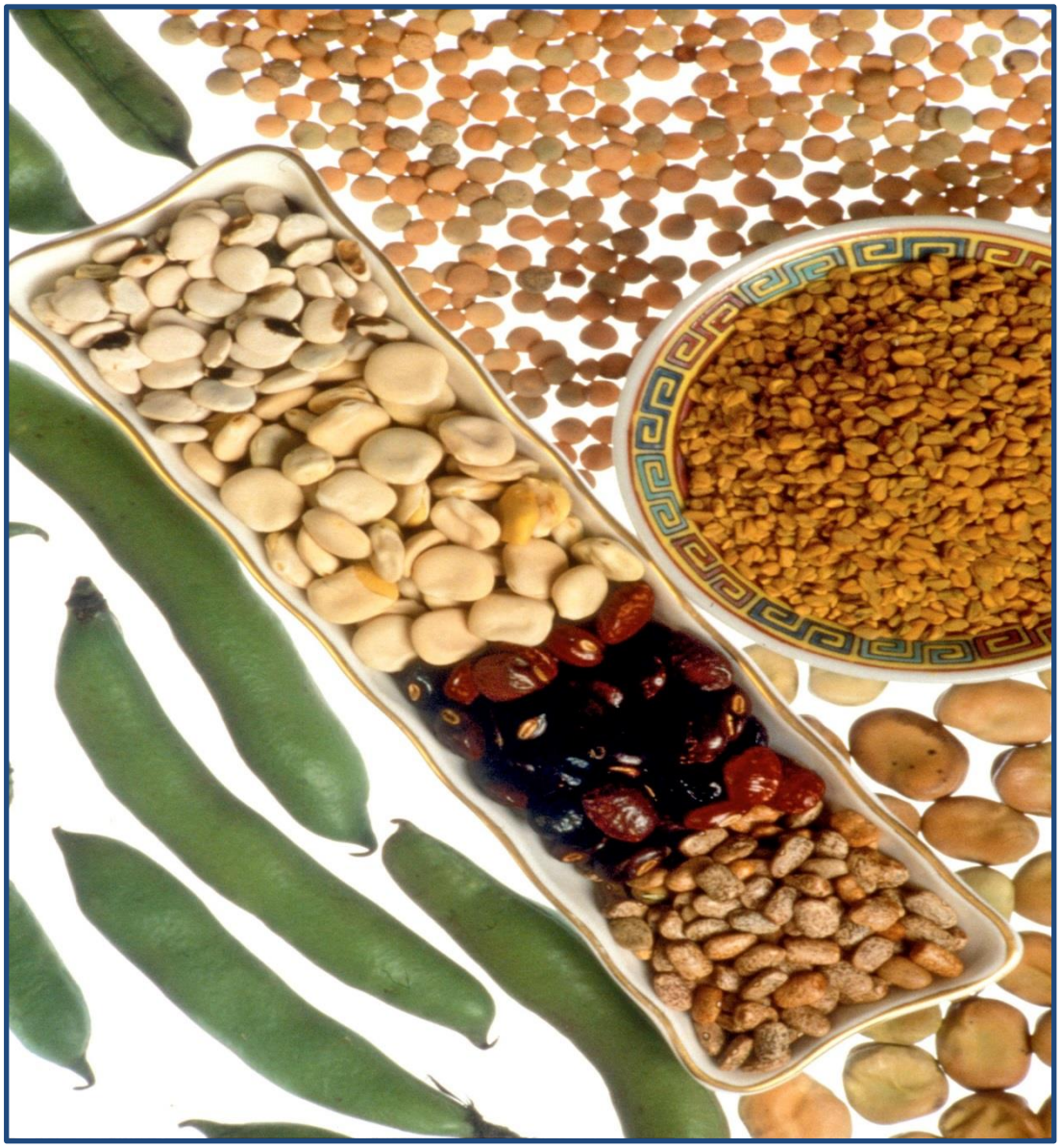
United States Department of Agriculture

USDA Roadmap for Plant Breeding March 11, 2015

Final Report

Office of the Chief Scientist
Research, Education, and Economics Mission Area



USDA Roadmap for Plant Breeding

USDA Plant Breeding Working Group

Including USDA Agencies ARS, ERS, FS, NIFA, and NRCS

Contents

This report is online at: http://www.usda.gov/wps/portal/usda/usdahome?navid=OCS.

Summary

Plant breeding is one of agriculture's most effective tools for adapting to new circumstances. It will be a key component in ensuring versatility and adaptability of agriculture systems, through plants bred for adaptation and productivity in conditions more variable than in the past, with many other characteristics such as pest resistances, cooking qualities, and nutritional value. As the future unfolds, the U.S. Department of Agriculture (USDA) has a unique role in ensuring our plant breeding capacity to address needs and opportunities, foreseen and unforeseen.

In August 2013, USDA's Research, Education, and Economics (REE) mission area held a public Stakeholder Listening Session on Plant Breeding to gather input on plant breeding priorities (http://www.usda.gov/documents/plant-breeding-listening-session.pdf). Stakeholder input revealed areas of broad national agreement, including the essential role of the National Plant Germplasm System (NPGS); the need to recruit and educate the next generation of plant breeders; and the need for enabling conditions for plant breeding through longer term, more stable funding and through attention to issues including intellectual property rights (IPR). In other areas, REE found ongoing debates, such as appropriate public/private balance in plant breeding.

An overview of USDA investment in plant breeding finds unique benefits across all USDA and REE goals. Private enterprise also benefits because many USDA plant breeding achievements create commercial opportunities at both large and small scales. Collaboration with State, private-sector or farmer partners and combinations of multiple funding sources are common features of USDA and USDA-funded plant breeding. An expressed concern was that public funding sources such as competitive grants are short-term, leading to frequent diversion of a breeder's attention toward fund raising(i.e., away from the tangible work the breeder is educated and hired to do).

Drawing stakeholder input and an overview of USDA's current work in plant breeding, needs and opportunities for USDA's leadership are seen in:

- Genetic resources conservation and characterization
- Education of the next generation of plant breeders;
- Plant breeding including allied research in genetics and genomics;
- Convening stakeholders across all sectors of agriculture to look at issues of common concern, such as education, intellectual property rights (IPR)/technology transfer, and priorities for public-sector attention;

Expected outcomes of USDA's work in plant breeding include:

- Continued U.S. leadership to meet national and global challenges and create opportunities;
- Successful plant breeding outcomes even for situations that are pioneering and/or complex, such as new crop uses or complex cropping systems;
- An enabling context for both public and private plant breeding, including better insights regarding priorities for each sector.

USDA has the experience, the agro-ecosystem presence and the partnerships to enable these results. Additional funding resources will be needed, including sustained and increased funding for the National Plant Germplasm System (NPGS); for USDA in-house plant breeding and for plant breeding funded through the USDA National Institute of Food and Agriculture (NIFA) at land-grant universities and other institutions.

I. Introduction

A. Plant breeding

Essential for adapting to coming challenges and new opportunities, plant breeding is the human-aided development of new plant cultivars with needed characteristics. Today's agricultural productivity rests on remarkable cultivars developed through over a century of concerted plant breeding, much of it from public investment through USDA. Because agriculture's environment is always dynamic, plant breeding will always be necessary.

Visible ahead are challenges of climate change, including changing patterns of heat, cold, drought, and flooding; population growth; globalization with accompanying constant movement of insects, diseases, weeds, and diminishing resources such as water and soil nutrients; just as emphasis is being placed on reduced use of inputs and fossil fuels. Other challenges include world events, in many places creating crises that severely limit agricultural activity for local food security. Plant breeding is also a tool for innovation to create or add value to opportunities such as new markets; increasing consumer interest in nutritional value and in local, regional, and international foods; and public interest in conserving natural environments.

Plant breeding is a core capacity for robust response to USDA's strategic and action goals (appendices 1 and 2). Plant breeding's role varies: it may be *in the foreground of the action*, as for food security or climate adaptation; or a *prerequisite*, as for human and animal nutrition; or a *component* at the core of complex food systems. Specific examples of how USDA plant breeding achievements address REE and USDA goals are found in App. 3, along with information about the diverse partnerships that make them possible.

The present Roadmap for Plant Breeding takes a look at USDA's roles and achievements in plant breeding, and at recent stakeholder input, to "map out" ways in which USDA's plant breeding work can contribute to ongoing success and future preparedness across all sectors of U.S. agriculture.

B. Public sector investment in plant breeding

There is broad consensus among stakeholders that certain plant breeding related investments are priority roles for USDA and its public-sector partners. These include the National Plant Germplasm System (NPGS), and the education of plant breeders.

In other areas, debates persist over public and private-sector roles. For example, as important as plant breeding is, should it be done with public funds? Given the many competing needs for public funds, this question is all the more relevant because the private sector does outstanding plant breeding for some crops and situations. Given its role as an economic enterprise, private sector breeding typically focuses where markets and other aspects of a situation are favorable, mostly for commodity crops over large areas. Economic analysis suggests that the private sector will underinvest, compared to overall needs, in both basic and applied agricultural research, including plant breeding.

Underinvestment is likely to be greatest when there is a large gap between private and social returns. Underinvested areas may include, for example:

- Identification and characterization of unique genetic traits from plant germplasm resources (such as from the NPGS) for breeding new cultivars;
- Applied research for technologies that are especially difficult to patent or appropriate, such as breeding new varieties of "orphan" crops that include some small grains, root and tuber crops, tree crops, and others;
- Breeding cultivars to be grown outside current major production areas or for small markets such as organic.

Private incentives for plant breeding can shift over time, with changes in the costs of certain kinds of research, in intellectual property rights systems, or in market opportunities. USDA's Economic Research Service (ERS) analysis has shown that public investment in fundamental breeding research has stimulated private investment in applied cultivar development. In recent years, however, public investment in cultivar development has fallen, while private applied breeding has increased. This suggests that public-sector plant breeding priorities should reflect a consideration of areas of private underinvestment, as well as continued dialogue with the private sector, rather than hard-and-fast rules (e.g., the public sector does "basic" research while the private sector does "applied" research).

This Roadmap seeks a forward-looking assessment of areas requiring public-sector plant breeding, with the realization that these areas may change over time.

