Enhancing the delivery of genomics research outcomes

Genomics Research in the CGIAR:

Effective means of establishing platforms for genetic research

Contents

1. Executive Summary

The CGIAR conducts genetics research for the characterization, enhancement and conservation of species important for food, feed and livelihoods in developing countries.

There is currently a great variety of means through which Centers access required technology. However, the technology is changing rapidly and new opportunities for technology application are continuously arising. Therefore, Centers should consider how the technologies are going to develop, and whether this will entail adaptations by the CGIAR System. The Science Council has commissioned this Report to consider if there are opportunities to develop more unified approaches or generic platforms to streamline genomics research in a cost effective manner and optimise investments. The Report is based on an evaluation of current best practice in industry, public breeding and research needs at the Centers. The Report and a Recommended Strategy has been developed in consultation with the biotechnology focal points in the CGIAR Centers and Challenge Programs.

It is proposed that a CGIAR Genomics Taskforce (TF) should be convened from key plant (crop and tree), livestock and fish Centers across the System. The remit of the TF will be, with a ten year horizon, to identify opportunities for coordination of genomics research within the System to achieve maximum impact on breeding and genetic resource management at the Centers, most appropriate assistance to national agricultural research program partners, and the optimum return on research and capital investment.

The TF should be a science advocacy group for CGIAR research that will be the focal point for interaction of the Centers with international and national funding and research agencies and genomics networks. The principle role will be to identify the optimal deployment of CGIAR resources – either individual Center-based, centralized within CGIAR regional Hubs or outsourced regionally or internationally – for biotechnology research, including genetic transformation, marker-assisted breeding, proteomics, metabolomics and informatics applications. The TF will maximize leverage from pan-System purchases and contracts, and thus facilitate rational and strategic decision-making within Centers. In addition, the TF will contribute to the work of Centers by:

- working with scientists in CG, NARS and SME (small to medium enterprises) breeding programs to identify high priority traits for incorporation in CGIAR commodities using biotechnology means, and establish these in high profile flagship projects at the system level;
- working with breeders to identify opportunities to strengthen phenotyping capacity and the adoption of biometrics best practices and general modernization of breeding programs in CG and partners;
- helping to identify optimal locations for regional training and technology "Hubs" and promote the development of training materials on the application of biotechnology results;
- working with Center bioinformaticians to develop common platforms for biotechnology data storage and analysis and install them System-wide.

The TF will seek to catalyze and oversee the transition from biotechnology data acquisition to highlighting data interpretation and experimental design in breeding and genetic resources management.

2. Background

In the light of the rapid pace of change in biotechnologies which can support CGIAR research, the CGIAR Science Council is evaluating the development of the CGIAR's genomics capacity and associated future requirements. Under the Chairmanship of Dr Mike Gale, the CGIAR's Science Council's Standing Panel on Priorities and Strategies (SPPS), commissioned a study of the issues related to **"Genomics Research in the CGIAR: effective means of establishing platforms for genetic research".** A broad definition of genomics is being used to include molecular markers, gene discovery, transgenic technologies, transcript profiling, proteomics, metabolomics and the underlying bioinformatics infrastructures.

There are three key areas of delivery of the outcomes of genomics for CGIAR research; (1) crop, livestock and fish improvement through the application of molecular markers to improve the sophistication, speed and flexibility of breeding and selection: (2) through genetic modification or engineering of target CGIAR target organisms: (3) livestock and fish improvement through the development of vaccines and diagnostics and (4) application of computational systems to improve breeding efficiency (including bioinformatics, modeling, biometrics and data integration/ management).

In addition to product development genomics research will also help us understand the characteristics, behaviour and expression of the genome and is becoming increasingly valuable in understanding the nature of genetic variation and support the analysis, conservation and utilisation of crop, livestock and fish genetic resources.

However, while biotechnology now permeates most biological research, it has been slow to demonstrate real outcomes for primary producers and consumers. The limited uptake of foodstuffs derived from biotech crops and animals has clearly hindered technology delivery. It is also noteworthy that despite large gene discovery programs in both the public and private sector, GM (genetically modified) crops are still dominated by just two groups of genes - insect resistance, predominantly through BT, and herbicide, mainly glyphosate, tolerance. Other genes, including virus resistance and modified quality traits have also been important but only released on a small scale. Adoption of other biotechnologies, notably molecular markers in breeding programs, has also been slower and less extensively adopted than anticipated although several varieties selected with markers have now been released.

In contrast, we have seen rapid adoption of biotechnology in the medical and veterinary areas with the majority of protein-based pharmaceuticals now derived from gene technology. Also DNA-based methods are now widely used in medical, forensic and veterinary diagnostics. The high level of funding available for research, high value of returns and ready consumer acceptance have all been important in this rapid adoption.

