THE NATIONAL ACADEMIES
REPORT IN BRIEF

A New Biology for the 21st Century

Now more than ever, biology has the potential to contribute practical solutions to many of the major challenges confronting the United States and the world. This report recommends that a "New Biology" approach—one that depends on greater integration within biology, and closer collaboration with physical, computational, and earth scientists, mathematicians and engineers—be used to find solutions to four key societal needs: sustainable food production, ecosystem restoration, optimized biofuel production, and improvement in human health. The approach calls for a coordinated effort to leverage resources across the federal, private, and academic sectors to help meet challenges and improve the return on life science research in general.

Imagine a world where food is abundant, the environment is flourishing, energy comes from clean, renewable sources, and good health is the norm. A collaborative, interdisciplinary approach to biological research—a New Biology—could contribute real progress towards these goals.

In recent years, boundaries between the sub-disciplines of the life sciences have begun to blur. Tools and concepts that arose within specialized fields are now applied throughout biology, revealing connections between the fields. For example, now that the genetic information for many organisms has been completely identified, researchers can compare the evolutionary development of species as diverse as fruit-flies and humans, uncovering the features shared by all living species and differences that make each organism unique. A specific example comes from research combining evolutionary and developmental biology. Evo-devo, as the new field is called, has demonstrated that the body plans of different animals result from different levels of expression of a "toolbox" of genes found in almost all life forms.

With new technologies and tools, biologists are moving beyond studying a single cell, genome, or organism, and are drawing closer to understanding the secrets of nature's engineering, from molecules up to whole ecosystems. Collaboration between biologists and scientists and engineers in other disciplines is helping to develop practical solutions to major challenges, such as interpreting the vast amounts of data generated by genome sequencing projects.

Despite the potential of these recent advances, there is still much to be done to move from identifying parts to defining complex biological systems. Furthermore, the systems design, manipulation, and prediction needed for practical applications such as ecosystem repair or individualized medicine, are still well beyond current capabilities. The report's authoring committee has developed the idea of the New Biology to provide a framework to connect biological research with advances in other branches of science and engineering.

To take advantage of the great potential the biological sciences offer, the National Institutes of Health, the National Science Foundation, and the Department of Energy co-sponsored this National Research Council report 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 will allow biologists to integrate biological research findings, collect and interpret vastly

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increased amounts of data, and predict the behavior of complex biological systems.

Rising to the Challenges

The report recommends focusing research efforts on critical economic sectors with many practical benefits––food, the environment, energy, and health––to which the New Biology could make important contributions. Each challenge is beyond the scope of any single scientific community or federal agency, and developing an effective strategy to tackle these concrete problems will bring diverse talent and resources together, providing significant momentum to the emergence of the New Biology.

The Food Challenge: Adapt any food plant to any growing conditions

Providing enough healthful food to feed the world's growing population is an enormous challenge, compounded by the fact that changing climatic conditions could alter temperature and rainfall patterns in coming years, altering growing conditions in the world's farmlands and even leading to flooding of low-lying fertile lands. Those challenges require an ability to breed crop plants with greater productivity, increased pest resistance, lower fertilizer and water requirements, and the ability to thrive under a variety of conditions.

Advances in genetic engineering and plant breeding in the last few decades have allowed substantial increases in productivity in a small number of important food crops, but breeding new crop varieties with desirable traits is still a long and expensive undertaking. The New Biology could deliver a more efficient approach by facilitating collaboration between geneticists, ecologists, and plant biologists to increase understanding of plant development and the array of naturally occurring traits that help some plants thrive in challenging environmental conditions. Improvements in genetic engineering and conventional breeding techniques, along with a greater understanding of the complex ecosystems within which crop plants grow, will help to produce crops that can thrive in changing conditions.