C. Background to the USDA Plant Breeding Roadmap

With many challenges and opportunities ahead, and with stakeholder attention to plant breeding increasing, USDA's Research, Education, and Economics (REE) mission area held a public Stakeholder Listening Session on Plant Breeding on August 15, 2013, to begin gathering input to help prioritize its work in plant breeding. The listening session was co-organized by USDA's Office of the Chief Scientist (OCS), and the five USDA agencies involved in plant breeding, working through the USDA Plant Breeding Working Group (PBWG). Approximately 80 participants represented public (State and Federal), private, and non-profit sectors, including universities, federal agencies, industry, professional societies, and growers groups. In addition to 18 volunteered oral presentations, 38 written comments were received during the open comment period, July 29-August 22, 2013 (report at *http://www.usda.gov/documents/plant-breeding-listening-session.pdf*). In response to comments from the listening session, the USDA Chief Scientist requested the PBWG to draft a roadmap to synthesize USDA plant breeding achievements, identify gaps, align a forward vision with the USDA strategic plan, and serve as a useful basis for planning across agencies.

The August 2013 Listening Session, and other input from stakeholders over the past several years (Section III.C.3), revealed areas of broad national agreement. As noted above, these include the critical value of genetic resources collections and the urgency of recruiting and educating the next generation of plant breeders, given upcoming retirements. Other areas of agreement included the need for reiterative national discussions across all sectors, to ensure well-

informed public-sector priority setting and the need for funding mechanisms that allow longer term planning and research -- including research that may fail but must be explored and research-readiness for emergencies.

Regarding other issues, however, USDA has found ongoing public debate. One area of disagreement lies in the role of the public and private sectors in plant breeding, especially at the stage of developing user-ready new cultivars. Others include questions such as, what are appropriate mechanisms of intellectual property rights (IPR) and technology transfer (TT) for transferring varieties to users; and whether and what proportion of public investment should be directed to addressing immediate agricultural needs with proven breeding methods compared to developing new mechanisms and tools.

Some issues in the second group have implications for the first. For example, public programs are widely seen as necessary not only for their plant breeding outcomes *per se*, but also to educate future plant breeders in working field-based programs.

II. USDA roles and achievements in plant breeding

As context for the roadmap, this section provides a brief description of the role of each USDA agency active in conducting, guiding, and/or supporting plant breeding. It also provides a discussion of agency achievements and what we can learn from studying the objectives, partnerships, and funding patterns associated with these achievements.

A. USDA agency roles in plant breeding

Five USDA agencies, each with a distinct role, participate in plant breeding to address USDA and REE goals. Three agencies -- Agricultural Research Service (ARS; including the National Plant Germplasm System, or NPGS), Forest Service (FS), and Natural Resources Conservation Service (NRCS) -- conduct plant breeding and/or research that directly supports plant breeding. Appropriated funding allows these three agencies to operate plant breeding programs directly. The Economic Research Service (ERS) conducts economic research on public program and policy issues, including plant breeding and genetic resources. The National Institute of Food and Agriculture (NIFA) is REE's public funding agency. A broader summary of each agency's overall responsibilities is found in Appendix 4. All five agencies participate in the USDA Plant Breeding Working Group (PBWG) created in 2013 to foster interagency interaction within USDA and to support REE leadership in planning and in REE's interaction with external partners and stakeholders.

ARS is noted for original research accomplishments for transformation of unadapted, unimproved genetic materials into more usable forms, an essential step for breeders to rapidly generate advanced breeding stocks and superior cultivars. ARS breeders conduct pre-breeding to eliminate undesirable traits; devise new ways to access genes from these unadapted sources; and develop novel fundamental knowledge, evaluation information, and new methods for genetic analyses to reduce variety development time. These activities help commercial breeders deploy genes from ancestral and crop wild relatives. In crops without commercial breeders, ARS breeders also develop finished varieties. ARS crop genome databases act as repositories for data

generated by research projects funded by USDA's ARS and NIFA, National Science Foundation (NSF), U.S. Department of Energy (DOE), and National Institutes of Health (NIH), and also serve as research and training resources for students. In addition, new tools are under development for genomic, phenotypic, and genetic analyses that compile, analyze, interrelate, manage, and visualize the large datasets from diverse research projects.

The **NPGS** is an ARS-led collaboration in partnership with NIFA, the State agricultural experiment stations, and, increasingly, other stakeholders. It distributes an average of more than 250,000 accessions per year to researchers, breeders, and educators. The highest NPGS priority is to conserve genetic resources and associated knowledge in state-of-the-art seed and plant collections (genebanks) and databases. These collections and descriptive information, vital to domestic and international food security, are safeguarded in both primary and back-up sites. The NPGS is valued by scientists, farmers, and growers in all sectors of agriculture and agricultural research. In response to increasing tribal nation interest in conserving and using tribal genetic resources as a means to preserve cultural identities, promote healthy diets, and foster local employment and economic development, NPGS staff have provided information on strategies and protocols for collecting, characterizing, and conserving genetic resources of wild cranberries, ash trees, and traditional potato varieties. NPGS curators, drawing on extensive experience in managing plant genetic diversity in genebanks, have also discussed with tribal nations the challenges and logistics of establishing and maintaining their own plant genebanks. Stakeholders and customers overall increasingly point out the pressing need for diverse, well-characterized, and well-conserved collections that are secure, with continuity of collections and associated information; efficiently distributed for timely use in research and crop genetic improvement; and strategically managed in alignment with USDA goals.

FS, acting on its mandate to protect our national forests, conserves genetic resources of forest species, develops appropriate seed sources, conducts research on genomics and breeding, and in specific cases for disease resistance, also conducts applied breeding work for improved traits and performance through recurrent selection programs, and monitors changes in the pathogen populations relative to the host species.

NRCS, through its network of Plant Materials Centers (PMCs), selects and tests plants for specific natural resource conservation functions for preventing erosion; improving soil, water and air quality; maintaining the productivity of grazing lands; enhancing wildlife and pollinator habitat; and helping to create a landscape better adapted to a changing climate. The conservation plants and technologies developed by PMCs form the backbone of the vegetative recommendations used in conservation planning by the NRCS on privately owned agricultural lands and natural areas, and by Federal and State land management agencies for use on public lands.

ERS supplies and analyzes economic and policy data, to inform decisions about public investments in agricultural science, including plant breeding.

NIFA is a funding agency providing capacity funding and competitive grants to land-grant universities and competitive grants to a wide range of partners, including USDA and other Federal agencies, States, and others. The capacity funding model is intended, as the term

implies, to enable both long-term and rapid-responsive plant breeding capacity and is based in the public land-grant university system. Such capacity funding through NIFA has the potential to provide a stable core around which long-term breeding research and extension programs can build competitivity for grants programs, build partnerships, and attract other, complementary funding, including for education. The competitive funding model is used to solve specific scientific questions and enable new plant breeding-related discoveries. NIFA funding contributes to all of the agricultural science disciplines, including a wide spectrum of plant breeding research, reaching from genetic resources conservation and characterization; and research in genetics, quantitative genetics, genomics, through their use in plant breeding and cultivar development.

B. USDA achievements in plant breeding: Examples and implications

A range of achievements from plant breeding conducted and/or funded by USDA is presented in Appendix 3. The achievements contribute to positive outcomes across all USDA and REE goals. They illustrate the role of USDA in providing public benefits that would be difficult for a private-sector enterprise to justify.

These examples include:

- Research to locate new traits in wild germplasm and transfer it into parental lines that breeders can readily use (e.g., cold tolerance in rice, nutritional quality of soybean and peanut, pest and disease resistance for wheat and cotton, nutritional quality of fruits). This type of exploratory research requires long-term commitment and a robust ability to absorb results that come slowly, or are even disappointing, because of many unknowns.
- New breeding approaches and tools that allow a wide range of users, crops, and goals to benefit from new scientific advances;
- Improvements in crops like sweet potatoes, raisin grapes, and beans are unlikely from private enterprise, because these types of crops can be multiplied on-farm. That makes investment difficult to recoup. The public sector, on the other hand, can pursue breeding goals for these crops based on criteria such as their nutritional value or their potential to contribute to rural economies.
- Small markets create a need for public breeding, when commercial value is present but insufficient for efficient private investment at a larger scale (such as vegetables for local growers and markets).
- Ecosystem services and service to conservation goals, such as plants for wetlands restoration, commercial seed and nursery markets are very limited. Public investment is typically required in order to make the advances needed in plant performance and ecosystem function.

The examples also show that public investment on the "breeding end" can create new opportunities for private enterprise on the "marketing end." USDA plant breeding achievements have allowed private companies to market popular new processed products such as instant brown rice, sweet potato fries and chips, and new bread types. USDA plant breeding results have supported small-scale local seed companies and nurseries with locally specialized vegetables,

desirable new fruit cultivars, and "working plants" for conservation and ecosystem services, all of which create demand for seeds and transplants.

A study of the examples shows us other trends as well. Some of these trends are positive, such as a strong tradition of Federal/State collaboration, often with additional sectors (see "partners" in the examples in App. 3).

Other trends are more thought-provoking. Increasingly it is the individual public-sector plant breeder who is responsible for piecing together various short-term (1-, 3-, or sometimes 5-year) funding sources to reach from start to finish of cultivar development. Yet cultivar development is typically a 7-to-12 year process, or far longer, depending on the biology and the state-of-the-science for the given species, and the complexity of the target environment and cropping system. This creates a heavy time demand on the individual plant breeder, whose highly specialized education in plant breeding and associated sciences is repeatedly diverted from output-directed work to grant writing. Stakeholder input to USDA has been that outstanding graduate students in plant breeding may chose private-sector jobs, even if they are interested in contributing through the public sector to avoid such frequent distraction.

