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Committee on a New Biology for 21st Century Ensuring that the United States Leads the Coming Biology Revolution

Board on Life Sciences

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Summary

In July, 2008, the National Institutes of Health (NIH), National Science Foundation (NSF), and Department of Energy (DOE) asked the National Research Council's Board on Life Sciences to convene a committee *to examine the current state of biological research in the United States and recommend how best to capitalize on recent technological and scientific advances that have allowed biologists to integrate biological research findings, collect and interpret vastly increased amounts of data, and predict the behavior of complex biological systems*. From September 2008 through July of 2009, a committee of 16 experts from the fields of biology, engineering and computational science undertook to delineate those scientific and technological advances and come to a consensus on how the U.S. might best capitalize on them. This report, authored by the Committee on a New Biology for the 21st Century, describes the committee's work and conclusions.

The committee concluded that biological research has indeed experienced extraordinary scientific and technological advances in recent years. In the chapter entitled "Why Now?", the committee describes the integration taking place within the field of biology, the increasingly fruitful collaboration of biologists with scientists and engineers from other disciplines, the technological advances that have allowed biologists to collect and make sense of ever more detailed observations at ever smaller time intervals, and the enormous and largely unanticipated payoffs of the Human Genome Project. Despite this potential, the challenge of advancing from identifying parts, to defining complex systems, to systems design, manipulation, and prediction is still well beyond current capabilities, and the barriers to advancement are similar at all levels from cell to ecosystems.

Having delineated the advances, the committee set about reaching an agreement as to how the U.S. could best capitalize on them. The committee was invited to use the following series of questions to guide its discussions:

- *What fundamental biological questions are ready for major advances in understanding? What would be the practical result of answering those questions? How could answers to those questions lead to high impact applications in the near future?*

- *How can a fundamental understanding of living systems reduce uncertainty about the future of life on earth, improve human health and welfare, and lead to the wise stewardship of our planet? Can the consequences of environmental, stochastic or genetic changes be understood in terms of the related properties of robustness and fragility inherent in all biological systems?*
- *How can federal agencies more effectively leverage their investments in biological research and education to address complex problems across scales of analysis from basic to applied? In what areas would near term investment be most likely to lead to substantial long-term benefit and a strong, competitive advantage for the United States? Are there high-risk, high pay-off areas that deserve serious consideration for seed funding?*
- *Are new funding mechanisms needed to encourage and support cross-cutting, interdisciplinary or applied biology research?*
- *What are the major impediments to achieving a newly integrated biology?*
- *What are the implications of a newly integrated biology for infrastructural needs? How should infrastructural priorities be identified and planned for?*
- *What are the implications for the life sciences research culture of a newly integrated approach to biology? How can physicists, chemists, mathematicians and engineers be encouraged to help build a wider biological enterprise with the scope and expertise to address a broad range of scientific and societal problems?*
- *Are changes needed in biology education-- to ensure that biology majors are equipped to work across traditional subdisciplinary boundaries, to provide biology curricula that equip physical scientists and engineers to take advantage of advances in biological science, and to provide nonscientists with a level of biological understanding that gives them an informed voice regarding relevant policy proposals? Are alternative degree programs needed or can biology departments be organized to attract and train students able to work comfortably across disciplinary boundaries?*

The committee found that the third bullet, "*How can federal agencies more effectively leverage their investments in biological research and education to address complex problems across scales of analysis from basic to applied? In what areas would near term investment be most likely to lead to substantial long-term benefit and a strong, competitive advantage for the United States?*" provided a compelling platform from which to consider each of the questions, and a robust framework upon which to organize its conclusions. Thus, the committee's overarching recommendation is that the most effective leveraging of investments would come from a coordinated, interagency effort to encourage the emergence of a New Biology approach that would enunciate and address broad and challenging societal problems. The committee focused on those opportunities that cannot be addressed by any one subdiscipline or agency—opportunities that require

integration across biology and with other sciences and engineering, and that are difficult to capitalize on within traditional institutional and funding structures. Fully realizing these opportunities will require the enabling of an integrated approach to biological research, an approach the committee calls the New Biology.

