A NEW BIOLOGY FOR THE 21ST CENTURY

Statement of

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Before the

Subcommittee on Research and Science Education
Committee on Science and Technology
U.S. House of Representatives

June 29, 2010

Good afternoon, Chairman Lipinski and Members of the Subcommittee. Thank you for the invitation to present a statement before you today. I am Keith R. Yamamoto, Professor of Cellular and Molecular Pharmacology and Executive Vice Dean of the School of Medicine at the University of California, San Francisco, and Chairman of the Board on Life Sciences of the National Research Council. The National Research Council is the operating arm of the National Academy of Sciences, National Academy of Engineering, and the Institute of Medicine, chartered by Congress in 1863 to advise the government on matters of science and technology. In 2008, the Board on Life Sciences established the Committee on A New Biology for the 21st Century: Ensuring the United States Leads the Coming Biology Revolution, whose report I am very pleased to discuss with you today. The report "A New Biology for the 21st Century," which was released in August 2009, was sponsored by the National Science Foundation, the National Institutes of Health, and the Department of Energy. The study committee was co-chaired by MIT Professor and Nobel Laureate Philip Sharp and Dupont Senior Vice President and Chief Innovation Officer Thomas Connelly. I also served as a member of the study committee.

To begin to describe the New Biology report, allow me to weave for you an imaginary scenario, a scenario of research and science education, in the classroom or lecture hall of the introductory biology course this September in a college or university in your district. Listen in with me to the professor:

> *"Thirty years from now, farmers in the United States and around the world could be producing sufficient food locally to nourish people in their regions, with no net increase in arable land and*

fresh water use, and a decrease in use of fertilizer, pesticides and fossil fuels. Furthermore, each region of the United States could have a thriving and sustainable biofuel industry, with liquid transportation fuels produced from locally grown biomass. Importantly, these advances in food and biofuel production could be carbon neutral, in other words, releasing no more greenhouse gases than they consume. And carbon flows into and out of the environment could be monitored by sensors that also assess ecosystem health, and provide immediate warning and simple restitution of environmental stress.

How will we achieve this? We must find ways to quickly and safely breed new and different food crops to achieve maximum production under any growing condition. We must find ways to adapt biomass crops to capture solar energy efficiently and convert it into easily processed biomolecules. We must find ways to detect early signs of stress to our ecosystems, and ways to restore them when they've been damaged. These are all challenges that demand aggressive and substantial advances in our knowledge and understanding of biology. Getting there will demand your best efforts should you become a biologist. But getting there will also require that some of your classmates who become physicists, chemists, engineers, mathematicians and computer scientists apply their skills to biological problems. It will take all of you, working together, to crack the deepest secrets of how living organisms obtain energy, grow, interact, resist stress, combat disease, reproduce, and dispose of waste. And it will take all of you to apply that understanding, and invent the technologies to advance our knowledge and achieve these goals.

The United States has determined that it must and will lead the world in achieving carbon neutral and sustainable agriculture and biofuel production. A national New Biology effort has been undertaken jointly by the National Science Foundation, the Departments of Agriculture, Energy, Interior and Education, the National Institutes of Health, and many other partners both public and private. The scope and scale of this challenge are such that no individual, no *university, no company, no federal agency could possibly solve it alone. Today you begin the process of learning how biology – the New Biology-- can enable the United States to meet these challenges."*

The Committee on a New Biology for the 21st Century recommended that just such an imaginary scenario become reality—perhaps not by this September, but very soon. The scientists and engineers on the committee agreed that biology is at an inflection point – poised on the brink of major advances that could address urgent societal problems. Importantly, these problems demand bold action—they cannot be solved by a 'business as usual' approach. The United States has invested wisely to make us the world leader in life science discovery by promoting and supporting the curiosity and creativity of individual scientists. It is crucial that this investment continues and expands. But in addition, the committee recommended that now is the time to recognize some profound challenges, and to address those challenges by undertaking a bold experiment-- to augment current life sciences research, which is spread across more than 20 Federal agencies, with a small number of 10-year challenges that are urgent and inspiring, but unreachable without a coordinated approach that draws from and aligns the separate strengths of multiple agencies.