The rate of adoption of biotechnology in agricultural sector has been slower than advocated by some researchers and some funding agencies, and this has placed pressure on the large research investment in genomics. The growth in funding for genomics seen over the past decade may not continue and in many countries public and private investment in genomics is already declining. However, when compared to the adoption of other technologies in agriculture, has biotechnology really been slow?

Breeding new strains of crop plants, livestock and fish is not a rapid process. For example, for annual crops it is not unusual for a period of 10 to 20 years to elapse between the first cross and release of a new variety. Thus, it is in this product development time frame that we need to consider the application of molecular technologies. In addition, it should be remembered that the first reports of useful marker trait associations in the major staples appeared in the literature only about 10 to 15 years ago, and these were based on marker systems, such as RFLP, that were technically difficult, expensive, time consuming and, by today's standards, very low throughput technologies..

Over the past decade the focus of genomics research has been on technology development, establishment of key genomics resources, such as sequence databases and gene expression platforms, and creating a better understanding of gene and genome structure and regulation. There have been only a few serious efforts to examine the processes, paths and mechanisms of delivery of genomics outcomes to the end-users namely, farmers and consumers. An important task will be to convert the information generated into efficient tools and novel strategies that can be implemented to increase rates of genetic gain for target species in target environments.

The objective of this first initiative of the CGIAR Genomics TF has been to:

1. Develop a view of where the technology may be in five to ten years time;
2. Examine the capabilities, processes and mechanisms that will be required if the application of genomics to breeding is to be realized;
3. Identify factors that may limit or inhibit the use of genomics by the CGIAR and its partners;
4. Recommend the ideal level of adoption and engagement with the technologies in the Centers and national partner breeding programs; and
5. Devise an action plan that will help ensure optimum impact of the CGIAR System in the timely delivery of genomics outcomes to poor farmers.

3. Process

This document has been prepared by the CGIAR Genomics TF comprising:

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The first draft plan was developed based on a workshop held in Rome on 3rd and 4th October 2005.

At the workshop the facilitator reported on status and strategy of marker applications in the public and private sector and a preliminary draft of an action plan was developed. The draft report was then modified by a sub-group of the TF members and a second discussion was held in San Diego on 17th January 2006 to further refine the document and action plan.

Additional input was solicited and received by the TF members from staff at each Center.

4. Expected resource and capacity demands for genomics applications

Attempts to estimate demands for particular technologies ten years into the future is fraught with difficulties and many factors may influence the ultimate extent of application. Perhaps the easiest way to make realistic estimates is to look at the current scales in breeding programs where the technology is well integrated and assume that the overall scale of the breeding programs will remain constant but the technology costs will reduce significantly. Models for the path genomics technologies are following can been seen in human research and in large scale private maize and soybean breeding programs.

Genomics is primarily about understanding the function of an organism. This allows several avenues for exploitation, only one of which is transgenics. Others include marker assisted introgression and improved means of identifying appropriate genotypes for given systems and novel interventions, arising from improved understanding of the biology. Computational systems will play a critical role in integrating this information into breeding programs in a useable form. It also plays an important role in environmental management of genetic resources for improved targeting of agricultural biodiversity conservation. It is also important to remember that one of the key areas of genomics research has been a detailed understanding of the control of key traits and developmental processes. The outcomes derived this new knowledge can be delivered through conventional or transgenic crop, livestock and fish improvement programs (including diagnostics and vaccine development) and in the management of genetic resources.

4.1 Molecular markers

Large reductions in costs per data point are expected to continue, given the trend over the past few years and the new technologies for high throughput marker screening that are in the pipeline. Although the cost per data point will decline, numbers of markers screened will rise, and the costs of the equipment required will almost certainly remain high or even increase. The unit cost reductions for marker screening overall are likely to be closely related to throughput.

For markers, whole genome screening, albeit at a generally low marker density, is already feasible for some species and it is probable that assay systems that determine genotypes at 10,000 loci simultaneously will become available. This is already feasible for human and mouse genetic studies as well as several species of livestock (notably cow, chicken, pig) and, in the private sector, for maize and soybean. Preliminary public sector projects in crops are also underway towards routine screening of 500-10,000 loci. All future truly high throughput assay systems are likely to be based around SNP (Single Nucleotide Polymorphism) detection techniques and require large genomics resource bases. This may appear to limit access to these new systems to the major species of study but large reductions in sequencing costs are also expected over the next few years so it is reasonable to assume that it will be possible to generate large EST (Expressed Sequence Tag) or genomic sequencing databases at increasingly lower cost and faster speeds. However, as the development of marker technologies can be species specific and related to the level of available resources, it is also probable that a series of "transition phase" technologies, probably SSR (Simple Sequence Repeat) or STS (Sequence Tagged Sites)-based, will still be required to carry less developed species through the early stages of marker implementation.