III. USDA plant breeding for the challenges and opportunities ahead

Stakeholder input to USDA during the August 2013 Listening Session and other recent interactions, such as the 2011 ARS Stakeholder/Customer Workshop and the 2014 National Association of Plant Breeders meeting, can be thought of in roughly these categories:

A. Recruitment and education of the next generation

B. Funding and funding mechanisms

C. Opportunities for USDA leadership: convening, and interaction
    1. Intellectual property rights and technology transfer
    2. Cross-sector discussions
    3. Interaction with Federal agencies beyond USDA

D. USDA plant breeding directions
    1. Outlook by agency over the next 5 to 10 years
    2. Glimpses farther ahead

A. Recruitment and education of the next generation

Stakeholders have continued to call for increased USDA involvement in training of plant breeding professionals. A large cohort of plant breeder retirements has begun and will continue through perhaps a decade before leveling off. In addition, the science and methodology of plant breeding are being transformed by the integration of new discoveries. Both developments are occurring just as agriculture globally is challenged by emerging threats of diseases, pests, and environmental extremes; changing consumer needs and preferences; expanding demand for biomaterials of all kinds; and the need and opportunity for crop products of higher quality than ever before.

At the same time, as the number of family farms declines, fewer youth grow up with an awareness of the agricultural sciences. Urban youth with an interest in biology and genetics may look to jobs with well-funded research in the highly visible biomedical sector. Even those who do enter plant breeding find that although private-sector demand is high, it is for a limited number of crops, while there is unmet need for breeding contributions in many other crops and plants such as forest tree breeding. Together, all these factors create a pressing need to recruit motivated, well-educated young people to become plant breeders to meet current and anticipated industry demands and food security.

Some of the stakeholder suggestions for meeting this goal included competitive grants to integrate plant breeding research and education; and strengthened capacity funding—the latter because capacity funding may be, and often is, used by recipients to include research assistantships that attract and support graduate students. Other suggestions included experience and mentoring for new Ph.D. graduates public and private sector programs, (e.g., through the ARS Post-Doctoral Fellowships Program, NIFA Postdoctoral Fellowships, and public- private partnerships for internships with private plant breeding companies). Cooperative Extension 4-H programs were mentioned as partners for recruiting students into plant breeding. There was also mention of the increasing importance of ongoing education for active plant breeders, given the rapid pace of development of new plant breeding tools and methods.

The Agriculture and Food Research Initiative (AFRI) Plant Breeding and Education program is a successful example. NIFA regularly receives requests from stakeholders to continue a competitive grants program for plant breeding and education, originally offered in 2008 and 2009. The Plant Breeding and Education program resulted in outcomes in three areas: (1) it increased the number of students and scientists trained in plant breeding; (2) it allowed educators to design contemporary curricula, both rooted in experience and incorporating the newest science; and (3) it transferred benefits from science-based knowledge to producers and consumers through "classical breeding or breeding combined with biotechnology." Program characteristics included, among others:

- Education and training in an academic and field setting, combined with research focusing on a specified priority breeding objective;
- Mutually dependent research and education objectives and educational deliverables (e.g., interdisciplinary curricula and/or experiential learning for graduate and undergraduate students).

Projects were encouraged to (1) use NPGS germplasm; (2) identify and recruit undergraduate students interested in careers in plant breeding and "pipelining" into graduate training; and/or (3) use internships to place graduate or undergraduate students in industry, academic, or government settings (such as ARS mentoring situations) for experiential learning in plant breeding.

A perspective on the vigor with which universities pursue plant breeding education when resources permit is provided by estimates for NIFA's AFRI competitive grants from the Plant Breeding and Education program (15 awards) and 5 AFRI Coordinated Agricultural Project awards (CAPs) in plant breeding, from 2008-2013. Together, these awards supported plant breeding education of over 200 undergraduates, 170 graduate students, and 25 post doctorals, and developed 32 plant breeding courses in land-grant universities. A total of 115 graduates from 3 CAPs were tracked and, as of 2013, were employed in plant breeding positions, across the public (about 40%) and private (about 50%) sectors in the United States; and internationally (about 10%).

These totals would be higher if they were surveyed over all NIFA funding for plant breeding during the interval, that is, if they included education outcomes from other competitive programs and from capacity funds. Among competitive program opportunities, NIFA's AFRI Challenge Area awards, the Specialty Crops Research Initiative (SCRI), the Organic Agriculture Research Initiative (OREI), and the Biomass Research and Development Initiative (BRDI), also offer avenues to train students and postdocs, because project directors may request and do receive funding for student workers, graduate assistants, and post docs.

At the present time, NIFA has few opportunities to fund projects that integrate research and education objectives. The current AFRI structure includes plant breeding, but places it in AFRI's Foundational Program, which is limited to research and does not fund education. Indeed, most of NIFA's current competitive funding opportunities for plant breeding are limited to research; some may include extension. AFRI's Fellowship typically includes a few plant breeding awards each year, based on scientific merit of a student's proposal. Overall, there are limited opportunities through USDA for faculty to develop attractive, contemporary plant breeding curricula. In view of the priority of plant breeding education expressed across all stakeholder groups, and the quality and success of the earlier Plant Breeding and Education funding program, NIFA will continue to seek opportunities to develop programs to fund plant breeding and education.

For recent Ph.D. graduates, the ARS Postdoctoral Research Associate Program continues to offer a unique opportunity to conduct critically needed research on specific projects in association with prominent scientists. The program provides new doctoral graduates with advanced and highly specialized training and experience that may not be available anywhere else. Since 1980, more than 750 people have been appointed to the 2-year ARS Postdoctoral Research Associate Program.

B. Effective funding mechanisms for plant breeding

A frequent topic in stakeholder input from all sectors was the need for funding mechanisms that are *more stable and longer term*. Stakeholders cited a range of reasons for the need for longer-term funding sources. Some of the scientific reasons cited included:

- To allow long-term attention to obstinate challenges and new scientific opportunities;
- To enable adequate pre-release field-testing of predicted variety performance, to represent the complexity and variation of targeted growing environments.

Some societal reasons included:

- To permit responsiveness to stakeholder requests for cultivars targeted at regional needs, as well as sustained engagement with farmers, ranchers, and land-owners;
- To make plant breeding as a profession more attractive to top students in biological or quantitative sciences-- students who may otherwise choose fields with more consistent funding opportunities.

In response, NIFA, REE's funding agency for research, education, and extension, proposes a two-pronged approach:

For its *competitive funding* programs, NIFA will continue to explore the possibilities for up to 5-year awards that are renewable for a total of 10 years. Because of trade–offs between longer funding for earlier awards, and the number of awards that can be made or the frequency with which a funding program can be offered, total funding levels will be a factor in whether or not longer duration competitive awards are feasible.

Capacity funding through NIFA has been proven to be efficient, versatile, and inclusive for serving a complex food and agricultural sector, including both long-term and rapid response research. Capacity funds typically function as "nuclei" around which other partners are attracted to cluster, bringing additional funding sources with them and extending each other's reach and impact. This magnifying effect of capacity funds can be discerned in many of the examples in Appendix 3. A 2006 study by Huffman and Evanson found that capacity funding for ag research had a larger per-unit impact on local productivity than competitive grant funding.

Going forward, as a possible approach to a number of stakeholder themes, NIFA may seek funding to create regional *centers of excellence* for plant and animal breeding. NIFA is examining strategies to do this (e.g., whether through capacity funding; opportunities created in section 7214 of the 2014 Farm Bill ("Centers of Excellence "); and/or post-doctoral researcher support through existing programs).

C. Opportunities for USDA leadership: Convening, facilitating, and interacting

An emergent theme from stakeholder comments was the need for more interaction on issues that no group can address alone. The two most frequently mentioned were intellectual property and technology transfer, and public sector/private sector balance in plant breeding. The importance of interagency interaction within and beyond USDA was another often-heard comment. The PBWG notes that USDA is in a position to offer "soft" leadership to convene broad discussions on some of these topics, across sectors and stakeholders, to permit exchange of information and

views and to provide opportunities for improved insights and arrangements to come into view and develop.

1. Intellectual property rights and technology transfer arrangements

Intellectual property rights (IPR) and technology transfer (tech transfer, or TT) systems have developed over time as a tool for getting innovative results to intended end users. Most public breeding programs typically work with commercial partners such as seed producers and distributors, or nurseries, to move new cultivars through the final steps to farmers and growers. Some public programs also move unique new advanced lines to commercial breeding companies for further breeding before they are ready as cultivars. These commercial partners, large scale or small, almost always rely on some form of IPR or tech transfer system to achieve a sustainable enterprise.

Stakeholder input revealed a range of views on IPR and TT. Some stakeholders expressed dissatisfaction with the current IPR and TT systems, and/or with their functioning, for a range of varying reasons.

USDA/REE may consider engaging stakeholders across sectors in a conversation on IPR with regard to adaptation of research results and realization of research benefits. A broader understanding of the role of IPR in agriculture would be one positive outcome; others may emerge. Concepts and insights from the discussion could then be shared broadly through one or more white papers.

2. Regular public-private sector discussions, to identify gaps and avoid duplication

Appropriate public/private sector balance in plant breeding was one of the topics most frequently raised by stakeholders. As with IPR, there was a broad range of views. Again, as with IPR, there may be a constructive role for USDA as a convener of round-table discussions among the different sectors to discuss research focus and research needs from all perspectives.
While there may be limits to how much may be shared, over time, the experience gained through sustained and regular discussions—say, at 2 or 3-year intervals – may be expected to lead to improved understanding.

A resulting better understanding of areas of private "underinvestment" (Sect. 1.B.) would be an important input to developing appropriate public sector priorities for plant breeding. Similar recommendations have been proposed by the NAREEE Advisory Board. The perspectives gained could lead to better targeting of both Federal competitive grants, and State or regional decisions in capacity-funded programs.

Regular discussions may have additional benefits, for example, all sectors are concerned about recruiting and educating the next generation. Regular interaction might include sharing ideas about what more might or might not be done and by whom, and help to generate common action

for recruitment and education. Regular conversations could also provide a meeting place from which new public-partnerships (another frequent stakeholder recommendation) could develop.

3. Interaction with Federal agencies beyond USDA

Stakeholders encouraged interaction with science agencies beyond USDA. Such interaction can help maximize creative and effective use of new biological knowledge and tools to achieve their intended impacts for agriculture. For example, National Plant Genome Initiative Postdoctoral Research Fellowships, co-sponsored by NSF, DOE, and ARS, are designed to create opportunities for integration of plant genomics information and tools with quantitative genetics and with bioinformatics, for use in plant breeding.