Why did the committee decide that a new approach is needed? For two reasons: first, the science is ready. And second, it is clear that we are missing important synergies and opportunities to leverage advances being made across the life sciences.

The report details five reasons why biology is ready to take on major challenges:

- First, the fundamental unity of biology has never been clearer or more applicable. Knowledge gained about one genome, cell, organism, or ecosystem is useful in understanding many others. The same technologies that allow us to survey human genomes for disease-associated genes also power high-throughput approaches to screening millions of plant seeds for desired genetic characteristics. It no longer makes sense to talk about biomedical research as if it is unrelated to biofuel or agricultural research; advances made in any of these areas are directly applicable in the others and all rely on the same foundational technologies and sciences.

- Second, new players are entering the field, bringing new skills and ideas. Physicists, chemists, mathematicians and engineers are increasingly attracted to the field of biology because of the fascinating questions it poses-- questions that they can uniquely contribute to answering.

- Third, a strong foundation has already been built. Life science research has been amazingly productive for the last fifty years. The effort to construct the "parts list" for living systems has been a tremendously exciting intellectual adventure in its own right, and has had revolutionary outcomes in agriculture, health and industry.

- Fourth, past investments are paying big dividends. The Human Genome Project and subsequent advances in other high-throughput approaches and computational analysis have dramatically increased the productivity of life sciences researchers no matter what organism they study. Being able to collect and analyze comprehensive data sets allows researchers to study biological phenomena at the level of systems. The explosion of unanticipated benefits of the Human Genome Project demonstrates how biology can benefit from large-scale interdisciplinary efforts.

- Finally, new tools and emerging sciences are expanding what is possible. In addition to high-throughput approaches, information and imaging technologies have dramatically expanded the kinds of questions biologists can ask and answer. Systems, computational and synthetic biology are contributing to advances across the field of biology, from biomedicine to bioremediation.

The report gives many examples of advances that have been made possible by interdisciplinary teams integrating past discoveries and new technologies to produce major advances. The committee called this new approach the 'New Biology' and examples of the new approach are already emerging in many universities. But the committee's discussions with scientists and supporting agencies made it clear that the New Biology is as yet poorly recognized, inadequately supported, and – critically – delivering only a fraction of its potential.

The committee concluded that the United States has an unprecedented opportunity to capitalize on the new capabilities emerging in the life sciences by mounting a multi-agency initiative to marshal resources and provide coordination to empower and enable the academic, public, and private sectors to address major societal challenges.

Why major challenges?

First, because the problems are urgent. We must find ways to provide food and energy to a growing population without destruction of our ecosystems; we must find solutions to the increasing burden of chronic disease in our society, and to malnutrition and infectious disease in the developing world.

Secondly, because big goals – like putting a man on the moon, or sequencing the human genome – can inspire both scientists and the public. Big goals can attract the efforts of scientists and engineers who currently may not see how they could contribute their expertise to solving these urgent problems. Big goals can focus the imagination, creating the technological breakthroughs essential for achieving the goals. Finally, big goals provide explicit accountability: in enunciating a major challenge, the New Biologists and the public sector make a compact––a commitment to a sustained investment that will produce concrete, measurable results.

In the report, the committee described four broad areas of urgent need––food, energy, the environment, and health––and gave examples of the kinds of challenges that the New Biology could take on. In the area of food, for example, the committee suggested that the New Biology might develop ways to quickly, inexpensively, and safely adapt any crop plant to any growing condition. Success could enable local production of sufficient food, even on land that is considered non-arable today.

But the committee avoided prescribing specific projects or action plans. Instead, they called for visionary scientists and engineers from each area to identify great challenges for the New Biology that seem impossible now, but within reach if attacked in a coordinated way. A recent workshop demonstrated that the scientific community is more than up to the task.