The rapid advances in DNA sequencing technology will lead to many more whole genome sequences becoming available. Indeed it is possible that genome sequences will be available for most major crop, livestock and fish species. This will underpin the development of broad scale screening capabilities and increase options for whole genome analysis. It is possible that sequencing costs will even drop low enough to allow many lines or varieties within a species to be sequenced and we may move to a position where full sequences are available for most key breeders' lines. For less well studies crops these developments should make it possible to move directly to creating a large-scale SNP-based screening platform. Comparative genomics is already playing an important role in identifying targets for development of vaccines and diagnostics in livestock and fish and will increase in the future as more genomes are sequenced.

The reduction in marker screening costs and the availability of whole genome screening capabilities will allow large numbers of lines to be assessed. This will drive a change in breeding strategies from analysis of specific loci to an assessment of the entire genome and a consideration of background genome effects. Therefore, a consequence of the high marker density will be the possibility for breeders to screen for recombination events in specific chromosome regions and to target specific epistatic and heterotic effects in the breeding process. These changes may necessitate an increase in the sizes and nature of populations being developed in the breeding programs. In any event breeding protocols and optimum population sizes at different generations will change with the incorporation MAS at any level. Modeling or simulation of molecular breeding strategies will provide a critical link in this process. However, access to appropriately trained and skill staff will also be crucial.

Finally, the continuing development of platforms for gene expression profiling at the mRNA, protein and metabolite levels can be expected to open the option of screening based on expression information. Integration of genomics markers with comparative mapping and gene expression analysis is already giving insights into mechanisms of disease resistance in many species. Links and collaborative projects with ARI's is likely to be critical in accessing and applying these types of technologies.

4.2 Transgenics

The major limitation to widespread adoption of transgenic crops and animals lies in the poor consumer and governmental acceptance. Although this is not expected to remain a problem over the next ten years it is unclear when general acceptance will occur. For several CG Centers it is seen as important to retain a capacity in the development of transgenic germplasm and in brokering access to the necessary genes and technologies.

However, it is expected that the current dominance of the commercial sector in transgenics for the major crops will remain and several donors are beginning to actively support this by a pro-public-private sector partnership approach. Nevertheless, there has been increased activity in public research institutes in developing countries to develop transgenic organisms and Centers may link with these initiatives. Activity in the Centers is expected to focus on crops or traits not covered by the private sector. The high regulatory costs and costs associated with food safety testing may prove a major impediment to the timely delivery of transgenic crops and animals. It is important to remember that the level of investment by the commercial sector in specific species and specific traits is very large compared to the public sector where not only are many species being tackled but also a large diversity of traits. Links to the private sector will be valuable in accessing suitable technologies, genes and supporting some of the regulatory costs and procedures. However, we should also not underestimate the collective scale of research being carried out in the public sector. Where effective coordination has occurred, significant advances have been achieved.

4.3 Other delivery mechanisms

While molecular markers and transgenesis are the most widely advocated directions of application of genomics tools, it is important to remember that these technologies have the potential to enhance our understanding of a wide range of features of an organism's behaviour, both in isolation and within a population. We can therefore expect to see increasing implications of genomics technologies for environmental management and in characterising and conserving biodiversity.

5. Nature of infrastructure required to meet predicted needs.

5.1 Molecular markers

If the rate of technology development and application continues to differ between species, it is likely that the high throughput equipment requirements will also vary. However, if universal platforms do become available there may be some commonality. It is certain that the preferred technologies for marker detection will continue to change rapidly and costs will continue to plummet. Consequently there is a very real danger of the Centers being trapped with outdated and obsolete equipment. It is also important to note that the new developments in equipment for marker detection have focused on high throughput and low cost per data point. Most centers have already moved from flat-bed gel detection methods through to the use of multi-channel capillary systems in recent years. Platforms based on microarrays, fluorescent particle sorters and mass spectrometry are now gaining momentum and are likely to dominate marker screening within a few years.

The high equipment costs and the need for high usage at high throughput to justify these costs and to keep operating costs low will drive centralization of marker screening facilities or a general move towards outsourcing. However, it is still expected that Centers will require access to internal and/or low and mid- throughput molecular laboratories for marker development and validation and continued research on marker-trait associations. The centralized facilities are then likely to provide the high throughput screening needed by the breeding or genetic resources programs.

It is also hoped and expected that commercial service providers will continue to expand into this area. Ultimately, service providers are expected to represent the most efficient method for ensuring widespread access to marker screening and to keep costs low by supporting many high throughput requirements. Commercial service providers will be particularly important for providing DNA sequencing capabilities and for offering a variety of SNP detection platforms. Service providers could even develop as "spin outs" from Center programs providing routine services to Centers, NARS and others. These could have access to new developments coming out of the Centers' research programs. They could also interact with Centers in delivery of training programs.