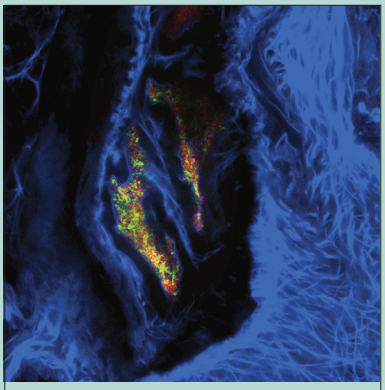
The Environment Challenge: Diagnose and repair ecosystem damage

Humans depend on ecosystems for everything from the bare necessities of life, such as food, oxygen and water, to the raw materials that allow human life to flourish, such as building materials, fuel and fiber for clothing. Ensuring that ecosystems continue to thrive in the face of rapid climate change is essential for human life, but current ecosystem monitoring activities are insufficient to spot problems or to provide the means to restore damaged ecosystems.

The Human Genome Project, and Beyond

The 2000 release of the draft sequence of the human genome was the culmination of a decade-long project and billions of dollars of investment—but in the end, far more was gained from the project that anyone could have predicted. At the beginning of the project, the technology needed to complete the task did not exist, so interdisciplinary teams of engineers, computer scientists and biologists worked together to develop new sequencing technologies. Today, these technologies are routine components of all genome sequencing projects, and have led to an exponential increase in the number of genomes that have been sequenced.

Low cost and high-throughput sequencing techniques have also helped to make DNA sequencing a useful tool in many unanticipated areas. A good example is the field of metagenomics, which involves sequencing the combined DNA of all the microbial inhabitants of a particular environment, such as a sample of soil or water. This provides insight into the previously hidden world of microbial diversity, important because microbes support the growth of plants, affect human health, are critical components of all ecosystems, and can be engineered to produce fuels—meaning that they can contribute to all four goals featured in this report.



Metagenomics can provide insight into microbial communities, such as these bioluminescent bacteria (red and green) that live on the mantle of the Hawaiian squid (blue), seen here using confocal microscopy. Image courtesy of Dr. Joshua V. Troll, University of Wisconsin, Madison.

The New Biology approach can help to sustain ecosystems by combining the knowledge base of ecology with other aspects of the life sciences and engineering fields to improve understanding of ecosystem function, implement an ecosystem monitoring system to track ecosystem change, identify ecosystems at risk, and develop effective interventions to protect and restore ecosystem function. The report suggests that this new field of study, combining basic knowledge about ecosystem function with problem solving techniques and grounded in both the monitoring and treatment of ecosystems, could be called ecosystem engineering.

The Energy Challenge: Expand Sustainable Alternatives to Fossil Fuels

World requirements for energy are expected to grow by about 60 percent by 2030, with much of the increase coming from rapidly developing economies such as India and China. While the majority of the current energy need is met by fossil fuels, the development of sustainable, efficient and clean sources of energy is crucial to reducing our dependence on and depletion of fossil fuels. In 2007, Congress called for the volume of renewable fuel required to be blended into gasoline to rise significantly by 2022. The program stipulates that a substantial fraction of the biofuel must be made from cellulose (the stalks and other structural parts of plants), instead of producing ethanol from the starch in corn kernels.

To produce cellulose-based biofuel, plants are grown as a source of cellulose, and an industrial process serves to turn the cellulose into fuel. The New Biology offers the potential to make the production of biofuel more economically competitive by approaching it as a systems challenge: one that brings together expertise from different sectors to select or breed plants that produce the most cellulose with the least input of fertilizers and water, to genetically modify plants to produce biomass more efficiently or produce cellulose that is easier to process, and to adapt microbial enzymes and metabolic pathways for the optimal conversion of cellulose into fuel.

