Prepared Statement of Roland Otto
Head of the Center for Science and Engineering Education, Berkely National Lab
Before the Secretary of Education's Commission on the Future of Higher Education
Third Meeting, February 2-3, 2006

STATEMENT OF ROLLIE OTTO BEFORE THE SECRETARY OF EDUCATION'S COMMISSION ON THE FUTURE OF HIGHER EDUCATION

Essential Educational Elements for the Science, Technology, Engineering, and Mathematics (STEM) Pipeline:

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Thank you for the opportunity to discuss the future of higher education, and to provide comments related to innovative public/private sector models. My comments and recommendations will focus on the science, technology, engineering, and mathematics (STEM) pipeline. I take the position that the responsibility for the preparation of the 21st century STEM workforce does not rest with colleges and universities alone; this great responsibility should be shared by public and private scientific and technological enterprises, as they can have a direct role in the education of students and faculty.

I have spent 31 years at Lawrence Berkeley National Laboratory, both as a research scientist and head of the Center for Science and Engineering Education. Berkeley Lab is a multiprogram national laboratory operated by the University of California for the U.S. Department of Energy. The Laboratory is adjacent to the University of California at Berkeley and was founded by UC physics professor Ernest Orlando Lawrence, the inventor of the cyclotron, resulting in a legacy of advances in nuclear science and medicine, particle physics, and accelerator physics that continues today.

Berkeley Lab has been an internationally recognized leader in science and engineering research for 75 years. It holds the distinction of being the oldest of the U.S. Department of Energy's national laboratories. It has 3,800 employees, of which about 1,000 are staff scientists and engineers, and 500 are graduate students and postdocs. Berkeley Lab conducts unclassified research across a wide range of scientific disciplines with key efforts in fundamental studies of the universe; quantitative biology; nanoscience; new energy systems and environmental solutions; and the use of integrated computing as a tool for discovery. In the last ten years Berkeley Lab has won ten R&D 100 Awards, many of which have been licensed through technology transfer agreements. Berkeley Lab technology has formed the basis for twenty start-up companies capitalized at $1.9 billion. Leading private sector technology companies utilize the advanced user facilities at the Laboratory. Berkeley Lab collaborates with and hosts scientists from universities and government research facilities around the world, which is typical of the large DOE Office of Science multipurpose national laboratories. These DOE labs, often seen as national treasures for economic development, stand apart from both universities and private sector science and technology companies. The DOE labs do mission-oriented science research and technology development that often requires large-scale facilities. The DOE labs also stimulate technologies that lead to economic competitiveness without competing with the private sector, provide access to world-class user facilities for research university investigators, and educate and train thousands of students and faculty but do not grant degrees.

The education of the next generation of scientists and engineers is part of Berkeley Lab's mission and tradition. Berkeley Lab's Center for Science and Engineering Education (CSEE) was established in 1988 to extend its education outreach beyond graduate and postdoctoral professional development. The Center develops, implements, and evaluates programs that utilize the resources of Berkeley Lab to improve the quality of mathematics, science, and technology education. It supports projects and activities for public science and technological literacy, precollege (K–12), community college, and undergraduate and graduate education. It also serves as a coordinating center for outreach programs, and for the formation of partnerships with schools and school districts, science and technology education centers, colleges and universities, and the private sector.

Over the years we have developed strategies and approaches to utilize the human and technical resources of Berkeley Lab to achieve the following goals:

- Promote equal access to scientific and technical careers for all students.
- Improve the quality of science and engineering teaching and learning.
- Increase the number of U.S. students who become scientists and engineers, with an emphasis on those student groups historically underrepresented in the scientific and engineering enterprise.
- Promote scientific literacy.

Support for CSEE programs is provided by the Department of Energy's Office of Science. The comments and recommendations I will make are mine and do not necessarily reflect the views of the management of the Lawrence Berkeley National Laboratory or the Department of Energy, Office of Science.

You have asked for comments on innovative public/private sector models as you consider "how best to improve our system of higher education to ensure that our graduates are well prepared to meet our future workforce needs and are able to participate fully in the changing economy." Therefore, I would like to take some time to focus on the question: What are the essential elements of students' learning experiences in higher education that will prepare them to "enhance the science and technology enterprise so that the United States can successfully compete, prosper, and be secure in the global community of the 21st Century?" (*Rising Above the Gathering Storm*). The short answer to this question is practical hands-on mentored scientific research and technology development experiences with access to scientific tools, equipment, and computational capabilities for all students in the STEM pipeline.

