intense competition to obtain access to ESTs, either by sequencing them in-house, or by contract production or licensing. The ESTs have no inherent value except as tools for gene discovery. However, in today's research environment, they are but a short step from marketable products.

Much has been written about the patentability and patenting (not to be confused) of the products of genome research. Suffice it to say that it appears that ESTs are patentable subject matter in the view of the U.S. Patent and Trademark Office, as long as the patent application contains at least some evidence of known gene product function or discloses some other credible utility for the EST. Thus there is incentive in the private sector to rush to patent ESTs to prevent others from staking a claim to downstream products, or require others to license the patent-holder's EST, once a product has been developed. Because of the long lag between patent application and issuance, no one knows whether a patent application has been filed claiming a particular gene sequence has been patented, and who owns that patent, until it issues. This increases the pressure to apply for patents on genes and gene fragments.

Various research funding agencies have adopted practices for encouraging both commercial development of the results of government-funded research and the sharing of research tools. This led to some friction in the human genome research community early in the Human Genome Project. However, the presence of a concerted government project appears not to have detracted significantly from the myriad private sector activities such as subscription-accessible EST databases and partnerships or licenses based on genome information.

The government, to date, has not been a significant contributor to the sequencing of plant ESTs. In designing a plant genome initiative, the IWG has adopted the principle that Federally funded resources, including data, software, germplasm and other biological materials should be openly accessible to all. This principle is grounded in the belief, borne out in the Human Genome Project experience, that open access to a common set of research tools will advance the whole field of plant genomics and is a sound investment of public funds. Cottage industry sequencing is slow and tends to focus on genes of specific interest. A more ambitious but ultimately more useful approach is one that culminates in gene and chromosome maps with markers at intervals permitting rapid and efficient gene searches. Creation of common maps reduces duplication of effort and enhances quality control through verification by multiple users. Rapid release of data and sharing of material is desirable and necessary to expedite research and its application to the development of useful new products.

Open access to these resources can be accomplished with or without patenting. The preferred option supported by the IWG is not to attempt to patent early-stage research tools and to discourage plant genome initiative grantees or contractors from doing so. This is consistent with the policy adopted for the Human Genome Project and the proposal suggested by the National Corn Growers Association. Fears that disclosure of gene fragment sequence would render the full gene sequence or other downstream genome research products unpatentable have diminished, although not entirely. Nevertheless, the importance of providing information and materials to the plant genome research community as rapidly as possible should take precedence over other concerns as the optimal means for ensuring efficient incorporation into the body of scientific knowledge, necessary for development of new plant genotypes and other applications.

Public Issues

Just as in other aspects of genome science, plant genetics has a number of ethical, social, legal, and economic issues of interest to society. These issues are being addressed on a wide scale, both here in the United States and abroad. Most of these issues relate to the genetic engineering of crop plants, not to genomics research *per se*.

Issues regarding public perception of plant biotechnology are widespread and varied. All indications are that genetic engineering of food products will result in safer, more nutritious foods. Even so, some groups have expressed concerns about the perceived safety and quality of these products, such as the possibility of allergic reactions, introduction of toxins, or altered nutritional value. On the positive side, along with safer and better quality food, these products are expected to provide benefits to the environment. Some of the potential benefits include a reduction in the use of pesticides when plants are genetically modified to kill insects or the ability to withstand other environmental threats, including drought or extreme temperatures.

However, there is some public concern over potential adverse impacts of genetically modified plants on the environment, such as reduction in genetic diversity or possible increased use of pesticides and herbicides when plants are genetically engineered to withstand them. Other environmental concerns include the possibility of uncontrolled natural propagation of genetically modified organisms and the transmission of engineered genes to related varieties and species.

These safety and environmental concerns have spurred debate over regulatory issues, such as under what circumstances genetically engineered products should be labeled as such and what kinds of regulatory controls should be placed on the distribution and use of these products. There is currently public debate in the United States and Europe over whether genetically engineered food products should be labeled and how such labeling would affect public attitudes toward these products. Differences in regulatory approaches can impact international trade; therefore, international harmonization of these approaches and developing consensus on biosafety issues also need to be addressed. In addition, there is growing concern that, due to the cost of technologies resulting from plant genome research, developing nations may have slowed or limited access to them.