The essence of the New Biology, as defined by the committee, is integration—re-integration of the many sub-disciplines of biology, and the integration into biology of physicists, chemists, computer scientists, engineers, and mathematicians to create a research community with the capacity to tackle a broad range of scientific and societal problems. Integrating knowledge from many disciplines will permit deeper understanding of biological systems, which will both lead to biology-based solutions to societal problems and also feed back to enrich the individual scientific disciplines that contribute new insights. The New Biology is not intended to replace the research that is going on now; that research, much of it fundamental and curiosity-driven by individual scientists, is the foundation on which the New Biology rests and on which it will continue to rely.

Instead, the New Biology represents an additional, complementary approach to biological research. Purposefully organized around problem-solving, this approach marshals the basic research to advance fundamental understanding, brings together researchers with different expertise, develops the technologies required for the task and coordinates efforts to ensure that gaps are filled, problems solved, and resources brought to bear at the right time. Combining the strengths of different communities does not necessarily mean bringing these experts into the same facility to work on one large project—indeed, advanced communication and informatics infrastructures make it easier than ever to assemble virtual collaborations at different scales. The New Biology approach would aim to attract the best minds from across the scientific landscape to particular problems, ensure that innovations and advances are swiftly communicated, and provide the tools and technologies needed to succeed. The committee expects that such efforts would include projects at different scales, from individual laboratories, to collaborations involving many participants, to consortia involving multiple institutions and types of research.

The committee concludes that the greatest opportunity presented by the New Biology is its potential to provide solutions to major societal needs. In the chapter entitled “How the New Biology Can Address Societal Challenges” the committee describes four broad challenges, in food, environment, energy and health, that could be tackled by the New Biology. These challenges represent both the mechanism for accelerating the emergence of a New Biology and its first fruits.

1. Generate food plants to adapt and grow sustainably in changing environments
The New Biology could deliver a dramatically more efficient approach to developing plant varieties that can be grown sustainably under local conditions. The result of this focused and integrated effort will be a body of knowledge, new tools, technologies, and approaches that will make it possible to adapt all sorts of crop plants for efficient production under different conditions, a critical contribution toward making it possible to feed people around the world with abundant, healthful food, adapted to grow efficiently in many different and ever-changing local environments.

2. *Understand and sustain ecosystem function and biodiversity in the face of rapid change*

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Fundamental advances in knowledge and a new generation of tools and technologies are needed to understand how ecosystems function, measure ecosystem services, allow restoration of damaged ecosystems, and minimize harmful impacts of human activities and climate change. What is needed is the New Biology, combining the knowledge base of ecology with those of organismal biology, evolutionary and comparative biology, climatology, hydrology, soil science, and environmental, civil, and systems engineering, through the unifying languages of mathematics, modeling, and computational science. This integration has the potential to generate breakthroughs in our ability to monitor ecosystem function, identify ecosystems at risk, and develop effective interventions to protect and restore ecosystem function.

3. Expand sustainable alternatives to fossil fuels

Making efficient use of plant materials—biomass—to make biofuels is a systems challenge, and this is another example of an area where the New Biology can make a critical contribution. At its simplest, the system consists of a plant that serves as the source of cellulose and an industrial process that turns the cellulose into a useful product. There are many points in the system that can be optimized. The New Biology offers the possibility of advancing the fundamental knowledge, tools, and technology needed to optimize the system by tackling the challenge in a comprehensive way.

4. Understand individual health

The goal of a New Biology approach to health is to make it possible to monitor each individual's health and treat any malfunction in a manner that is tailored to that individual. In other words, the goal is to provide individually predictive surveillance and care. Between the starting point of an individual's genome sequence and the endpoint of that individual's health is a web of interacting networks of staggering complexity. The New Biology can accelerate fundamental understanding of the systems that underlie health and the development of the tools and technologies that will in turn lead to more efficient approaches to developing therapeutics and enabling individualized, predictive medicine.

Finally, in the chapter entitled "Putting the New Biology to Work", the committee proposes that a national initiative dedicated to addressing challenges like those described for the areas of food, the environment, energy, and health would provide a framework whereby the U.S. could best capitalize on recent scientific and technological advances. The committee recommends setting big goals and then letting the problems drive the science. It contends that interagency collaboration will be essential and that information technologies will be of central importance. Finally, the committee discusses new approaches to education that could speed the emergence of the New Biology, and provides examples of how a national initiative could spur the implementation of those new approaches.