Applied plant breeders in the field are watching for these advances, adapting them into breeding programs in remarkable ways in pursuit of challenging goals for plant productivity, adaptation, and value. Among these are ARS researchers, with funding sources including ARS in-house, NIFA competitive programs, the Bill and Melinda Gates Foundation, and the private sector, who are world leaders in inventing new genomics-assisted methods for improving yield and disease resistance in grain crops. In a different example, researchers at the University of Wisconsin, with funding from State sources and NIFA capacity funds, are exploring genomic-assisted methods to select for flavor and other traits for low-input and organic systems.

USDA's work with USAID provides many examples of delivering science through Federal interagency interaction. In 2012, USAID funded a NIFA-managed competitive grants program on "Common Bean Productivity Research for Global Food Security." Currently, ARS, USAID, State-university partners, and international partners are collaborating to address the global threat from the Ug99 wheat rust strain (App. 3), and more recently ARS has provided consultation to USAID on the emerging Wheat Yield Network, which will be co-funded by the BBSRC of the United Kingdom.

As part of the multi-agency, NIH/NSF-led STAR METRICS project, USDA agencies ARS, ERS, FS, NIFA, and NRCS have been working to increase integration of USDA program data through the VIVO platform, which helps USDA participate in the STAR METRICS activity. This will allow complex USDA research investment data and outcomes to be shared and compared across USDA and other agencies.

D. USDA plant breeding directions for the future

Looking toward the overall U.S. plant breeding effort in the future, each sector will likely continue to breed and release finished varieties—although to varying extent and for different situations. In something as critical as plant breeding, this is wise to ensure robust delivery capacity.

However, even across all sectors, it would be difficult or impossible to be working on all future needs, even if these could be correctly foreseen and prioritized. For example, what will be needed to enable plant breeding to respond to new knowledge about the many interactions between food and health? About "microbiome" interactions of crop plants? Or to new rural-urban interactions in food systems--systems that may well need new types of varieties? USDA has and will have a unique role in ensuring plant breeding's capacity and readiness to address questions like these, and other needs and opportunities that emerge as the future unfolds.

Recent interaction indicated that stakeholders indeed look to USDA in this role of ensuring readiness to meet a future that can never be fully predicted. Participants in the August 2013 listening session emphasized the importance of USDA's role in plant genetic resources and in education of future plant breeders. Urged by these and other stakeholders (see Sect. III.C.3), USDA is also at the forefront of innovative ways to use new scientific knowledge in tools and methods for plant breeding; tools and methods that can serve many crops, traits, and situations (see examples, Appendix 3). Each of USDA's Plant Breeding Working Group agencies participates in one or more aspects of USDA's work to ensure that present and future plant breeders have the education, genetic resources, and breeding tools and methods to develop optimal, robust plants for meeting our national goals.

1. Outlook by agency over the next 5 to 10 years

The National Plant Germplasm System (NPGS)

The NPGS is unique in its critical importance for plant breeding--a point of broad and emphatic agreement across stakeholders. Strengthening the NPGS is a priority for ARS, the lead agency for the NPGS; and for NIFA. The NPGS is funded approximately 90% through ARS appropriation; and 10% through NIFA-administered Hatch-funded projects (capacity funds).

A priority action item for USDA is the continued support and strategic expansion of ex-situ NPGS plant genebank collections in secure, well-maintained modern facilities that maximize genetic integrity, health, and viability.

- Collections will be expanded to include other agriculturally important organisms, such as microbes, new and specialty crops, and genetic/genomic stocks. When genetic gaps in collections are identified, new genetic resources will be expeditiously acquired through domestic and international field explorations and exchanges. Gaps in the genetic coverage of collections will be identified, especially for crop wild relatives and land races. The interdependence of nations for access to genetic resources necessitates international collaboration to share genetic resources and information, conduct research, combat genetic erosion and strengthen collections according to standards of access and benefit sharing embodied by both domestic legislation and relevant international agreements. Distributing well-characterized, healthy germplasm of known genetic integrity to bona fide requestors will maximize the positive impact of the NPGS.

- Descriptive information about the genetic resources will be efficiently curated, stored, and made available via GRIN-Global, a Web-based advanced information management system which will be implemented throughout the NPGS to provide genebank staff and

germplasm users with an easy-to-use, browser-based interface to support genebank curation, and enable a wide clientele to select the optimal genetic resources for their needs through access to ample passport, phenotypic, and genotypic data. Data documentation will be standardized to align with and promote database interoperability. GRIN-Taxonomy will be supplemented with additional information on crop wild relatives. Prioritized descriptor and trait lists for phenotypic evaluation and genotypic characterization will be developed or enhanced to facilitate cross-crop comparisons.

- Characterization and evaluation of genetic resources for priority traits and generate data are particularly important for effective acquisition and curation, and to enable requestors to identify the optimal germplasm for research, education, and breeding. New, less costly gene or sequence-based markers and high through-put phenotyping methods will be applied for collection characterization. These efforts will be coordinated with genomic sequencing and genetic marker analyses conducted by ARS, university, and private-sector genomic research consortia and other genebank systems, to enable ready cross-dataset comparisons.

- New statistical genetic approaches, based on genetic relationships among accessions, will optimize the efficiency and effectiveness of germplasm management. Commonalities across crops will first be determined to strategically develop methods that are broadly applicable for maintaining the genetic diversity during storage and regeneration, particularly during replenishment of aging materials in the base and active germplasm collections. Superior viability testing and monitoring protocols will be developed and implemented to increase the percentage and quality of stored accessions, and to lengthen the intervals between regeneration events. Methods for conservation and back-up for vegetatively propagated and non-orthodox seeded plants, such as *in vitro* and cryopreservation, will be improved and applied.

Agricultural Research Service

Customer and stakeholder interactions and research coordination play important roles in helping ARS guide plant breeding research to maintain its relevance to U.S. agriculture. ARS breeding priorities are developed from formal and informal communications among ARS scientists, agency administrators, customers, stakeholders, and research partners working together to identify major crop breeding issues and research priorities. These are used to create an action plan to guide research. Workshops are held to address crop/commodity-specific challenges, emerging high-priority issues, and new scientific developments in the fields of crop genetic resource management, genetics, genomics, genome databases, germplasm enhancement, and breeding. Interagency discussions are a key part of the process. For further information, the ARS Action Plan for 2013-2017 that guides plant breeding research can be found at: http://www.ars.usda.gov/research/programs/programs.htm?np_code=301&docid=22479.

Based on the national stakeholder interactions described above, ARS believes that U. S. agriculture, more than ever, requires superior crop varieties, and enhanced germplasm with higher yields; resistance or tolerance to biotic stresses and environmental extremes; improved agronomic or horticultural characteristics; and specific superior processing and product quality properties to

produce a safe, plentiful, high-quality food supply and a stronger, more secure agricultural industry. In the next 5-to-10 year period, ARS will focus resources on addressing these needs. The priorities dictate that superior products must be adapted to a wide variety of multiple cropping systems and to competitive global market needs. Faced with climate change and shrinking supply of land, labor, water, and inputs, the varieties that ARS develops must have enhanced water and input-use efficiencies, as well as optimal production efficiencies, to address priorities over the next 10 years. Crops will be developed with genetic resistance to replace or supplement pesticide use and improve competitiveness of U.S. agriculture in both traditional and organic farming sectors. Crops with resistance or tolerance to multiple diseases and pests will reduce pre- and post-harvest losses. ARS will also focus on more durable resistance to diseases and pests and resilience to climate change to address the need to reduce the risk of catastrophic losses and improve food security. New crops will also be designed to meet the needs for bioenergy, bio-based products, new uses, and market demands.

Given the diversity of high-priority needs from ARS plant breeding programs, the agency will increase efforts to build cross-linked research efforts among the four programmatic areas (crop production and protection; nutrition and food safety, and quality; natural resources and sustainable agricultural systems, and animal production) to develop a systems approach to help with the priority setting. This, along with the ever-increasing efforts to work across multiple USDA agencies, universities, key global research platforms, and private industry, will increase the capacity to enhance plant breeding and increase sustainability of agricultural production, particularly of food crops.

ARS will strive to develop more effective partnerships with commercial companies, large or small as appropriate, and /or with universities and other appropriate institutions to enhance transfer of improved germplasm or varieties to agricultural users through efficient seed multiplication systems. In addition, ARS proposes to enhance current databases to upgrade data capacity and hire more technical experts and students as trained personnel in areas such as bioinformatics, computer programming, statistics, and other computational sciences to support its commitment to open data access.

The following critical gaps where ARS plant breeding priorities can be strengthened have been identified through the various input and communication processes within agencies and at the REE level:

- Increase public plant breeding research capacity should be improved to address all crops, including regional varieties that meet stakeholder's demands for enhancement of more traits faster, in both applied plant breeding and essential supporting scientific disciplines.

- ARS should work with stakeholders to remove constraints between pre-breeding of germplasm lines with new traits through timely access to elite genetic backgrounds so that new traits can be moved expeditiously into agriculturally outstanding cultivar backgrounds. There is also a need for enhanced systems for timely propagation, seed increase and distribution of new varieties to farmers and growers.

- There are unprecedented capabilities to obtain large amounts of genomic information from plants at reasonable costs and new technologies to obtain high-throughput phenotypic information from a large number of field plots. There are also increasing computing capabilities and bioinformatics pipelines to store and analyze these massive datasets and to link the genotypic and phenotypic information for improved varieties.

- There are growing needs for informatics/bio-informatics and biometrics, and other essential supporting disciplines and capabilities for moving and storing data, and for translating raw data (field or lab) to knowledge for use in breeding. There are needs to develop new software tools, e.g., for association mapping and diversity analysis, to enhance selection.

- For successful implementation of plant breeding output, ARS will streamline the process for efficient and timely transfer of new varieties to farmers and growers for use in crosses with experimental/advanced lines carrying new traits, including commercial partners, who enable final breeding, seed increase, and/or seed distribution.

Forest Service

There is a growing need to maintain healthy, productive ecosystems in the face of increased pest and pathogen movements, and unpredictable climate that can survive in long-term, low-input systems. Research is finding genes for key economic properties and pest resistance; information that is being used to develop marker-assisted selection. This is especially valuable in long-lived species that have long generation intervals (> 10 years). These tools can be combined with traditional breeding methods to improve growth, wood quality, and disease/insect tolerance in economically important hardwoods and conifers. Given the longevity of trees and the impact of invasive species and climate change on our natural ecosystems, and the fact that forests are low-input systems relative to agricultural crops, there is an ever-growing need to incorporate biotic and abiotic resistance in forest regeneration programs to keep forests healthy in the future.

