I recently came across the title of an opinion piece that I thought I should read. “What genes make a tree a tree?” was published in the May, 2005 issue of *Trends in Plant Science* by Andrew T. Groover. A decade ago I would have passed over this title without notice. But the Arnold Arboretum has recently put forward a plan to make a major investment in molecular and genomic approaches to research on the biology of woody plants and this research will call upon the resources of our living, herbarium and library collections. It will also cost a lot of money. Because the Arnold Arboretum receives no funds from the University (we are financially self-sufficient, depending almost entirely on past and present philanthropy), a large invest-
ment in research presents a major financial challenge to the institution. Let me discuss collections-related research in more general terms first, and then return to those genes that make a tree a tree.

Over the past couple of decades, directors of many botanic gardens and arboreta, especially those associated with colleges and universities, have wrestled with the question of the role that research should play in their institution’s mission. In part this reflects the historical roots of botanical collections gathered and curated as a basis for advancing knowledge of the botanical world and as an important foundation for economic advancement and commerce through the development of new plants. At modern research universities, the substantial budget allocations once enjoyed by botanical collections have increasingly come under scrutiny by the administration as the research use of those collections, particularly living collections, has shrunk in importance. Likewise, the availability of external research funds from federal agencies to support the use of living collections (to say nothing of their upkeep) is non-existent. In many public gardens and arboreta, the purposes of the living collections have expanded to include educational and horticultural display values which have surpassed any research use the collections may have once served. This leaves the fiscally conscientious director to ask: how important a role should research play in the mission of the organization?

Supporting a Research Function

For many institutions whose mission is fundamentally educational, supporting a research dimension confers great interest and legitimacy in the eyes of the institution's supporters. The investment required may be modest and the rigor of the research can be high if pursued systematically. The research can bolster the primary mission to educate and increase scientific literacy. But major research investments require a realistic assessment of what will be the cost of achieving long-term, high quality results as judged by publication in peer-reviewed journals. Most institutions are not well positioned to make such open-ended investments.
The proposed research facility on Weld Hill as designed by KlingStubbins Architects.

tal variables such as climate and soil chemistry. Depending upon the scope of the measured variables, and the quality and duration of the monitoring records, this can yield publishable information that constitutes valuable research. The creation of such formal programs can, but need not, require expensive equipment; rather, it requires a long-term commitment to the management and evaluation of data, and its subsequent publication. These days the web can be an excellent medium for providing inexpensive access to this information.

Beyond the gathering of data for the purposes of collections management, research investments are often motivated by the desire to discover unknown aspects of the natural world, by the application of existing knowledge to the development of improved horticultural plants
(stress tolerance, pest resistance, morphological variety, urban horticulture), or to the testing of specific hypotheses about the evolutionary history and functional biology of plant diversity. Whether an institution should invest in any or all of these types of research, and how much investment is appropriate, depend very much on the specific circumstances of that institution.

**Discovery Research**

Among large botanic gardens in this country that are involved in discovery research, the Missouri Botanic Garden and the New York Botanic Garden clearly stand out as leaders. Both institutions continue to mount major efforts in botanical exploration at multiple locations around the world, and this work is accompanied by significant publications in plant floristic and monographic research. The Arnold Arboretum, by virtue of its age and history, and in collaboration with other botanical institutions at Harvard University (the Gray Herbarium, the Botanical Museum, the Farlow Herbarium, the Oakes Ames Orchid Collection) maintains a modest effort in this type of research, and it will continue to do so in the future, with particular emphasis on the floras of Asia. Absolutely essential to this kind of work is the collection and maintenance of a large herbarium (over 5 million specimens at Harvard) and the related library collections (280,000 volumes, 900 current journals) without which such research would be impossible. In recent years, this type of research has been complimented at the Arbo-

*A well-laid out research collection can be enjoyed by people with little or no interest in science.*
return with molecular systematic studies utilizing its well documented living collections. Of particular interest are phylogenies that relate to our understanding of the biogeography and evolutionary history of the disjunct floras of eastern Asia and eastern North America.