An advantage of commercial service providers is that they would provide a commercial focus to activities and help ensure efficient service provision and accountability. This is not the ultimate area of expertise or interest of Center staff. The use of service providers should also help address problems of trouble shooting, maintenance and repairs to equipment that can be expensive and difficult to access at some sites. The service providers would need to address the issue of ensuring timely delivery of results to remote facilities and of transfer of biological material between sites. There is, of course, the danger that commercial service providers would focus activities on species and breeding programs where there was high turnover and greater opportunities for profit than those presented by species for which there was only a small breeding or genomics community. This will need to be closely monitored but demand across multiple species from Centers, their partners and collaborators should help ensure sufficient business to maintain efficient service provision. The service providers could offer a wide range of assays and the breeders identify which assays were required with the samples they send in for analysis.

In addition and in partnership with service providers a set of service Hubs could be developed that would not necessarily have "state-of-the-art" equipment but would have capabilities to act as learning centers for teaching and would have procedures in place to ensure access to "state-of-the-art" equipment. For commercial service, providers it may be necessary to pay for access to suitable training courses. These Hubs could be located within Centers to provide regional support and act as a source for intellectual input into breeding programs and other biotechnology applications both within the Centers themselves and also within NARS.

An example of such a Hub is the *Biosciences eastern and central Africa* genomics and bioinformatics platform that is being established at ILRI, Nairobi. This platform will serve as a hub for eastern and central Africa, including CGIAR Centers in the region and national research institutes and universities. South Africa is also developing a similar platform to serve southern Africa. Both these platforms were developed in Africa, and they could serve system wide needs in Africa, and partner with other players not yet involved.

With an effective service provision network and a series of regional Hubs, the Centers would focus their activities on the interpretation and integration of genomics data, plus, developing and validating new molecular breeding strategies. Increasingly they will not necessarily be directly involved in the technology nor actual data generation at every level but will play an increasing role in coordinating the overall system.

In this scenario there would remain a need for NARS to have access to well-established molecular laboratories to allow them to conduct preliminary analyses, undertake preparation of samples that are sent for analysis, and for interpretation and utilization of the data, in order to obtain maximum benefits from training and advice provided by the Hubs.

5.2 Transgenics

It is considered important that Centers develop and retain capacity to generate and evaluate transgenic organisms. However, this may also become a sphere of activity for service providers as has already happened for some species. A change in community acceptance of GM crops and animals will necessitate a rapid response from Centers even though there may appear to be limited scope for exploiting GM organisms at present. CG breeding programs must prepare themselves for breeding with transgenic materials from a variety of sources. One option may be to establish a transgenic facility, particularly for field testing, in a country or region with a long history of field evaluation of GM. Such an option will require serious consideration of issues such as intellectual property and international transport issues for GM materials.

However, the regulatory issues surrounding transgenic crops and animals will require attention. The Science Council biosafety study of 2004 made a series of useful recommendations including the proposal that the CG Centers should pay attention to regulatory issues and costs early in the research process.

Centers may also need to maintain research capabilities in the development of transformation protocols for orphan species and for the discovery of genes controlling traits that may be of major importance to some communities but unlikely to attract the attention of other organizations.

Centers should also ensure that they have access to a capacity for rapid phenotyping and genotyping of transgenic organisms, again possibly through access to field resources in a country with a long history of field evaluation of GM organisms. Should GM technology and its products become widely used, it is highly probable that careful checking and monitoring of transgenes will be a high priority. The phenotypic evaluation of transgenic organisms should include a capacity for transcript, protein and metabolite profiling. This activity could well be provided by external groups of service labs.

6. Mechanisms for ensuring access to genomics infrastructure

Four strategies are proposed to help accelerate the development of effective methods for accessing facilities, capabilities and information needed to deliver genomics outcomes.

1. Options and roles for service providers are described above. In practical terms a group will need to take responsibility for helping to establish new service providers or to negotiate with existing groups or organizations to develop and deliver the most appropriate service. This is probably best done by arranging common species groups to facilitate negotiation with possible service providers.
2. Access to information and data on marker systems, genes and technologies requires the enhancement of bioinformatics capabilities. These should be established to improve use of data and help shift emphasis from data generation to data utilization.
3. Training programs in genomics technologies, particularly marker training programs, should shift their focus to the use of technology rather than on the technology itself. This will require careful revision of current courses.
4. It is important to identify high priority targets and use these to demonstrate effective outsource strategies. Centers should lead by example through demonstrating effective outsourcing of certain capabilities.

7. Delivery of genomics outcomes

A clear path and mechanism for delivering the products from the applications of genomics to farmers is required. In many cases, the key delivery path is likely to be from Centers to NARS and SMEs to farmers. The path(s) will need to consider issues of germplasm supply and distribution and where necessary, intervention may be needed to ensure effective flow. It is also important to allow for the wide differences that already exist in the capabilities and resources of NARS and private sector breeding programs. The role of the Hubs in technology delivery will require tuning to the needs of individual NARS and SMEs and their client farmers.