The August 2013 Plant Breeding Listening Session confirmed the need for the USDA Forest Service efforts in research and National Forest System's (NFS) breeding, selection, and deployment strategies. The current needs brought on by a changing climate and the increased pressure from native and exotic pests require that the agency regularly assess its program direction to ensure that its limited resources are directed to priority areas.

The needs of the National Forest System will continue to dictate the direction of the NFS genetics program, while the Forest Service Research and Development (FS R&D) program will continue to focus on the Nation's forests and rangelands (which include the NFS lands). Given the relatively small amount of resources allocated to breeding in this sector and the need to maintain healthy and resilient forests, FS R&D and NFS and State and private partners through the Forest Health Protection Program will continue to allocate resources to breeding for forest health, productivity, and resilience. Because of the long generation intervals of forest trees, FS R&D will consider its role in supporting the genomic needs of the forest genetics community to bring new genomic and biotech tools online faster. As resources become available and the program evolves,

this could include supporting the bioinformatics needs in a manner similar to what ARS does for the crop communities.

We propose to expand selection and testing of Forest Service materials in different environments and improve coordination among Federal agencies and university breeders to ensure that achieving maximum application of new plant selections will be a future priority. Greater efforts will be made to coordinate selection and testing efforts with private seed and plant growers; to identify plants adapted to regional applications; and to ensure the better integration of these well-suited plants into the commercial marketplace. Given adequate resources, FS will review the 2004 Genetic Resource Program Strategic Plan (http://fsweb.wo.fs.fed.us/fm/genetics/index.shtml) to determine if it needs or does not need updating. The review will consider whether or not the Plan is still relevant to FS's current direction. The revised Plan should provide strategic direction to address current and future forest threats, most importantly, climate change and insect and disease infestation. It is necessary to collaborate with resource managers and outside partners to enhance use of improved genetic plant material in reforestation programs. FS will continue to develop an assessment and prioritization of forest trees at risk of extirpation. This assessment and prioritization will provide critical information and direction to many areas, including forest restoration, adaptation strategies and mitigation to climate change, and gene conservation. Knowledge will be developed to increase our understanding of the genes controlling traits of importance (disease resistance, abiotic stress, wood quality and growth), and resources will be provided for curation of genomic data and tools for forest trees. Methodologies for ex situ conservation of species will be developed, especially those that cannot be stored as seeds for the long term.

Natural Resources Conservation Service

Regionally adapted plant materials are increasingly important for revegetation and restoration activities, protecting or restoring ecosystem services, and creating landscapes that are better adapted to a changing climate. Improved characterization and potential breeding of range and pasture grasses is required to ensure that grazing systems remain as productive as possible through droughty periods. Increased competition from invasive plants, particularly on western rangelands, will require new strategies and germplasm to restore critical ecosystems. Improved varieties that capture and recycle agricultural nutrients and improve soil health will protect the quality of our water, as well as increase the resilience of agricultural soils. Species and plant selections targeted to specific pollinators and at-risk wildlife species will contribute to food security and ecosystem diversity.

Even with hundreds of publicly available varieties of NRCS plants in the commercial marketplace for natural resource conservation, there are still specific instances and emerging needs for additional plant breeding and selection. NRCS, through its network of Plant Materials Centers, will continue to assemble and evaluate germplasm for a variety of natural conservation activities and will conduct plant selection efforts when critical gaps are found. Plant Materials Center efforts will continue to target plant needs for NRCS private lands conservation activities. Cooperative efforts with other Federal and State agencies and private seed and plant growers will ensure that NRCS efforts have broader implications to conservation activities on all U.S. lands. Increased coordination with Federal partners such as ARS, FS, and Bureau of Land Management

will leverage limited agency resources to the extent possible to enhance the tools available for natural resource conservation activities.

Economic Research Service

ERS will continue to study linkages between public and private agricultural research and how technological advances in agricultural production are responsible for abundant and affordable food and fiber, both domestically and internationally. ERS maintains that plant breeding will remain a key agricultural research component. (See appendix for a summary of ERS activities related to plant breeding.) Over the next few years, the ERS research most relevant to plant breeding will focus on the resources needed for genetic enhancement, particularly in the context of climate change.

National Institute of Food and Agriculture

Going forward, NIFA's funding programs include opportunities for plant breeding research to address needs and opportunities across most USDA Strategic Goals and REE Action Plan Goals. This is especially so when capacity and competitive funds are viewed together. Moreover, the range of eligible applicants is broad.

However, although well-developed "in principle," the adequacy of NIFA funding opportunities for plant breeding faces major challenges. The core challenge is low funding levels for both competitive and capacity funding programs. For competitive grants, this translates into both low application success rates (less than 10%, and sometimes less than 5 %.), and, a mismatch between award duration (typically 2 to 5 years, non-renewable) and plant breeding timelines (typically 7 to 12 years, or longer, depending on the breeding materials and goals). The two constraints interact: low overall funding is one reason why NIFA seldom uses longer awards that would better fit the plant breeding process from concept to cultivar (i.e., variety). NIFA stakeholders (see Section III. A.2) pointed to consequences of concern for the present and future, ranging from limited attention to recalcitrant breeding problems, fewer opportunities to follow-up on promising results, and to discouragement of students pondering careers in public plant breeding. The short-term nature of competitive awards also has consequences for tracking and reporting results: short projects lack a mechanism for reporting what targeted breeding results were achieved.

Capacity funds are critical in this situation, for allowing NIFA's partners to conceptualize new breeding projects, and for carry-through on successful projects. Capacity funds can be used for both the high-risk early and exploratory stages of plant breeding; and, later, for necessary completion stages. Both of these phases are essential; and both are typically ineligible for competitive funding. Capacity funds also allow breeding programs to adjust very quickly to address unexpected emerging needs if/as these arise. NIFA is exploring creative ways (See Section. III.2.A) to focus and build on these *enabling effects* of capacity funds for plant breeding as well as for other agricultural research outcomes.

To address the reporting artifact of short-term awards, NIFA is exploring a mechanism—an optional mechanism--for longer term reporting after projects are ended. The feature, including timed reminders, would be implemented in a future version of NIFA's "REEport" reporting

system. In informal conversations, researchers and research directors have expressed interest and even enthusiasm about sharing their longer term results with NIFA.

3. Glimpses farther ahead

Stakeholders across all sectors, public and private, were unanimous in their input to USDA, that education and genetic resources – human resources and genetic resources -- are the two highest priority areas for plant breeding. Stakeholders consistently urged USDA that it has an indispensable role to play in contributing to success in plant breeding broadly, across all sectors and end-users. As evident from the descriptions above, each USDA plant breeding agency will address this role according to its mandate. USDA's future contributions will include plant breeding research (e.g., on mechanisms, methods and tools); plant breeding *per se* for cultivar development*;* economic studies of various aspects of breeding; participation in national interactions and leadership functions; funding; and combinations of these.

In its intramural research, USDA plans to continue its work on new breeding approaches and methods, as foreseen in the REE Action Plan (e.g., Goal 1C, Crop and Animal Genetics, Genomics, Genetic Resources, and Biotechnology). These research plans are responsive to input from the 2011 customer/stakeholder workshop for ARS National Program 301: Plant Genetic Resources, Genomics, and Genetic Improvement; and are incorporated in USDA's ARS NP 301 Action Plan for 2013-2017 (http://www.ars.usda.gov/SP2UserFiles/Program/301/NP301ActionPlanRevised-April2010.pdf). Similar recommendations for public research were developed at the private-sector-hosted 2008 American Seed Research Summit, which included public-sector participants, and which was noted by some participants in the 2013 Plant Breeding Listening Session.

ARS expects to conduct research that will be uniquely associated with its NPGS responsibilities:

- Development of novel tools to exploit crop genetic resources, such as the landraces, crop wild relatives, and older varieties in the NPGS, and elite breeding stocks, as experimental populations for identifying and understanding the genetic bases for key traits.

- Design of more efficient and effective genetic resource and information management methods to ensure long-term genetic integrity, health, and availability of genetic stocks that will be needed in the future.

- Improvement of data management and solutions for "big data." Management, analysis, and interpretation of genotypic and performance data has become a greater bottleneck for plant breeding than producing data. Needs include standardized protocols, superior database interfaces, and stand-alone informatics tools.

Looking far beyond current planning cycles, into future plant breeding priorities and needs, ARS crop geneticists and breeders will integrate existing and future knowledge into new tools and approaches such as improved, high-throughput phenotyping, new crossing schemes, and novel predictive computational tools. All of these approaches will be aimed at improving breeders'

ability to design optimal processes to meet multiple breeding objectives, while minimizing costs and time.

Stakeholders reminded USDA that transgenic crops have been widely adopted by farmers and can provide solutions to very difficult problems in agriculture. ARS is working on some of these (e.g., pest resistance for endangered citrus and ash trees). In future, ARS expects to design novel methods for crop genetic engineering, working at the intersection of genetic engineering, genomics, and plant breeding, to develop technologies that can genetically modify a plant directly but without the use of transgenic methods. This future work may find better acceptance based in part on USDA's present interagency work to create improved policies and management methods to promote coexistence of transgenic with non-transgenic agricultural systems.

Through NIFA funding and other sources, plant breeding approaches to coexistence are also being explored (see App. 3). These are based on naturally occurring traits that could allow future cultivation in proximity of various specialty types of the same crop.

Future directions for NIFA-funded research in partner entities, through its capacity and competitive funding programs, will continue to span the plant breeding trajectory: from the more basic to the most applied final stages of cultivar development. NIFA awards will continue to contribute to research complementary to, or directly in partnership with, ARS work outlined above.

Other NIFA programs and funding will support cultivar development and related research on specific crops or agricultural systems, such as breeding cultivars with traits to optimize viability of small farms, or for organic systems. Stakeholders at the August 2013 Listening Session noted that there are researchable topics for improving phenotypic breeding strategies and farmer-participatory breeding.

