

Achievements of the National Plant Genome Initiative and New Horizons in Plant Biology

Plant genome sciences, and plant biology as a whole, contribute significantly to human health, energy security, and environmental stewardship. The National Plant Genome Initiative (NPGI) has been funding and coordinating plant genome research among agencies successfully for nine years to understand how plants function and how to develop desirable plant characteristics. Research breakthroughs from NPGI and the National Science Foundation's (NSF) Arabidopsis 2010 Project, such as how the plant immune system controls pathogen defense, demonstrate that the plant genome science community is vibrant and capable of driving technological advancement. Therefore, these programs should continue in order to increase the contribution of plant science to vital areas of national interest.

Human life would be impossible without plants. Most clothing, furniture, and food come from plants. Modern plant biology is about improving human health and well being, nutrition from new and better foods, fiber and wood production, and finding renewable alternatives to imported fossil fuels, all of which fall under the umbrella of responsible environmental stewardship. Therefore, understanding plants, how they grow, and how they produce essential products has never been more important.

Basic plant genome research serves a wide diversity of agricultural and environmental purposes, as well as contributing to basic scientific discovery. For example, by increasing knowledge of how plants cope with extreme environmental stresses, plant genomics research can help scientists more precisely breed or engineer plants that can thrive as climates change. This knowledge is particularly important with respect to how water is used to grow crops. Economically viable production of fuels from plant biomass, in quantities that could contribute to a reversal of the world's dependence on fossil fuels, will require increases in plant productivity and advances in plant biomass-to-fuel conversion. Finally, sustainable agriculture will require reduction in fossil fuel-derived inputs and in agricultural runoff and soil degradation.



Plant genome science has improved characteristics of many plants such as this soybean plant ready for harvest. (Photo courtesy of USDA)

The National Plant Genome Initiative represents a unique, cross-agency funding enterprise for plant genomics coordinated by the Interagency Working Group on Plant Genomes, which is comprised of various federal agencies. As NPGI approaches its 10th anniversary, the Working Group asked the National Research Council (NRC) to evaluate the program and to make recommendations about the future of plant genome science. The NRC convened a committee of experts in the fields of plant genetics, epigenetics, informatics, biology education, and molecular and cell biology to evaluate the NPGI program, which involved reviewing the science already produced and the science soon to come.

ASSESSMENT OF THE NPGI

The report concludes that NPGI has been successful overall. The program has contributed to revolutionary breakthroughs in genome sequencing of plants, including *Arabidopsis* (a small flowering plant related to cabbage and mustard), rice, and soon maize. Far more than just genomics, the technologies and information developed by NPGI and the *Arabidopsis* 2010 Project are the primary platforms for basic research in fundamental plant science—including genetics, biochemistry, physiology, developmental biology, evolutionary biology, and population biology.

Plant genome scientists have made excellent use of research on model species to explain basic biological principles in more complex species and subsequent applications to crop improvement. Some of the major breakthroughs that have resulted from these programs include: discovery of receptor molecules that bind to nearly all of the major plant hormones; a detailed understanding of how these receptors control subsequent plant developmental programs; knowledge of how exposure to winter-like temperature, knowledge of how to encourage the flowering and fruiting of plants by treating seeds, bulbs, or seedlings to induce a shortening of the vegetative period), and the correct photoperiod (a recurring cycle of light and dark periods) leads to flowering; how the flowers, leaves, and roots are built; and how plant “immune systems” control the different types of pathogen defense. Most of these breakthroughs are being translated to practical applications in crop species.

The significance of NPGI-funded research is reflected by the impact of the articles published

by the principal investigators. About 21 percent of primary peer-reviewed research articles that cited NPGI support were published in the top 10 percent of the most highly-cited journals, and around 45 percent of articles were published in the top 20 percent of journals. Research funded by NPGI to date has served as the springboard for several applied, agency-specific, mission-oriented programs that capitalize on either new funding from the public or on public-private partnerships.

In addition to advancing basic science, NPGI has contributed to training a large number of students and postdoctoral fellows, which in turn has created a pool of employees for growing enterprises in all bioscience sectors in the United States and abroad.

The case for continuing the program is straightforward: plant genomics provides a foundation for rapid, fundamental, and novel insights into the means by which plants grow and reproduce, produce organs and tissues essential to human nutrition and energy production, how plants adapt to different and often difficult environments, and how they help stabilize ecosystems.

RECOMMENDATIONS

NPGI and the *Arabidopsis* 2010 Project should continue in parallel. To miss the opportunity to capture and increase the momentum of the last 10 years would diffuse the tremendous gains made thus far and sacrifice vital opportunities to tackle national and global problems that could be addressed with plant-based resources.

To move forward, the committee recommends steps to significantly broaden NPGI’s mission to include the basic biology of economically relevant traits in model and crop species, deeper investigations into plant diversity and adaptation to various ecological niches, and continued expansion of translation to breeders and farmers. These changes are justified by the knowledge to be gained from comparative genomic analyses within and across species, and by the need to understand how plants function to provide the conditions required for human survival.