It is possible that there will be shifts in the relationship between the groups involved in the delivery over time. Initially, the Centers are likely to have to play a lead role in not only the technology development but also in the delivery. The concept of technology development here is largely directed to transferring technologies that have been established in model or well studied species to less-well studied and more challenging species of importance to Centers. It is unlikely that Centers will be directly involved in adapting and translating the base technologies which are now largely carried out in highly specialized laboratories. Over time, this role will move more to germplasm development or pre-breeding with the NARS and SME focused on adaptive breeding, and, development and release of finished varieties. As the technology becomes widely adopted and forms an integral component of the NARS breeding programs, the Centers will be able to move more into technology development, focus on using the molecular information to devise new breeding strategies, identify new marker-trait associations, investigate key issues of genome behaviour and help solve complex genetic problems that can help increase the speed and sophistication of the germplasm development work in the Centers and the varietal development in the NARS. As quickly as possible the NARS and SME need to become involved in the development and validation of new breeding strategies with the Centers helping to catalyse this process and feeding in new developments. Again the speed and nature of these role shifts will vary depending on the technology status, the species and the capabilities of individual NARS and SMEs. In several cases (for example in India, China, South Africa, Brazil) the NARS and SMEs already have strong capacity in both the technology development and deployment.

8. Addressing current limitations to the use of genomics

The key limitation to an effective use strategy will be the strength of breeding capabilities in NARS. For some species and NARS, neither the infrastructure nor intellectual capacity is in place to allow effective use of genomics technologies. Consequently, the bottleneck for use may, in many cases, be the capacity and speed of NARS breeding programs. Centers should retain their emphasis on plant breeding training and adopt integrated breeding strategies in collaboration with NARS breeding programs. This problem can be partially addressed through new training programs, development of networks and collaborative groups to share knowledge and expertise and help with problem solving, and through provision of incentives for technology adoption. The Hubs and existing partnerships will play a key role in this aspect and should favor the development of efficient delivery plans. However, regional coordination across crops, institutions and sectors will be a critical element for success of the model.

Strengthening the breeding and delivery capacity in NARS will also help address several other problems that have tended to hamper biotechnology and product delivery in the past. Of particular importance is ensuring that the technology is delivered to farmers in well adapted and readily accepted lines. Conversely, information on the best lines to use for transgene backcrossing is most likely to be provided by NARS scientists, small to medium-size companies and farmers. Bottlenecks to the efficient delivery of improved varieties, such as weak extension or seed systems, must also be anticipated.

Close involvement of NARS scientists in the Hubs and networks that encompass delivery strategies including seed and regulatory systems would engage these scientists in the biotechnology programs and help allay some concerns that may exist on the nature and value of the technology. Strong linkages between the technology developers and breeders, through the Hubs would also provide stimulating scientific discussion and raise awareness about advances in breeding methodologies. This would help stimulate interest in the use of biotechnology in plant and animal breeding as a challenging scientific endeavor and help address the decline in the number of young scientists moving into breeding. The association between Centers and NARS scientists through the Hubs will also help provide feedback on key targets for gene discovery and marker development. This will help ensure that work is targeted to major problems.

For many species it is predicted that the applications of marker aided selection will shift from single gene traits to more complex genetic systems and then to whole genome analysis. This shift will be particularly challenging for scientists who have not had the opportunity for close involvement in the development of the technology. The Hubs will be crucial in helping to drive this transition.

Finally, in organizing and managing the Hubs it will be important to consider any rivalries or competitions that may exist between NARS or other groups.

The following three key issues need to be addressed.

1. Ensuring access to training, service provision, data, tools and data analysis capabilities - Information access will be crucial in addressing current limitations to technology delivery. An information management system will be needed that is usable across Centers and NARS. The key criteria will be provision of a system that provides simple and user friendly data entry, retrieval and analysis tools. Ideally the system should comprise both a database integrating all types of data and a series of data interpretation and decision-support tools.

2. Develop strong linkages to end-users via germplasm distribution businesses - Interactions with SMEs for germplasm business should be primarily through NARS but may also be directly with Centers. These SMEs should also have access to Hubs; albeit on an appropriate cost recovery basis. In many cases it will be critically important to help build or stimulate development and capabilities of the SMEs. This could be done by giving priority to targets in the development of varieties containing genes likely to build market and technologies that will support a strong SME industry for seed distribution. In return the SMEs should be required to provide feedback to the NARS and Center programs, via the Hubs to ensure that germplasm well accepted by the end-users is used to deliver products. They should contribute as full community members regarding information flow in both directions and their role in validation and optimization should not be underestimated.