NIFA programs may even support plant breeding for systems not presently foreseen. The new breeding methods being developed by and with ARS will create new possibilities for optimizing combinations of traits heretofore difficult to breed for. And other research, for example, the work of USDA and its partners at Long Term Agro-Ecosystem Research sites, will bring new understanding of what traits will be needed in cultivars adapted to new management practices for sustainability. One can well imagine, for example, that NIFA-funded plant breeding may include use of advanced breeding methods to breed perennial cultivars, something that will become more feasible in time and costs. These advanced breeding methods will also support new opportunities in forest tree breeding and ecosystem services, such as conducted by FS and NRCS, and breeding of other long-cycle crops for biomaterials and bioenergy, as well as perennial food and feed plants.

IV. Closing comments

Plant breeding will be critical for meeting the challenges ahead. This Roadmap exercise has highlighted the multiple ways that USDA's work will provide national support to plant breeding and plant breeding outcomes into the future and across all agricultural sectors. These include:

- USDA's own globally outstanding work in plant breeding and allied research for:
  - New traits in original and enhanced **germplasm**; improved **cultivars**; new genetic **tools and methods** for faster breeding progress, **databases** of research and germplasm information, and **mentorship** opportunities;

- **Recruitment and education** of the next generation of plant breeders, prepared to address the future with new breeding approaches that their predecessors could only dream of;

- A **facilitating role across public and private sectors** to help create an enabling environment for innovation in plant breeding;

- A **variety of responsive Federal funding mechanisms** to empower and stimulate plant breeding in State and other partner institutions to enable:
  - Creativity and management across national, regional, and State levels
  - New opportunities for interaction with other agricultural and basic sciences and with farmers, communities, and others who put plant breeding's outputs to work in farms and businesses, both large and small.

USDA has the experience and partnerships to enable these results. However, all of these future possibilities for USDA plant breeding will depend on additional resources:

- Resources for USDA's intramural work to enable, guide, and conduct plant breeding;
- Resources for USDA external funding programs for a wide range of partners.

The Plant Breeding Roadmap exercise has been timely for USDA. Actions at this present crossroads will impact our plant breeding capabilities for another generation—a generation likely to see more challenges to food and agricultural systems than the generation of plant breeders who are retiring now. Stakeholders across all sectors, public and private, were unanimous in their input to USDA, that education and genetic resources – human resources and genetic resources -- are the two highest priority areas for plant breeding.

Keenly felt are decades of mostly stagnant funding for plant breeding in USDA and its State partners. This is in effect reduced funding, due to inflation, especially in the stable, longer term sources that attract investment by other partners. Stagnant funding has led to declines both in infrastructure and in the attractiveness of plant breeding to young people for whom research funding opportunities in health or computing may come more reliably. Yet, these professions too are ultimately dependent on plant breeding. Stakeholders have been emphatic that with current funding resources, both education and genetic resources face shortcomings that are alarming for our national and global future.

V. References

Huffman, W., and R.E. Evanson, 2006. Do formula or competitive grant funds have greater impacts on state agricultural productivity? Am J Agric Econ 88:783-98.

Appendix 1: USDA REE Action Plan Goals, 2014

http://www.ree.usda.gov/ree/news/USDA_REE_Action_Plan_03-2014.pdf

Goal 1. Sustainable Intensification of Agricultural Production
- Subgoal 1A. Crop and Animal Production
- Subgoal 1B. Crop and Animal Health
- Subgoal 1C. Crop and Animal Genetics, Genomics, Genetic Resources, and Biotechnology
- Subgoal 1D. Consumer and Industry Outreach, Policy, Markets, and Trade

Goal 2. Responding to Climate and Energy Needs
- Subgoal 2A. Responding to Climate Variability
- Subgoal 2B. Bioenergy/Biofuels and Biobased Products

Goal 3. Sustainable Use of Natural Resources
- Subgoal 3A. Water Availability: Quality and Quantity
- Subgoal 3B. Landscape-Scale Conservation, Management and Resiliency

Goal 4. Nutrition and Childhood Obesity
Goal 5. Food Safety
Goal 6. Education and Science Literacy
Goal 7. Rural Prosperity/Rural-Urban Interdependence

Appendix 2: USDA 2014-2018 Strategic Goals

http://www.usda.gov/documents/usda-strategic-plan-fy-2014-2018.pdf

Strategic Goal 1. Assist rural communities to create prosperity so they are self-sustaining, re-populating, and economically thriving.
1.1 Enhance rural prosperity, including leveraging capital markets to increase Government's investment in rural America.
1.2 Increase agricultural opportunities by ensuring a robust safety net, creating new markets, supporting a competitive agricultural system.
1.3 Contribute to expansion of the bioeconomy by supporting development, production, and consumption of renewable energy & biobased products.

Strategic Goal 2. Ensure our national forests and private working lands are conserved, restored, and made more resilient to climate change, while enhancing our water resources.
2.1 Improve the health of the Nation's forests, grasslands and working lands by managing our natural resources.
2.2 Lead efforts to mitigate and adapt to climate change, drought, and extreme weather in agriculture and forestry.
2.3 Contribute to clean and abundant water by protecting and enhancing water resources on national forests and working lands.
2.4 Reduce risk of catastrophic wildfire.

Strategic Goal 3. Help America promote agricultural production and biotechnology exports as America works to increase food security.
3.1 Ensure U.S. agricultural resources contribute to enhanced global food security.
3.2 Enhance America's ability to develop and trade agricultural products derived from new and emerging technologies.

Strategic Goal 4. Ensure that all of America's children have access to safe, nutritious, and balanced meals.
4.1 Improve access to nutritious food.
4.2 Promote healthy diet and physical activity behaviors.
4.3 Protect public health by ensuring food is safe.
4.4 Protect agricultural health by minimizing major diseases and pests to ensure access to safe, plentiful, and nutritious food.

Appendix 3: Examples of USDA plant breeding achievements

USDA Strategic Goal 1: Plant breeding conducted or supported by USDA has a strong record in providing crop varieties that support rural income and jobs, create new markets, and enable competitive ag systems. Some current examples include rice varieties in Arkansas, table grapes in California, sweet potatoes in Louisiana, and vegetables for local growers in northern states.

ARS and University of Arkansas (UA) researchers collaborate to develop rice lines with disease resistance and cold tolerance. ARS researchers use the lines in crosses to develop unique new varieties that combine quick-cooking with whole-grain nutrition. These allow processors to develop attractive new consumer products, which in turn expand markets for rice farmers. UA breeders focus on breeding long-grain table rice for stable high yields. Together, these varieties comprise most of the rice acres planted in Arkansas.

Partners: ARS, NPGS, U. Arkansas; Uncle Bens, Campbell. Funding: ARS intramural, NIFA-administered Hatch funds, State funds (Arkansas), rice growers. USDA Strategic Goals 1.1, 1.2; REE action goals 1A, 1D.

ARS researchers developed pest and disease resistance in grapes, which allowed growers to open new market niches and use lower energy production systems. Almost three-quarters of the table grapes we enjoy today are varieties developed by the ARS grape breeding program.

Partners and funding sources: ARS intramural funds, commercial wine and grape producers. USDA Strategic Goals 1.1, 1.2; REE action goals 1B, 1D, 4.

Louisiana State University (LSU). has increased on-farm sweet potato yields 20% through new varieties and cultural practices. A new plant for sweet potato "French fries," high in Vitamin A and fiber, has created over 100 jobs in rural Louisiana. The new varieties and practices are suitable for small farmers, including African–American farmers, whose sweet potatoes are typically sold on the fresh market for higher prices.

Partners: LSU, ConAGRA. Funding: NIFA-administered Hatch funds; State funds. USDA Strategic Goals 1.1, 1.2; REE action goals IA, 1D, 4, 7.

Professional and farmer breeders in NOVIC, the Northern Organic Vegetable Improvement Collaborative, used participatory breeding methods and disease-resistant lines from the NPGS to develop and release varieties that fill a market void in NE and NW States. Local sales have increased, as has income, for small-scale seed producers and vegetable farmers in these regions.

Partners: Oregon SU, U. Wisconsin, Cornell U., ARS, Organic Seed Alliance; farmers. Funding: NIFA OREI, ARS intramural, Hatch and State funds from OR, WI, NY; and farmer collaborators. USDA Strategic Goals 1.1, 1.2; REE Action Plan Goals 1A, 1D, 7.

USDA Strategic Goal 2: USDA takes very seriously the challenge to ensure that our national forests and private working lands are conserved, restored, and made more resilient to climate

change, while enhancing wildlife habitat and environmental quality. Contributions of plant breeding include trees and range plants that cope with present stresses and allow us to be prepared for the future.

Pine trees bred by the Forest Service for resistance to blister rust disease (an exotic disease) and high timber yields are being developed to keep these species on the landscape so that they continue to provide ecological roles, while also valued economically. These disease-tolerant trees have been planted on approximately 257,011 acres of Federal lands in the Northwest; an additional 65,472 blister rust-resistant white pine are growing on State, tribal, and private industrial landholdings.

Funding: Forest Service intramural funds; USDA Strategic Goal 2.1; REE action goals 1B, 3B.

Forest Service breeders have developed highly productive seed "orchards" of both common and endangered forest species. As climate stresses create new challenges for forests, these orchards will be invaluable sources of genetically diverse seed for resilient forests in future. Such forests will protect our soils, water resources, and wildlife and provide recreation and timber.

Funding: Forest Service intramural. USDA Strategic Goals 2.1, 2.2, 2.3, REE action goals 1C, 2A, 3A, 3B.

High quality grazing lands are critical to U.S. food and nutritional security for meat and dairy products. Over 150 selected grasses, and 30 legumes and forbs, are used for prairie restoration and range, pasture, and hay production on tens of millions of acres of private grazing lands, and for restoration of public lands managed by Federal and State agencies. This palette of diversity will be even more important to maintain grazing land productivity in the future.

Partners: NRCS, ARS, BLM. Funding: NRCS and ARS intramural. USDA Strategic Goal 2.1; REE action goals 1A, 2A, 3B.