**Improved Horticultural Plants**

The use of the living collections of a botanic garden or arboretum for the development of better plants for agricultural production, for landscape use in suburban and urban settings, and for improving basic mechanisms of stress tolerance and pest resistance has been closely tied to the land grant university system with its long history of support from the Department of Agriculture and related commercial sources. The research mission of botanical gardens within such a setting will always depend upon its relationships with various research departments (horticulture, crop physiology, plant breeding) and the idiosyncratic needs of faculty members and senior research scientists for the resources of the gardens. Directors of these gardens may feel captive to these academic sources of power and funding, and independent investment in research not defined by faculty needs and external funding sources can be politically risky. Of course, independent institutions outside the academic system of universities have much greater leeway to pursue problems of applied research of their own choosing.

**Evolutionary Relationships and Functional Biology**

Basic research into the evolutionary history and functional biology of plants has generally been less closely allied with botanical gardens than with academic departments of botany, biological sciences or ecology and evolution. On the face of it, the great diversity of the living collections of botanic gardens and arboreta would seem a particularly valuable resource for such research, especially for comparative experimental approaches to addressing functional and evolutionary questions about plants. Twenty-five years ago, my predecessor as director, Professor Peter Ashton, put forth a vision for the use of the living collections of the Arnold Arboretum to investigate basic questions of plant functional biology in an evolutionary context. At that time, however, Peter’s vision did not find fertile soil among his faculty colleagues and he was unable to implement it.

There are a number of challenges facing a director inclined to invest in such research. Generally large questions of this nature require the development of specific hypotheses about mechanisms and controls that can only be addressed through experimental designs using molecular, genetic, and biochemical approaches. This kind of research can only be done in a highly sophisticated laboratory setting with expensive equipment and protocols. Technical support is essential and, therefore, expensive. Senior research scientists usually establish large labs consisting of multiple technicians, post-doctoral researchers, undergraduate assistants, and several graduate students working on elements of the problem at hand. The research is highly collaborative, both within the laboratory setting and among different labs located at other institutions. Funding the research requires a continual flow of money, most often provided by the federal government through grants from organizations like the National Science Foundation. This system of funding is closely tied to the peer review system that dominates both the publication of results from such research and the advancement of faculty members through traditional ladder positions within university departments.

As this implies, the director of an independent botanical garden needs to think twice before embarking upon such research investments without having in place close working relations with an academic institution that can provide access to students and faculty resources. The investment in modern research laboratory and growing facilities must be of a large scale to attract the quality of researchers able to support their research through successful, peer-reviewed grant applications. Finally, an institution will want a critical mass of such researchers, at least five or six senior scientists, each capable of supporting a laboratory staffed with up to half a dozen technicians and students. The hiring
of each is usually accompanied by significant start-up requirements (laboratory equipment, laboratory assistance until the first grants are received). It is all a very expensive affair and it can’t be done in incremental steps.

**Investing in Research**

At the Arnold Arboretum, we are prepared to make such an investment. Ironically it will be very much based on the vision of research with the living collections articulated by Professor Ashton twenty-five years ago. How can such a vision succeed today if it was not able to do so two decades ago?

Two major advances in the biological sciences have fundamentally altered the context surrounding such a vision. First, the proliferation of molecular approaches to investigating the evolutionary history of organisms has dramatically altered our understanding of the phylogenetic relations among species. This new understanding provides a solid evolutionary foundation for the comparative study of the functional and developmental biology of closely and distantly related species. Second, with the sequencing of the human genome in the past decade, biological science has made tremendous advances in creating genetic and molecular tools for investigating basic questions about the functional and developmental biology of organisms. These tools have led to the subsequent sequencing of the genomes of the tiny herbaceous plant *Arabidopsis thaliana*, in the mustard family, and the first woody plant in the genus *Populus* as model species for the understanding of plant biology at the genetic and molecular level. Over the coming decade, the genomes of a number of other species will also be partially or fully sequenced, creating an immense opportunity for comparative studies of plant diversity.