Another set of issues revolves around whether patenting the results of plant genomics research is the most appropriate way to protect private sector investment. This leads to concerns about intellectual property rights and the increasing amount of R&D conducted by the private sector, particularly by a few large companies. Concerns over the increasing amount of plant genomic information held in the private sector and restricted access to this information drive the need to consider the implications of public/private initiatives in making genomic information more accessible to all researchers. This is also an issue internationally, where significant amounts of crop germplasm may be held outside the country from which it was collected.

Given the number and complexity of ethical, social, legal, and economic issues related to plant genomics, the committee recommends that they should be addressed by the NPGI. Policy options to consider include establishing a fund for research into societal aspects of plant genome research and establishing mechanisms to improve the flow of information to the public on these issues.

Cost Estimates for Achieving Five-Year Objectives

It is estimated that at least $320 million, spent over five years, would be needed in order to make significant progress on the scientific objectives outlined above. In such a rapidly advancing field, where new technologies and discoveries may dramatically affect the costs and the direction of the science, it would be counterproductive to attempt to predict specific scientific goals or budget needs beyond five years.

Fiscal Year 1998 plant genome funds already appropriated to NSF ($40 million) will allow initiation of a number of research and infrastructure projects (see attached NSF program announcement in Appendix C). An additional investment of $280 million could be used to ensure that the nation will be in a position to fully exploit the plant genomics revolution by the end of this five-year period. This estimate is based on the following anticipated needs:

- $20 million to speed up *Arabidopsis* genome sequencing, so that the complete sequence will be available by the year 2000; this amount will be complemented by comparable expenditures in the remaining countries participating in the multinational coordinated *Arabidopsis* Genome Project (including the European Union, France, and Japan);

- $40 million to sequence approximately 20 percent of the rice genome sequence, with the remainder of the genome to be sequenced by other nations, principally Japan and the European Union;

- $30 million for EST projects for 20 major economically important species and 10 major classes of plants (cost based on an estimate provided by The Institute for Genomic Research at the NAS Colloquium "Protecting Our Food Supply: the Value of Plant Genome Initiatives");

- Up to $100 million for cDNA and related genomic sequencing of selected plant species, such as corn, wheat, soybean, sorghum, tomato, barley, pine, etc.;

- Up to $60 million to meet the infrastructural needs of plant genomic research; and

- Up to $150 million for functional genomics research.

The Interagency Working Group cautions that flexibility in this budget distribution will be essential, because relative costs of plant genome research are changing constantly with rapid advances in technologies.

Appendix A

Appendix B

Non-IWG Meetings Used to Gain Scientific Insight

- The first was organized by the National Academy of Sciences (NAS) Board on Agriculture and Board on Biology at the request of USDA. The meeting entitled, "Designing an Agricultural Genome Program," was held at the National Academy of Sciences (NAS), Washington, D.C., on April 29, 1997, and attended by about 60 invited participants. Four members of the IWG were in attendance.

- The second meeting was a NAS Colloquium, "Protecting Our Food Supply: The Value of Plant Genome Initiatives." This meeting was held in Irvine, California, on June 2-5, 1997. Approximately 85 attended the meeting (including three IWG members) and included many of the world′s top scientists in plant genomics. A report of that meeting will be forthcoming.

- The third meeting was the Gordon Research Conference on Plant Cell Genetics and Development in Henniker, NH, on June 8-13, 1997. This meeting had many of the same scientists present as speakers, including Ronald Phillips, who reviewed the history and potential of a plant genome program. A subgroup at the meeting was assembled by the Conference Chair, Jo Messing, Director, Waksman Institute, Rutgers University. Others attending were the leader of the Rice Genome Program in Japan, Takuji Sasaki, Tsukuba; the leader of the *Arabidopsis* Genome sequencing projects of Japan, Satoshi Tabata, Kazusa DNA Research Institute, Chiba Prefecture; a leader of the American Arabidopsis Genome Sequencing Project, Joe Ecker, University of Pennsylvania; the leader of the International Triticeae (wheat, barley, oats, rye, etc.) Mapping Initiative, Michael Gale, John Innes Center, Norwich, UK; and the Chair of the International Grass Genome Initiative (funded by USDA, NSF, and DOE), Jeff Bennetzen of Purdue University. This subgroup discussed the idea of an international consortium.