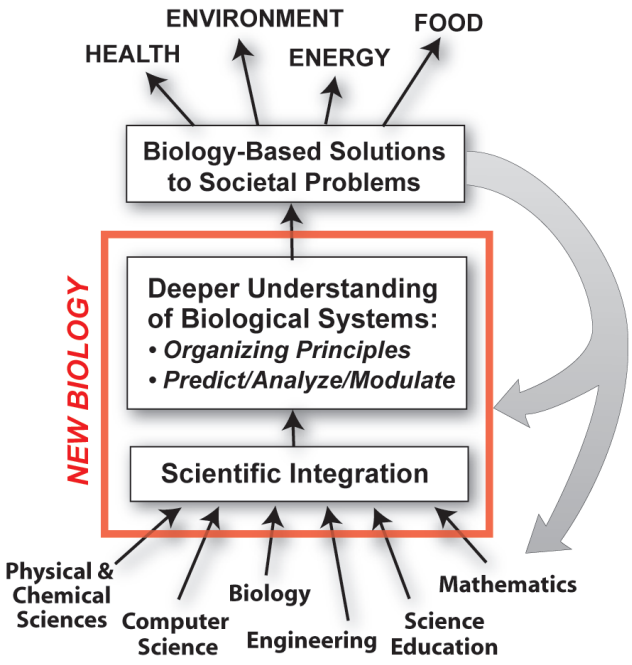


Figure 1. New Biology relies on integrating knowledge from many disciplines to derive deeper understanding of biological systems, allowing the development of biology-based solutions to societal problems, and enriching the individual scientific disciplines that contributed to the new insights.

The Health Challenge: Achieve Individualized Surveillance and Care

At present, medical decision-making is often based on probabilities; for example, high cholesterol levels are associated with heart disease and early-stage cancers metastasize at predictable rates. But not every case is the same: the spreading of a given tumor can occur with frightening speed in some people, and not at all in others, and some individuals with high cholesterol do not develop heart disease at all.

Although it will soon be economically feasible to sequence the genome of every individual, genuine understanding of the connection between an individual's genetic makeup and environmental history, and that individual's health risks, disease susceptibility, and response to treatment, is still well beyond current capabilities. Making sense of those connections will require understanding how environmental factors such as diet, exercise, exposure to sunlight, chemicals, viruses, and bacteria affects how an individual's genetic blueprint is executed. Increasing evidence shows that human health depends on the microbial communities that live on or in each human's body, so microbial genomes must also be taken into account in health analyses.

The challenge of truly personalized medicine will require a New Biology-driven research

community empowered by scientific and technical resources from across the federal government, the broad community of scientists, and the private sector to spur the conceptual and technological advances needed to monitor individual health and understand the roles that individual genetics and environmental history play on individual health.

Putting the New Biology to Work

To best leverage resources, the committee recommends establishing a New Biology Initiative to marshal the necessary funds and provide the coordination to enable academic, public and private sectors to address major societal issues. Building on the strengths and resources of universities, federal agencies, and the private sector, the New Biology would integrate a wide range of disciplines as necessary to meet the challenges laid out above. The committee makes the following recommendations for establishing the New Biology Initiative:

- The National New Biology Initiative will accelerate the emergence and growth of the New Biology to achieve solutions to societal challenges. In this report, challenges in the areas of food, energy, environment and health are emphasized, with the reasoning that establishing a bold and specific target spurs innovation to create unforeseen routes to the solutions. Setting big goals will lead to innovation as the problems will drive the science.

- This National Initiative should be an interagency effort, with a timeline of at least 10 years and funding in addition to current research budgets.

- Priority should be given to information technologies and sciences that will be critical to the success of the New Biology. The need remains for cross-cutting technologies and tools that would empower the New Biology, but a relatively small investment could reap enormous returns in each of the four challenge areas.

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

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This report brief was prepared by the National Research Council based on the committee's report. For more information, contact the Board on Life Sciences at (202) 334-2187 or http://dels.nas.edu/bls.A New Biology for the 21st Century: Ensuring the United States leads the Coming Biology Revolution is available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; http://www.nap.edu/catalog.php?record_id=12054

The National Academies appointed the above committee of experts to address the specific task requested by the National Institutes of Health, the National Science Foundation, and the Department of Energy. The members volunteered their time for this activity; their report is peer-reviewed and the final product signed off by both the committee members and the National Academies. This report brief was prepared by the National Research Council based on the committee's report. For more information, visit the Board on Life Sciences at http://nationalacademies.org/bls. Copies of A New Biology For The 21st Century are available from the National Academies Press, 500 Fifth Street, NW, Washington, D.C. 20001; (800) 624-6242; www.nap.edu.