To provide just an illustration of this, let me briefly return to the publication, “What genes make a tree a tree?” Woody stems, of course, develop from growth in the vascular cambium that is generated by meristematic stem cells whose daughters differentiate into the carbohydrate-conducting phloem and water-conducting xylem (wood). As Andrew Groover, the author of this article, points out, “trees” may be categorized at the local nursery as a group based on the presence of a woody trunk; but it is a completely artificial classification. Nearly all orders of higher plants in the Angiosperms contain tree-like species and many families have both herbaceous and woody species. Because woody growth is evolutionarily ancient and probably predates the divergence of Angiosperms and Gymnosperms, the appearance of woody taxa may be a matter of degree rather than a trait that has arisen uniquely within a single lineage. Even within a species, the expression of woody growth can depend upon environmental conditions. Not surprisingly, then, we find that woody species on remote islands have evolved rapidly from closely related, herbaceous ancestors on the mainland. Groover concludes that the genes regulating woody growth ought to be evolutionarily ancient and common to all taxa, ought to be present in a broad range of taxa including herbaceous species, and ought to be readily modifiable to express or suppress woody growth in the process of speciation or in response to changes in the environment.

With the sequencing of the genomes of the herbaceous species *Arabidopsis* and the woody species *Populus*, scientists can now determine whether woodiness in the latter species depends on genes not found in the former species. In fact, the same genes that regulate primary growth in the shoot apical meristem in *Arabidopsis* are also involved in the regulation of secondary growth in *Populus*. Thus these genes are probably present, but suppressed, in many herbaceous species. Tree forms therefore reflect differences in the expression of a similar set of genes that are present in a vast number of taxa. Woodiness—the genes that make a tree a tree—could be studied and artificially manipulated in almost any species. Groover argues that this fundamental understanding, and the genetic tools that have led to it, will usher in a revolution in approaches to increasing our knowledge of woody plants.

**The Arnold’s New Research Initiative**

I believe that these new approaches to addressing basic research questions about the evolutionary diversification of plants through a deeper comparative understanding of their functional
biology should be at the heart of the Arnold Arboretum’s research mission. At the same time, I do not believe that this should necessarily serve as a model for other botanical gardens and arboreta. The Arnold is in a relatively unique position because of several important factors. First, we have an exceptionally well-documented collection of woody taxa, many of known wild origin. Second, we are part of a university able to provide a constant stream of students (if not money) and a brand identity that can be immensely helpful in recruiting the finest scientists. Finally, a long history of philanthropy has created a substantial endowment able to provide a dependable financial foundation upon which to build new programs.

To staff this large investment in research, the Arboretum has created a new type of research position which we have named Sargent Fellows. We intend to recruit individuals of the highest quality as judged by their colleagues and permanent appointment will require rigorous peer review. Two Sargent Fellows are currently appointed. Sarah Matthews is an expert on the molecular biology and evolutionary history of the light sensing pigment phytochrome in plants, and Maciej Zwieniecki studies plant hydraulics, the micro-fluidic systems that control the long-distance movement of water, solutes and energy from roots to leaves.

In 2007, we will break ground for the construction of a $38,000,000 laboratory and greenhouse facility able to support up to eight senior researchers and their associates. This state-of-the-art facility will also serve to integrate the research efforts of our Sargent Fellows with those of faculty and students in Cambridge through common use of greenhouses, growth chambers and experimental gardens. This substantial investment will return the Arboretum to the forefront of basic research on the biology of trees. As Peter Ashton stated shortly after arriving as director in 1979, “Only if it maintains its preeminence in research and education can the Arnold Arboretum continue to develop its complementary function as a unique public amenity and an authoritative source of information on the culture of woody plants.”

Robert E. Cook has been director of the Arnold Arboretum since 1989. An earlier version of this article appeared last year in Public Garden, vol. 21, no. 1.