3. Generate ownership of genomics technologies for Center and NARS breeders - There is a need to increase involvement of breeding programs in genomics programs. Breeders from

both Centers, NARS and SMEs should be involved in early decision making for genomics programs to help ensure genomics groups are addressing real issues identified by end-users. Again the Hubs can provide the key mechanism for this process. The Hubs can also work with NARS programs to develop succession planning strategies and stimulate broader interest in breeding. This would involve development or re-vitalization of breeder networks as a core component of the Hubs. The objective will be to develop dynamic and innovative breeder and biotech communities; molecular breeding communities of practice. A component of the process would be the development of incentive systems for breeders to reward those who show innovation in technology adoption and for encouraging out-sourcing of genotyping. Biotechnology staff should be strongly encouraged to accept responsibility for the delivery of their work and should take leadership in tracking and mentoring the technology through to delivery.

9. Accessing new genomics technologies

9.1 Role of Centers

The cutting edge of technology development for marker screening currently lies in the medical area and this is likely to remain at the forefront; for example the use of mass spectrometric methods for SNP detection. However, cutting edge science can occur at several levels along the product development and delivery path and it is considered important that Centers focus on activities where they will have the greatest impact and where breaks or weaknesses exist along the product development and delivery path. Similarly it is important that Centers have access to the latest developments and are not relegated to using outdated and inefficient technologies. The out-sourcing and alliance model will help prevent this relegation from happening.

Genomics technologies are evolving rapidly. Techniques and equipment bought today will be out of date in two to five years. In well researched and resourced species, Centers will be able to conduct research more in the application areas than in the development of technologies; while in poorly researched species, Centers will need to lead the path of technology development and application. This leadership is likely to involve a major advocacy role to encourage ARIs to work on these species. Certain targets, such as some nutritional traits, will require research or strong advocacy from Centers. The recent substantial funding of biofortification of staple crops by the Gates Foundation shows that there are interested parties in the ARIs.

As elsewhere, the role of the Centers in biotechnology will need to be carefully and continually reviewed to ensure Centers are not competing with NARS and ARIs but developing approaches that promote partnerships. In particular Centers should be positioned to act as "technology champions". This will involve providing up-to-date training and remaining skilled in the application of the latest technological developments.

A formal group, such as the CGIAR Genomics TF, will provide a good vehicle for providing this oversight.

9.2 Gaining access to the latest developments

Access to some technologies can be achieved directly through the service providers where they have sufficient scale and scope of activities. However some technologies may be proprietal, particularly in the transgenic area. Negotiations with private sector and ARIs can be complex and time consuming. It will be necessary to develop and strengthen negotiation capabilities and establish processes for broad technology access. Some mechanisms already exist with the CG system and related programs to develop such linkages, such as in the Challenge Programs. However the capacity could be expanded by ensuring information on capabilities, requirements and opportunities, flows from the Hubs and the Genomics TF to the negotiation groups about the types of technologies required and the ways in which they could be deployed.

A centralized database providing details of what technologies are available, information on restrictions or conditions of use, information on unsuitable or poor technologies, and key contacts would be valuable and such a list is being compiled by CAS-IP.

Links with the multinational corporations will be highly beneficial in this process not only to access new technologies but also to obtain information on technologies or approaches that have failed. Such information is valuable in avoiding investment in failed approaches.

Mechanisms need to be established that provide broad access to technologies and it will be important to avoid creating exclusive groups that may restrict access. This can be an issue when collaborations are established between Centers and private sector or ARIs. Wherever possible the negotiators should seek to gain access for all Centers and freedom to circulate information on the technology and its application throughout the System and to partner NARS.

Collaborations with publicly funded groups in developed countries should be considered as a strategic approach to obtain access to rapidly changing and expensive genomics technologies.

A more comprehensive treatment of access to third party IP by CGIAR scientists will be available from the joint SC-GRPC commissioned studies to be published later this year.

9.3 Role of Centers in accessing technology

In negotiating access to technologies and developing collaborations with organizations involved in technology and resource development, Centers need to be clear on what they have to offer in exchange. Six capabilities of Centers were identified that could be used to leverage access to technologies:

1. Germplasm in the broad sense. Accessions of landraces, wild relatives, breeders' lines and cultivars. Also mutant populations and a wide range of specialized genetic and cytogenetic stocks.
2. Knowledge and capability for working in many countries under a wide range of cultural and regulatory regimes.
3. Broad experience of commodities and regions to act as unbiased brokers of collaborations between NARS and with ARIs and commercial groups.
4. Leadership in specific research areas and aspects of technology development. For example, through coordination of germplasm resources, mutant and tagged populations, etc.
5. Phenotyping capabilities. It was noted that this is declining in some Centers. This could be addressed by developing communities or networks focused on specific problems.

Strong phenotyping will also allow Centers to help identify and define important biological problems for research in ARIs.

6. International breeding programs. This goes beyond only phenotyping to include developing and providing early segregating populations to NARs and others in most cases but also providing almost near-finished material where the national breeding programs are less developed.