Expanding NPGI will require research projects driven by single principal investigators, collaborations of investigators at multiple institutions, and large data production centers. Collectively, all of these projects will use methods of inquiry that span the entire scale of plant biology—from atomic-

level analysis of molecules inside plant cells to agronomic analysis of yield, and from the study of individual cells, through their assembly into organs, and onwards to population-wide analyses of whole-plant phenotypes in field environments or natural ecological communities.

The following recommendations made by the committee are well-aligned with the Administration's Federal Research and Development Budget Priorities for Fiscal Year 2008.

Gene Sequencing

Expand plant genome sequencing, plant-associated microbial sequencing, and plant-associated metagenome sequencing, and associated high quality annotation by (a) using the DOE's Joint Genome Institute's sequencing capacity to generally serve plant sciences and (b) empowering individual principal investigators or collaborative groups to access and utilize next generation sequencing technologies for a broad spectrum of genomics and metagenomics discovery. Genome sequence is the raw material for functional, evolutionary, and translational tool development at the center of plant genome sciences, providing the backbone on which all other resources depend.

Tools and Resources

The NPGI's future success relies on the development of computational methods, tools, and databases that enable the integration of data from multiple technology platforms and geographically distributed laboratories. Tools for genomics, epigenomics, transcriptomics, proteomics, metabolomics - often referred to collectively as "omics" tools - are critical to the success of genome initiatives. The tools result from large datasets that, for example, catalog mRNAs, RNAs, proteins, or metabolites.

- **Develop "omics" resources and tool kits at high resolution in a few, carefully chosen plant species, including expansion and deeper investment in currently leading model species.**
- **Develop "omics" resources at a broader, shallower level across a number of additional species to (a) expand the phylogenetic scope of functional inference, particularly when this is justified to test clearly specified hypotheses, (b) understand physiological and**

developmental processes to a depth that is not feasible in the model systems, and (c) provide the foundation to improve U.S. competitiveness for important crop and tree species.

- **Use systems-level approaches to understand plant growth and development in controlled and relevant environments, with the goal to create the iPlant, a large family of mathematical models that generate computable plants capable of predicting plant system behavior under a range of environmental conditions.**
- **Develop and deploy sustainable, adaptable, interoperable, accessible, and evolvable computational tools to support and enhance the actions highlighted in the other recommendations.**

Increased Understanding of Plant in Environments

Increase the understanding of plant evolution, domestication, and performance in various ecological settings via investment in comparative genomics, and in the metagenomics of living communities of interacting organisms. Selection of plants with particular traits by humans (the process of domestication) has increased production in crop species, altered many plant developmental characteristics in relation to the wild ancestors of crop species, and allowed humans to shape ecosystems through agriculture and urbanization. A genomics-based understanding of the genotypic basis of phenotypic diversity in developmental, environmental, and evolutionary contexts will allow better manipulation of crop systems for improved agricultural productivity and enable the preservation of near-wild ecosystems.

Translation to Plant Improvement

Enable translation of basic plant genomics towards sustainable deliverables in the field, and continue to use NPGI as a foundation for new, agency-specific, mission-oriented plant improvement programs. The first 10 years of NPGI have made a strong start toward understanding the fundamental challenge of how plants work. In order to most effectively translate knowledge from the basic science at the core of NPGI into commercial innovation, additional tools and methods for enhanced transfer from model systems to crop species should be developed.

Recruitment of Trained Scientists

Improve the recruitment of the best young, broadly trained scientists into the plant sciences. Attracting new and diverse scientists to plant genomics will likely require reaching out to students who might not have considered plant biology or genomics when they began their studies. Given the interdisciplinary nature of genomic analysis, new scientists could enter the field from quantitative and computational disciplines, such as mathematics, computer science or statistics. As genome sequencing expands to capture diversity and natural selection, more students with backgrounds in ecology may also be drawn to plant genomics. The future of plant genomics will require a variety of students who bring broad skills and knowledge to a wide-ranging set of problems.



NPGI helped to build an international consortium for sequencing the rice genome. (photo courtesy of USDA)

Outreach

Promote outreach on plant genomics and related issues that are critical to educating the American public on the value of genomics-based innovations. Many research programs include components to reach out beyond the scientific community and emphasize the importance of increasing the public understanding of science. Outreach programs in plant genomics are important because end users—food consumers, breeders, farmers, and others—are likely to use products and tools of plant genomic research if they understand the value and benefits of them, and their potential risks.

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This report brief was prepared by the National Research Council based on the committee's report. For more information, contact the Board on Life Sciences at (202) 334-2187 or <http://dels.nas.edu/bls>, or the Board on Agriculture and Natural Resources at (202) 334-3062 or <http://dels.nas.edu/banr>. *Achievements of the National Plant Genome Initiative and New Horizons in Plant Biology* is available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; http://www.nap.edu/catalog.php?record_id=12054