NRCS has released plants selected for their ability to stabilize and restore productivity of critical and often fragile ecosystems. For example:

- An NRCS cultivar of American beachgrass, used for rebuilding dunes, reduced property damage on upper Mid-Atlantic coastline areas during Hurricane Sandy in October 2012.
- Over 75 NRCS-selected grasses and shrubs provide filter strips along stream banks and lakes, capturing sediment which would otherwise pollute our water.
- NRCS conservation plants are mainstays for restoring productivity to degraded western rangelands where challenges include low rainfall, weed pressure, and neglectful management.
- Of 750 conservation plants selected by NRCS over the past 75 years, more than 500 are still grown and available commercially, creating jobs and income in addition to their ecological service.

Funding: NRCS intramural funding. USDA Strategic Goal 2.1, 2.2, 2.3; REE action goals 2A, 3A, 3B.

Food crops, too, can be bred for traits that help protect natural resources. For example, new, higher yielding bean varieties are bred for a new growth habit that allows fewer field-machinery passes than formerly, reducing both grower costs and soil compaction.

Partner: Michigan State University and others. Funding: NIFA-administered Hatch funds, State funds. USDA Strategic Goal 2.3; REE action goals 1A, 3B.

USDA Strategic Goal 3: For over a century, USDA scientific advances and plant breeding have been essential to allow the United States to export food and to contribute to global food security. Current examples include powerful new breeding methods for all crops, plant traits that will allow natural coexistence of transgenic and other corn, use of genetic diversity to extend crop ranges, and-- as important now as it was a century ago-- genetic resistance to protect the world's wheat.

ARS scientists combined molecular and statistical analysis with crossing widely diverse corn lines in a nested pattern, to allow association mapping (NAM). The group then field-phenotyped the resulting progeny, and sequenced the parents' genomes. Combining the data, researchers produced the highest resolution genetic maps yet made. The maps reveal, for example, that corn's hybrid vigor is related to specific optimal gene combinations; and its flowering time is controlled by 50 to 100 genes—clues that will help breed corn for new environmental conditions. NAM is already being used in breeding other crops including wheat, barley, oats, rice, cotton, and soybean.

Partners: ARS, Cornell U. Funding: ARS intramural funds; NSF, NIFA NRI competitive grant. USDA Strategic Goals 1.2, 2.2, 3.1, and others; REE Action Plan Goal 1C, 2A.

ARS, North Carolina State University, and private breeders are using naturally occurring pollen-screening genes from corn to develop a type of corn that is expected to facilitate choice and coexistence when transgenic (genetically engineered) corn is grown near non-engineered corn.

Partners: ARS, North Carolina State University, and private breeders. Funding: ARS intramural, NIFA OREI, Hatch and State funds, private-sector funds. USDA Strategic Goal 3.2; REE action goals 1A, 1D.

Farmers in the northern prairies can now grow corn where short, dry growing seasons made it too risky before. Plant breeding has increased regional corn yields up to 190% in extreme environments, with 100% more kernel starch than in commercial hybrids. Regional corn acreage increased 460% in the past decade, as farmers responded to market demand. Seed of this unique corn germplasm is shared nationwide. Commercial breeding companies are now using the new materials to expand into the region.

Partners: North Dakota State Univ.; GEM project. Funding: GEM (ARS); NIFA-administered Hatch funds; State funds; corn growers associations of North Dakota and Minnesota. USDA Strategic Goals 1.2, 2.2, 3.1; REE action goals 1A, 1D.

Wheat geneticists and pathologists identified new sources of resistance to Ug99, globally the most virulent wheat stem rust strain in the past 60 years, and a pressing threat to world wheat production, including in the United States. They have developed genetic lines and breeding tools deploy the genes rapidly into advanced wheat and barley breeding lines to help breeders throughout the world develop more durable protection of the global grain supply.

Partners: ARS, Kansas State Univ., private sector. Funding: ARS intramural, NIFA-administered Hatch funds; State funds (KS), private funds. USDA Strategic Goal 3.1; REE action goals 1B, 1C. 1D.

Over a 10-year period, sources of genetic resistance to cotton root nematodes were identified and used, with molecular marker screening techniques, to develop parent-line germplasm with the resistance genes. This germplasm is freely available to public and private-sector breeding programs and has sped the development of cultivars now in farmer's fields. Educational media

informed cotton producers about nematode infestation consequences and the benefits of the resistant cultivars.

Partners: ARS, Louisiana S.U., Mississippi S.U., U. of Georgia, Auburn U., U. California-Riverside, Texas A&M U; New Mexico SU; Cotton Incorporated. Funding: ARS intramural funds; Hatch funds; State funds, Cotton Incorporated, farmer checkoff funds, and JAJO Genetics. USDA Strategic Goals 1.3, 3.2; REE Action Goals 1A, 1B, 1D.

USDA Strategic Goal 4: While combating diseases and pests has been part of USDA plant breeding since its beginning, some of the most exciting work in recent years has been in the area of crop nutritional value for our diets. On the market, or in advanced testing stages, are more nutritious fruits, common beans, peanuts, and soybeans, and a new class of wheat that makes attractive new whole-wheat products.

New experimental varieties of apples, pears, cherries, peaches, and almonds are already being tested, thanks to new genomic and data management tools developed by the "RosBREED" project. These tools are taking years off the time needed to identify and recombine sources of improved fruit quality, nutritional value, flavor, and disease and pest resistance. The new varieties will also help sustain U.S. fruit farming by lowering production costs, reducing pesticide use, and improving profitability.

Partners: Michigan S.U., Cornell U., Wageningen (Netherlands), ARS; Texas A&M U., U. Arkansas, U. California-Davis, U. New Hampshire, Clemson U., Oregon S. U., U. Minnesota, Washington S.U. Funding: NIFA SCRI award, Hatch funds, State funds, ARS intramural funds; international (Netherlands, as matching funds), and fruit industry sources. USDA Strategic Goals 1.1, 1.2,4.1, 4.4; REE action goals 1A., 1C., 4, 7.

Bean breeders in ARS and six land-grant universities, along with the ARS Children's Nutrition Center, are studying and improving nutritional value of common bean. Bean breeders are also working with the National Cancer Institute to study how beans help protect against some forms of cancer. These benefits will reach farmers and consumers in new bean varieties from collaborating breeding programs in the United States and around the world.

Partners: Colorado S.U., Michigan S.U., N. Dakota S.U., Oregon S.U., U. California-Davis, U. Nebraska-Lincoln, ARS. Funding: NIFA AFRI award; Hatch funds, State funds, ARS intramural funding. USDA Strategic Goals 4.1, 4.2, and 1.2; REE action goals 1A, 4.

An ARS National Germplasm Resources Laboratory staff member served as an instructor at the Crop Wild Relatives Workshop in the August 2014 Zaagkii Wings and Seeds Project. The workshop focused on the emerging challenge of conserving crop wild relatives, native plants closely related to food crops. Specific training focused on joint ARS-FS strategy and collection protocols for conserving native cranberry species of cultural, nutritional, and economic importance to Native American communities of the upper Midwest.

Partners: Cedar Tree Institute, Forest Service (FS), ARS, Chicago Botanic Garden and (host) Keweenaw Bay Indian Community. USDA Strategic Goals 4.1; and 1.1,1.2, 2.1. REE Action Goal 4.

"Olé" is a new high oleic Spanish peanut, bred to combine increased nutritional value with enhanced yield, grade and disease resistance. It is estimated that "Olé" will increase growers' profit margin by an average of $130 per acre and the local economy by potentially $7 million annually.

Partners: ARS and Oklahoma State U. Funding: ARS intramural; NIFA-administered Hatch funds; and State funds; USDA Strategic Goals 4.1, 4.2; and, 1.1, 1.2

Nutritional value and stability of soybean oil is increased in crosses with wild soybeans from the NPGS collection. Two genes, discovered in these crosses, reduce saturated fat content by a third and triple oleic acid content. New soybean varieties with these nutritional traits are being tested and are expected for all U.S. producing regions by 2016.

Partners: ARS, U. Missouri. Funding: ARS intramural; NIFA-administered Hatch funds; State funds. USDA Strategic Goals 4.1, 4.4; and, 1.1, 1.2. REE action goals 1A, 1C, 4.

A team at West Virginia State University is using the new ARS/Cornell U.–developed NAM molecular-assisted breeding method with heirloom melon cultivars, to develop new melon types that will combine disease resistance and small-farm market appeal. Undergraduate and graduate students on the project are gaining both lab and field experience including on-farm trials.

Partners: West Virginia S.U. Funding: Evans Allen. USDA Strategic Goals 4.1, 4.4, REE Action Goals 1B, 1C, 4, and 6.

In the past 6 years, several bread wheat varieties have been released for both U.S. and export markets that allow bakers to make whole-wheat bread with mild flavor and lighter color, similar to white bread that is often preferred but not as nutritious. Flour of this new wheat type is marketed by both large companies and small artisanal millers. Schools and others can now serve nutritious whole-grain products with broad taste appeal.

Partners: Colorado S.U., U. of Idaho, Kansas S. U., N. Dakota S. U., S. Dakota S.U. Funding: NIFA AFRI WheatCAP award; Hatch funds; and State funds. USDA Strategic Goals 4.1, 4.2; and 1.2. REE action goals 1D, 4.

In support of **all USDA Strategic Goals**, and unique to the REE Action Plan, are **REE Goal 6**, Education and Science Literacy, and **REE Goal 7**, Rural Prosperity/Rural-Urban Interdependence. REE action goal 6 includes strengthening science capacity at minority-serving institutions and exploring use of technology and innovation to distribute educational materials. Plant breeding is the focus of a tribal-college's germplasm and conservation project, and plant breeding educators are sharing high-quality instructional materials through the Internet.

A group of tribal land-grant colleges in North Dakota and Montana is piloting a project with corn varieties and educational outreach. The work will lay a foundation for future breeding and preservation of additional native crops, based on needs of the regional tribal communities.

Partner: United Tribes Technical College. Funding: NIFA AFRI award; Tribal Colleges capacity funding. USDA Strategic Goals 1, 2.1, 4; REE action goals 6 and 7.

The Plant Breeding Training Network provides continual learning resources on plant breeding's basic principles and cutting-edge tools. The site also has materials for teachers and extension educators to help recruit and train the next generation of plant breeders. http://passel.unl.edu/communities/index.php?idcollectionmodule=1130274157

Partners: Montana S. U., U. Minnesota, U. California-Davis. Funding: NIFA AFRI Triticeae CAP award; NSF, Hatch and State funds. REE action goal 6.