The starting point was a March 16th meeting, where Department of Energy Secretary Stephen Chu, Department of Agriculture Secretary Tom Vilsack and HHMI President Robert Tjian agreed after a briefing from members of the New Biology committee to sponsor a workshop to generate challenge ideas at the scope and scale envisioned in the report. Secretaries Chu and Vilsack, and President Tjian all recognized the interconnections among their missions––human health depends on achieving sustainable production of food and energy in the face of multiple environmental stressors, including climate change. Clearly, none of these challenges can be addressed in isolation, but equally clearly, all four challenges are critically dependent on rapid advances in biological understanding and application.

The resulting June 3-4 workshop sought to develop broad ideas and project areas that could provoke quantum leaps of progress toward sustainable production of both food and biofuels.

(Subsequent workshops will focus on other combinations of the four areas of need identified by the committee.) The workshop brought together an extraordinary group of scientists and engineers that spanned the scales, from molecules to ecosystems, and spectrum, from viruses to microbes to plants to animals, of modern biology. Each participant arrived at the workshop armed with a transformative idea to be presented in a three-minute talk during the first session. After hearing these short talks, the group broke into small subgroups to separately mold this collection of thirty bold ideas into a few decadal challenges, map out strategies for reaching them, and identify knowledge and technology gaps.

Upon reconvening, the subgroups swiftly converged on a common overall goal: to sharply increase productivity in agriculture and biofuel production while simultaneously making both of these sectors carbon neutral. All agreed that reaching this goal would require major advances in our fundamental understanding of plants and microbial communities, substantial investment in computational theory and infrastructure, and development of a quantitative and biologically-informed system for measuring the flow of carbon and other greenhouse gas constituents. It became very clear that not only could neither USDA nor DOE achieve this goal alone, but that a coordinated effort would be required—a National New Biology Initiative that harnesses the capabilities of these and other agencies: NSF to stimulate necessary advances in fundamental knowledge of plants and ecosystems; NASA, NOAA, USGS and NIST to work with DOE's Ameriflux program and NSF's NEON program to develop the ability to monitor carbon flows; NIH to contribute its expertise in genomics, basic cellular, molecular and microbial biology, and bioengineering.

I would be remiss if I failed to return to the vision that opened my testimony – college students being challenged from the first day of class to consider how life science research is relevant, indeed essential, to the solution of serious societal problems. A New Biology Initiative would give students interested in real-world problems an incentive to learn fundamental principles of science, mathematics and engineering, and to acquire an integrated view of those disciplines.

At the same time, the Initiative would provide the opportunity to establish and evaluate new educational and training opportunities. Many reports have appeared that recommend ways to improve science education in the United States; few of the recommendations have been implemented. To promote and enable the New Biology Initiative, the committee strongly endorsed three major recommendations from the 2003 NRC report, *Bio2010*: First, design curricula to ensure that biology students are well grounded in mathematics, physical and chemical sciences, and engineering; conversely, biological concepts and examples should included in all science courses. Second, laboratory courses should be interdisciplinary, and independent research experience should be offered as early as possible. Finally, development time should be provided to enable faculty to appreciate fully the integration of biology with the physical sciences, math and engineering, and to revise their courses accordingly.

The New Biology committee issued a call to devote a modest portion of the life sciences research enterprise to empowering this new approach – to adding a new layer to the traditional strategies, a New Biology Initiative that marshals basic science purposefully toward solving urgent societal dilemmas, that focuses teams of researchers, technologies and foundational sciences required for the task and coordinates efforts across agency boundaries to ensure that gaps are filled, problems addressed, and resources brought to bear at the right time. Close interaction between these problem-oriented efforts and the more decentralized basic research enterprise will be critical––and mutually beneficial––as the traditional approaches will make relevant unanticipated discoveries, and advances that benefit all researchers will spin out from problem-based projects. A New Biology Initiative to address major challenges would represent a daring addition to the nation's research portfolio, with remarkable and far-reaching potential benefits: a more productive life sciences research community; a citizenry better informed about the logic and potential impact of biological research; a broad range of new bio-based industries; and, most importantly, a science-based strategy to produce food and biofuels sustainably, monitor and restore ecosystems, and improve human health.

This concludes my testimony. I would be pleased to answer your questions or address your comments. Thank you again for the opportunity to discuss this important matter with you.