9.4 Attracting and retaining highly skilled genomics staff

Any strategy for technology delivery will be dependent upon the skills, capacity and motivation of staff. It is recognized that high quality staff with training in genomics and practical plant and animal improvement are in rare supply. This applies at all levels, research leadership, scientific and technical staff. Mechanisms must be implemented that attract and retain the best possible staff. The issues of staff retention can be particularly significant in some countries hosting Centers where there are few options for long term alternative employment. Under these circumstances staff frequently seek more secure positions in other countries.

However, Centers do offer scientists the advantages listed above and these aspects should be publicized during recruitment. These advantages can be enhanced by involving staff in broad programs with diverse expertise and wide ranging opportunities for research. The utilization of Hubs and retention of clear focus will help to build critical mass for particular activities. The possibility of allowing staff to work across several Centers is also worth considering.

In addition to the Hubs, technology and delivery networks should be established to help integrate staff in broad research groups. The concept would be to build technology and delivery communities. A range of additional options should be explored to improve incentives for key staff. These could include:

1. Use of linkages to ARIs through targeted funding regimes such as the USAID linkage program and support for post-docs.
2. Longer term contracts for key staff and improve staff training options.
3. Commercial linkages to engage scientists in industry research and vice versa as is being promoted through the SKEP initiative.
4. Develop recognition systems that reflect CG objectives and targets and use this to raise the international profile of staff, such as providing opportunities and encouragement for staff to present work on delivery successes at international meetings.
5. Overall there is a perceived need to raise the profile of CG Centers through improvements and modernization of publicity material, particularly WebPages.

10. Actions (Recommendations):

Differing genomics technologies will follow differing paths for delivery to breeding programs. Several technologies, such as genotyping, sequencing, proteomics and metabolomics will be most appropriately delivered through service providers. Several options exist for ensuring the effective and timely development of such providers where they do not already exist. Centers should collaborate in the establishment of such service providers and help set an example to NARS and related organizations for outsourcing.

1. The "CGIAR Genomics Taskforce" should be reestablished and a Chair, and possibly an Executive, appointed. The roles and responsibilities of the TF are outlined below.
2. The first objective of the TF is to articulate the broad strategy for the delivery of genomics technologies by the CGIAR Centers over the next ten years. To this end the TF will work closely with NARS genomics researchers and NARS and CGIAR breeders and GR researchers. This document should establish a series of key objectives that demonstrate the value of molecular technologies for addressing simple and complex traits and germplasm characterization. These would be developed as models for technology delivery. They could be, for example, a set of key traits for a small number of commodities that could be developed as technology application "Flagships" objectives.
3. The involvement of breeders and other scientists from the Centers and NARS should be consolidated through the re-establishment or enhancement of breeder networks. During the initial phases, it would be useful to define a set of priority traits that could be integrated through pre-breeding programs and delivered to NARS as well defined packages. This is likely to involve only a few traits initially.
4. The TF will identify and collaborate with potential service providers to explore options for outsourcing specific technologies. It may be possible to embed Center or NARS staff within a service provider to access critical mass and capabilities. It could be a role of the Hubs to form a close association with specific service providers and provide regular reviews and assessment of breeders needs to the service providers and regular reports on the effectiveness and capacity of the providers to breeders. The Hubs could also investigate and help organize transfer of materials to ensure timely delivery of results. The TF should develop a database summarizing resources and service providers that will act as a corporate memory as experience is gathered. An example of the type of information that could be included is shown below. The TF would help lead and coordinate development and maintenance of the information in an easily accessible format.

Service	Provider	Cost	Capacity	Comments
DNA sequencing	Company X	$2 per run	Unlimited	Provide good quality sequence of around 500 bases
Chickpea transformation	Lab Y, University of Y	No charge if part of a collaboration	3 gene per year	Can be slow.
Genotyping	Company Z	Depends on species and assay	Unlimited	SSR primers available for cattle SNP platforms for wheat
Whole genome SNP haplotyping	Company A	$50 per genotype	Unlimited	Turnaround time for big projects may not be quick enough for breeders decision window

5. The TF should design and articulate the need and role of training hubs for breeders and other staff - these should be equipped to carry out experimental design, diagnostic and marker validation to reflect what would be available in NARS laboratories but they would not need state-of-the-art high throughput facilities. They should also focus training on experimental design, breeding strategies and data interpretation and use rather than the technology or data generation itself. The training should also help teach how to use the large datasets that may be generated and integrate high throughput data generation with decision making in the breeding programs. The Hubs should help build intellectual capital, evaluate service providers and negotiate access and could be "virtual". The Hubs would probably work regionally to provide information, help with problem solving, develop and maintain networks of breeders and researchers and help broker linkages and collaborations. The Hubs should be at the "cutting edge" of technology application in breeding programs but not necessarily at the "cutting edge" of technology development.
6. A further role of the TF should be to champion the development of software that will find application throughout the System and partner NARS. It is recognized that several programs have been established to enhance data capture and utilization for many target species. However, there is scope for improving the utility of databases and data management tools to support and encourage use of genomics data by breeders. This needs to reinforce the shift to data analysis rather than data generation and could link to the comprehensive crop information system. The bioinformatics systems will need to cover

both molecular, breeding and genebank data. There will need to be "top-down" policy to develop and use the platforms based around common (broad compatibility) and linked systems.