The Plant Breeding and Genomics eXtension Community of Practice provides a resource for students and professionals in plant breeding and producers who use new varieties

from traditional and emerging plant breeding methods. Materials on the site integrate plant breeding, genomics, and crop production.
http://www.extension.org/plant_breeding_genomics

Partners: eXtension, State and Federal partners in the SolCAP, Barley CAP, RosBREED, and Conifer CAP projects; NSF. Funding: NIFA AFRI SolCAP, BarleyCAP, and Conifer CAP award, and SCRI RosBREED award. REE action goal 6.

Many more plant breeding accomplishments by ARS and its partners are documented in a comprehensive retrospective report at:
http://www.ars.usda.gov/research/programs/programs.htm?np_code=301&docid=22191 (see especially Component 3).

For descriptions of current plant breeding projects, both NIFA-funded and ARS, see USDA's Current Research Information System (CRIS) database at http://cris.nifa.usda.gov/ (Field of Science code 1081).

Appendix 4. Areas of responsibility, USDA agencies involved in plant breeding: ARS, ERS, FS, NIFA, NRCS

Agricultural Research Service (ARS)

ARS is USDA's chief scientific in-house research agency charged with finding solutions to agricultural problems that affect Americans every day, from field to table. Seventeen National Programs include 800 research projects with 2,100 scientists and post-docs, 6,000 other employees, 90 research locations including overseas laboratories, and a fiscal budget of $1.1 billion. The mission of the agency is to conduct research to develop and transfer solutions to agricultural problems of high national priority and provide information access and dissemination to ensure high-quality, safe food and other agricultural products, assess the nutritional needs of Americans, sustain a competitive agricultural economy, enhance the natural resource base and the environment, and provide economic opportunities for rural citizens, communities, and society as a whole. Through Cooperative Research and Development Agreements (CRADAs), Specific Cooperative Agreements, and other arrangements, ARS partners with businesses, other Federal agencies, State and local governments, and universities to augment size and scope of research programs and expedite research results and ARS varieties to users.

Economic Research Service (ERS)

ERS analyzes economic and policy issues related to agriculture, food, the environment, and rural development. ERS supplies economic data and analysis to inform decisions about public investments in agricultural science, but does not produce or conserve genetic material. Research efforts focus on agricultural science policy, productivity, and innovation systems. ERS assesses the role of plant breeding in the process of genetic enhancement, technology creation and adoption. Economists use the concept of public goods, the role of incentives such as intellectual property rights, and available resources to help discern the optimal mix of public and private plant breeding efforts. ERS projects include:

• Using empirical information to inform plans for plant breeding and the need for plant breeding in adaptation to climate change;
• Guiding the search for plant traits using economic methods; and
• Estimating returns to research, including the value of genetic enhancement.

ERS has reached three major conclusions about investment in agricultural research:
• Increased productivity, arising from innovation and technological change, is the main contributor to economic growth in U.S. agriculture;
• Public and private agricultural research has been the foundation for these advances in agricultural productivity; and
• Public and private research may, in many cases, function as complements, rather than substitutes.

National Institute of Food and Agriculture (NIFA)

NIFA manages USDA extramural research funding and makes awards to plant breeding research, education, and extension.

Capacity programs: NIFA-managed capacity programs include Hatch (1862) and Evans-Allen (1890) land-grant universities, and McIntire-Stennis (State forestry) schools. Characteristics of capacity programs include specific eligibility, leverage of significant non-Federal matching funds (typically 100%), use for research including graduate assistantships and infrastructure, and Federal-State and multistate interaction. Within-program priorities for capacity funds are determined at the State level by State Agricultural Experiment Stations (Hatch), Agricultural Research Directors (Evans-Allen), and State Forestry Directors (McIntire-Stennis), respectively. Research partners from ARS and other public and private-sector entities may not receive capacity funds, but do participate as cooperators in multi-state Hatch projects that are organized around topics of common interest.

Competitive programs: NIFA competitive grant programs that have funded plant breeding include the Agriculture & Food Research Initiative (AFRI) Foundational, Challenge Area, and Fellowship programs; the Organic Agriculture Research & Extension Initiative (OREI) (plant breeding is one of eight OREI priority areas); the Specialty Crop Research Initiative (SCRI) (at least 10% of total funding in each award cycle); the Biomass Research & Development Initiative (BRDI); and Small Business Innovation Research (SBIR). Eligibility for these programs varies. AFRI, the broadest program, is open to any public or private-sector applicant. Plant breeding is one of about a dozen sub-program areas in the AFRI Foundational Program. AFRI challenge area topics are developed annually based on congressional guidelines and stakeholder input; plant breeding's relevance will vary with the topic.

Programs also vary in degree of integration across functions (research, education, and/or extension). All NIFA competitive programs require peer panel review. Competitive programs vary in matching-funds leverage, degree to which eligible project types are defined by the funding authority versus determined by NIFA, and extent of post-award interaction with NIFA**.** NIFA establishes priorities for its competitive grant programs within the context of the congressionally authorized purposes of each program, and with input from a broad range of

stakeholders. In addition, each request for applications (RFA) for a competitive program includes a request for public comment.

Special grant programs: NIFA special grant programs that currently include plant breeding are Potato Breeding Research and the Supplemental and Alternative Crops program.

Forest Service (FS)

FS manages 193 million acres of national forests and grasslands. The National Forest System (NFS), provides technical and financial assistance to landowners and resource managers to help sustain the Nation's forests and protect communities and the environment from wildland fires (State and Private Forestry, S&PF), and provides science to improve the health and use of our Nation's forests and grasslands (Research and Development). The Forest Service has internal programs that encompass breeding research and operational breeding programs. The operational breeding programs typically focus on developing tolerance to diseases, pests, and abiotic stress in seed sources used for reforestation and restoration on National Forest System and other forest lands. Most applied programs are run through the National Forest System in cooperation with the Forest Health Protection Program of the State and Private Forestry branch, but Research and Development maintains some operational programs as well.

FS research efforts include: developing genomic tools and markers for identifying genes underlying key traits (disease and insect resistance, adaptive traits, wood quality, and growth), developing screening procedures to identify resistance to diseases and pests, and documenting genetic variation and structure over the landscape for key adaptive traits. This information is used to improve breeding programs and to develop deployment options for forest and rangeland managers with regard to disease and pest resistance, climate change, and adaptation (seed movement guidelines and seed zones).

Natural Resources Conservation Service (NRCS)

NRCS provides technical and financial assistance to America's ranchers and farmers to encourage soil and water conservation practices on private lands. NRCS's Plant Materials Program tests and selects the proper vegetation to support this mission. The program develops the information and technology needed for establishing and managing plantings as well as information needed for large-scale production by private growers. Born out of the Dust Bowl era, the program evolved from conservation nurseries to produce large quantities of seed and nursery stock to a nationwide network of 25 Plant Materials Centers (PMCs) today. PMCs works on the premise that there are already plants available which will address natural resource conservation needs. PMCs find and evaluate plants useful in restoration and mitigation through a process of collection, assembly, evaluation, possible reassembly/crossing, field testing, and release to the public. Much of the Plant Materials Program's work is done in cooperation with other Federal and State agencies and with private industry.

Appendix 4. Abbreviations, acronyms, and glossary

AFRI	Agriculture and Food Research Initiative, a NIFA funding program
ARD	Association of 1890 Research Directors
ARS	Agricultural Research Service, USDA
BLM	Bureau of Land Management, United States Department of the Interior
BRDI	Biomass Research & Development Initiative
CAP	Coordinated Agricultural Project, NIFA project type
CRADA	Cooperative Research and Development Agreements
CSREES	Cooperative State, Research, Extension, and Education Service, USDA (predecessor of NIFA)
Cultivar	A plant purposely selected for desired traits (sometimes referred to as a 'variety')
DOE	U.S. Department of Energy
EPA	Environmental Protection Agency
ERS	Economic Research Service, USDA
FS	Forest Service, USDA
GEM	Germplasm Enhancement of Maize projects
GRIN	Germplasm Resources Information Network (NPGS, ARS)
IPR	Intellectual Property Rights (including plant variety protection ("plant breeder's rights," administered by USDA), and plant patents and utility patents (administered by the USPTO)
LGU	Land-Grant University
NAM	Nested Association Mapping
NAPB	National Association of Plant Breeders
NC	North Central
NE	Northeast
NFS	National Forest System, FS, USDA
NIFA	National Institute of Food and Agriculture, USDA
NIH	National Institutes of Health
NP 301	USDA/ARS National Program 301, Plant Genetic Resources, Genomics, and Genetic Improvement
NPGI	National Plant Genome Initiative (interagency)
NPGS	National Plant Germplasm System, ARS, USDA
NRCS	Natural Resources Conservation Service, USDA
NRE	Natural Resources and Environment mission area, USDA
NRI	National Research Initiative, an earlier NIFA competitive funding program
NSF	National Science Foundation
NW	Northwest
OCS	Office of the Chief Scientist, USDA
OREI	Organic Agriculture Research and Extension Initiative, a NIFA funding program
PBWG	Plant Breeding Working Group, USDA
PMC	Plant Material Centers, NRCS, USDA
PVPO	Plant Variety Protection Office (in USDA's Agricultural Marketing Service)
R&D	Research and Development
REE	Research, Education, and Economics mission area, USDA
RFA	Request for applications
S	South, or, State
SAES	State Agricultural Experiment Station. The four regional SAES associations are: *Northeast Regional Assoc. of State Agric. Experiment Station Directors (NERA); North Central Regional Assoc. of State Agric. Experiment Station Directors (NCRA); Southern Assoc. of Agric. Experiment Station Directors (SAAESD); Western Assoc. of Agric. Experiment Station Directors (WAAESD).*
SBIR	Small Business Innovation Research, a NIFA funding program
SCRI	Specialty Crop Research Initiative, a NIFA funding program
STEM	Science, Technology, Engineering, and Mathematics

TT	Technology Transfer
U, Univ.	University
USAID	U.S. Agency for International Development
USDA	U.S. Department of Agriculture
USPTO	U.S. Patent and Trademark Office