- The fourth meeting of direct benefit was between the IWG and the NSF Panel reviewing the NSF, USDA, and DOE *Arabidopsis* Genome Sequencing Project.

IWG Meetings Used to Gain Scientific Insight and Stakeholder Input

- On September 4, 1997, the IWG met with eight industry representatives to discuss the role of the private sector in plant genome initiatives. Attending the meeting were Scott Tingey and Barbara Mazur of DuPont Agricultural Products, Stephen Padgette of Monsanto Company, and Daniel

Alexander and Eric Ward of Novartis Seeds Biotechnology Research Unit, and Anthony Cavalieri and Peter Fuller of Pioneer Hi-Bred International.

- The IWG invited several prominent plant scientists to a meeting on October 14, 1997, to discuss their views on the science components that should constitute a plant genome initiative. These scientists included Jeff Bennetzen, Department of Biological Sciences, Purdue University; Michael Freeling, Department of Plant and Microbial Biology, University of California, Berkeley; Susan McCouch, Department of Plant Breeding and Biometry, Cornell University; Joachim Messing, Rutgers University, Waksman Institute; Calvin Qualset, Genetic Resources Conservation Program, University of California, Davis; Athanasios Theologis, Plant Gene Expression Center, U.S. Department of Agriculture, ARS; Elliott Meyerowitz, Division of Biology, California Institute of Technology; Ronald Sederoff, Department of Forestry, North Carolina State University; and Randy Shoemaker, Department of Agronomy and USDA-ARS, Iowa State University.

- On December 2, 1997, the IWG met with the following representatives of several commodities groups: Kellye Eversole, National Corn Growers Association; Mary Kay Thatcher, National Farm Bureau; Krysta Harden and Mark Berg, American Soybean Association; Michael May, United Soybean Board; James Miller, National Association of Wheat Growers; Daniel Shaw, National Grain Sorghum Producers; Marvin Zutz, Minnesota Barley Research and Promotion Council; Jane Shay and Gerald Lacey, Minnesota Barley Growers; and Philip Walkin, Cotton Council.

Appendix C

ABSTRACT

Recent scientific advances made through our nation's investments (private and public sector) in studying DNA structure and function in humans and model organisms have resulted in a new biological paradigm for understanding the traits of organisms. Through the National Plant Genome Initiative (NPGI), this paradigm can be extended to improving the useful properties of plants that are important to humanity. Solutions to many of our nation's greatest challenges can be met through the application of plant-based technologies. For example, the revitalization of rural America will come from a more robust agricultural sector; reductions in greenhouse gasses can be achieved from the production of plant biofuels for energy; chemically contaminated sites can be rehabilitated economically using selected plants; and worldwide malnutrition can be greatly reduced through the development of higher yielding and more nutritious crops that can be grown on marginal soil. This report recommends a long-term goal, five year objectives, and managment principles for the NPGI. To accomplish the five year goals of the NPGI, at least $320 million could be used by the Federal government in a targeted manner to leverage existing plant genome activities in the public and private sectors. Current estimates of cost could be decreased with advances in technology

For additional copies and further information, contact:
National Science and Technology Council Executive Secretariat
At 202-456-6120 (voice) or 202-456-6026 (fax)

Also Available on the NSTC Home Page via link from the OSTP Home Page at:
http://www.whitehouse.gov/WH/EOP//OSTP/html/OSTP_Home.html

Office of Science and Technology Policy
1600 Pennsylvania Ave, N.W
Washington, DC 20502
202.395.7347
Information@ostp.eop.gov