7. TF members should seek out and enhance "brokering" capability across Centers to develop collaborative research activities between Center and national programs and with ARIs or the commercial sector. Several possible structures exist as models for such a system including the Challenge Programs. The Genomics TF should act as advocates for the capabilities in the Centers and negotiate involvement of Centers in international and national research funding schemes.
8. The Genomics TF in collaboration with Centers should play a leading role in the establishment of international collaborations and networks in developing and accessing key genomics resources, such as mutant populations, large scale sequencing, and development of expression databases. The capabilities that Centers have to contribute leadership and access to germplasm and phenotyping capabilities should be exploited. This will require a clearly definition of these capabilities.
9. The Centers should also explore options for strengthening existing phenotyping capacity through establishment of phenotyping or technology communities across Centers. The phenotyping capabilities of Centers offer a significant attraction for ARIs to establish joint projects. Experts in Centers can provide strong biological focus to research activities in many ARIs and they could also help broker linkages to phenotyping capacities in NARS. In developing this role Centers must remain aware and where possible integrate into the many non-CGIAR initiatives and networks in both mandated and other species. Although Centers do not need to join all such networks they should explore opportunities for sharing data and experiences and help develop global groups to ensure coordination and interaction.

And finally a recommendation to the CGIAR System;

10. An incentives scheme should be developed that will help drive technology adoption. For breeders the objective would be technology adoption while for the technologists the incentives would to reward technology validation, delivery, tailoring and mentored operation. The scheme should also identify and remove impediments to technology delivery. In this context it would be valuable to identify "technology champions" and to develop a system for quantifying and recognizing significant contribution to technology delivery and adoption. The scheme would require clear definition but could offer increased allocation of funds and resources, new training opportunities or special acknowledgement at the system level. Both the breeders and technologists would be expected to have clear product development and delivery plans. The technology mentoring may extend to advocacy of the technology but the TF must be seen to be strategic and self-critical and not technology-driven per se.

11. Explanation of the roles of the "Genomics Taskforce", the "Hubs" and the "Networks"

11.1 "Genomics Taskforce"

The key role of the Taskforce will be as an advocacy and planning group operating both within the CG system and with external organizations and funders in the area of plant and animal genomics. In consultation with breeders, biotechnologists and others, the Taskforce will also:

- Devise and advocate a detailed model and operating plan for the delivery of genomics technologies and results to plant and animal improvement programs;
- Act as a steering committee for the product development and delivery model and monitoring the operating plan;
- Coordinate genomics related research activities across the CG system and with key NARS and ARIs;
- Conduct and maintain a detailed analysis and inventory of genomics related work within Centers and associated programs and lead negotiations for effective and efficient service provision to address these requirements; and
- Provide leadership in the design and development of optimal genomics-based breeding strategies.

Taskforce composition:

The composition and activities of the Taskforce must be consistent with the rules and process within the CGIAR system.

It is suggested that each Center be invited to provide a representative to the Taskforce. Other groups may also be invited to provide representative to act as advisors to the Taskforce. These groups could, for example, include the Challenge Programs. In designating staff to join the Taskforce, Centers should acknowledge that the Taskforce will have a large, complex and potentially time-consuming role in ensuring effective delivery of genomics technologies.

11.2 "Hubs"

The key role of the Hubs will be to ensure regional access to technologies and expertise in the area of genomics and genomics related-breeding strategies. Within defined geographic regions the Hubs will:

- Devise and deliver training programs;
- Facilitate technology and service access;
- Raise awareness of genomics information, technologies and applications; and
- Provide transitional support for NARS and other groups to help them develop and use new technologies.

The Hubs may also negotiate technology access and service provision within their target region. In this role they will liaise closely with the "Taskforce to provide information on regional needs and impediments to technology delivery.

11.3 "Networks"

The key role of "Networks" will be to ensure the latest relevant information on genomics developments for particular commodities are accurately relayed to relevant end-users of the technology.

In addition "Networks" will:

- Organize specialist workshops and training sessions in collaboration with the Hubs; and
- Bring together groups to tackle specific problems or issues that can best be resolved through cooperative action.

The "Networks" will be commodity focused with a global role or regionally focused around Hubs. They could build upon existing activities within Centers but would bring in expertise and strategies on genomics-assisted breeding methodologies and focus on outcomes of technology application.