A New Biology Initiative would represent a daring addition to the nation's research portfolio, but the potential benefits are remarkable and far-reaching: a life sciences research community engaged in the full spectrum knowledge discovery and its application; new bio-based industries; and most importantly, innovative means to produce food and biofuels sustainably, monitor and restore ecosystems and improve human health. To that end, the committee provides the following findings and recommendations:

Finding 1

- The United States and the world face serious societal challenges in the areas of food, environment, energy, and health:
- Innovations in biology can lead to sustainable solutions for all of these challenges. Solutions in all four areas will be driven by advances in fundamental understanding of basic biological processes.
- For each of these challenges, solutions are within reach, based on building the capacity understand, predict, and influence the responses and capabilities of complex biological systems:
- There is broad support across the scientific community for pursuing interdisciplinary research, but opportunities to do so are constrained by institutional barriers and available resources.
- Approaches that integrate a wide range of scientific disciplines, and draw on the strengths and resources of universities, federal agencies, and the private sector will accelerate progress toward making this potential a reality:
- The best way for the United States to capitalize on this scientific and technological opportunity is to add to its current research portfolio a New Biology effort that will accelerate understanding of complex biological systems, driving rapid progress in meeting societal challenges and advancing fundamental knowledge.

Recommendation 1

The committee recommends a national initiative to accelerate the emergence and growth of the New Biology to achieve solutions to societal challenges in food, energy, environment, and health.

Finding 2

- For its success, the New Biology will require the creative drive and deep knowledge base of individual scientists from across biology and many other disciplines including physical, computational and geosciences, mathematics, and engineering.
- The New Biology offers the potential to address questions at a scale and with a focus that cannot be undertaken by any single scientific community, agency or sector.
- Providing a framework for different communities to work together will lead to synergies and new approaches that no single community could have achieved alone.
- A broad array of programs to identify, support and facilitate biology research exists in the federal government but value is being lost by not integrating these efforts.
- Interagency insight and oversight is critical to support the emergence and growth of the New Biology Initiative. Interagency leadership will be needed to oversee and coordinate the implementation of the initiative, evaluate its progress, establish necessary working subgroups, maintain communication, guard against redundancy, and identify gaps and opportunities for leveraging results across projects.

Recommendation 2:

The committee recommends that the National New Biology Initiative be an interagency effort, that it have a timeline of at least 10 years and that its funding be in addition to current research budgets.

Finding 3

- Information is the fundamental currency of the New Biology
- Solutions to the challenges of standardization, exchange, storage, security, analysis and visualization of biological information will multiply the value of the research currently being supported across the federal government
- Biological data are extraordinarily heterogeneous and interrelating various bodies of data is currently precluded by the lack of the necessary information infrastructure
- It is critical that all researchers be able to share and access each others' information in a common or fully interactive format
- The productivity of biological research will increasingly depend on long-term, predictable support for a high-performance information infrastructure.

Recommendation 3

The committee recommends that, within the National New Biology Initiative, priority be given to the development of the information technologies and sciences that will be critical to the success of the New Biology.

Finding 4

- Investment in education is essential if the new biology is to reach its full potential in meeting the core challenges of the 21st century.
- The New Biology Initiative provides an opportunity to attract students to science who want to solve real-world problems.
- The New Biologist is not a scientist who knows a little bit about all disciplines, but a scientist with deep knowledge in one discipline and a "working fluency" in several.
- Highly developed quantitative skills will be increasingly important.
- Development and implementation of genuinely interdisciplinary undergraduate courses and curricula will both prepare students for careers as New Biology researchers and educate a new generation of science teachers well-versed in New Biology approaches.

- Graduate training programs that include opportunities for interdisciplinary work are essential.
- Programs to support faculty in developing new curricula will have a multiplying effect.

Recommendation 4

The committee recommends that the National New Biology Initiative devote resources to programs that support the creation and implementation of interdisciplinary curricula, graduate training programs and educator training needed to create and support New Biologists.

Publications

A NEW BIOLOGY FOR THE 21ST CENTURY: Ensuring the United States Leads the Coming Biology Revolution

ISBN:0-309-14489-2, 112 pages, 6 x 9, (2009)

Website: http://www.nap.edu/catalog/12764.html