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You have sufficient testimony regarding problems and challenges as well as evidence and statistics that we are not meeting the educational needs of many students in our K–12 schools and colleges that I will not repeat. I will instead discuss strategies we are using at Berkeley Lab to address these problems. I am not advocating these strategies as specific models, because they are uniquely matched to the resources that national labs bring to education partnerships. I am advocating policies and support for school, public, and private partnerships that find innovative ways to use their combined resources to provide mentorship and access to scientific tools for students in the STEM pipeline.

What are we preparing students for, and what skills and knowledge will they need?

The next several decades will be marked by an explosion of technological innovation and scientific discoveries. I recently read "that what will happen in the future is already happening now." My experience supports that what is happening at Berkeley Lab and other Department of Energy, Office of Science, labs provides a view of the future of science and technology and by extension an understanding of what skills and knowledge today's STEM students will need.

Scientific research and technology development at Berkeley Lab can be characterized by the integration of core competencies to solve the key problems facing humankind in areas of health, energy, materials, and the structure of matter. For example, Steve Chu, Berkeley Lab Director, Nobelist, and member of the National Academies committee that produced the report *Rising Above the Gathering Storm*, sees a lab positioned to utilize its core strengths to develop CO_2-neutral energy. Central to these strengths is the Lab's world-class facilities with state-of-the-art tools that attract international cooperation and participation, and a core of dedicated and talented scientists, engineers, and computer scientists. Director Chu states in the Lab's annual report *A View to the Future* that this single most important societal problem that science and technology must solve is central among America's most serious concerns of national security (intimately tied to energy security), long-term economic competitiveness, and the dangers of global warming.

Paraphrasing from articles in *A View to the Future*, the field of health will see scientific and technological breakthroughs difficult to imagine 20 years ago. At the start of the 21st century, scientists now have the tools needed to study living cells at the molecular and atomic levels. The information gained from this ever-expanding array of tools is opening entire new avenues for the prevention and control of some of our deadliest and most pernicious diseases, including major forms of cancer, HIV-AIDS, and malaria. It is also paving the way for learning to repair or replace damaged cells and tissues.

One dramatic example of *A View to the Future* is "Synthetic Biology," which aims to design and construct novel organisms and biologically inspired systems that can solve problems that natural biological systems cannot. Berkeley Lab scientists are developing an organism designed specifically to produce the chemical precursor to one of the most promising and potent of all the new antimalarial drugs — artemisinin. This drug is proven to work, but it is far too expensive to produce to impact the 500 million people who annually become infected with malaria. Jay Keasling, a UC and Berkeley Lab researcher and the Director of Berkeley Lab's Physical Biosciences Division, leads the synthetic biology research that will result in an anti-malaria drug that will be inexpensive to produce and distributed thanks to a $42.6 million grant from the Bill and Melinda Gates Foundation.

Atomic and molecular level imaging at Berkeley Lab, along with the development of nanoscale materials, is creating new technologies, tools, and capabilities. One example is the ability to track the path of a single molecule in the nucleus of living cells using nano-sized particles called quantum dots. An important application is tracking the interactions in living cells to determine the effectiveness of disease-fighting drugs.

One of the premier national user facilities of Berkeley Lab is its Advanced Light Source (ALS); the world's brightest source of ultraviolet and soft x-ray beams, it makes previously impossible studies possible in all fields of science. Synchrotron light sources like the ALS are being built around the world. Today, with advanced computational capabilities and the human genome completed, not only are we able to find genes, but we can also describe the three-dimensional structure of the proteins produced by those genes. With the Advanced Light Source, data can be collected and analyzed using advanced computation, and the entire process that only several decades ago took months to years is now done in a matter of hours and days. The relationship of structure and function has been a major paradigm in biology; we are now seeing this paradigm at the atomic, molecular, and cellular level. In the last two decades, we have moved from genomics to proteomics, entering the stage of atomic and molecular descriptions of living organisms.

The U.S. Department of Energy's Office of Science provides supercomputing facilities and computational tools for nonclassified research for faculty and investigators throughout the nation. Berkeley Lab's National Energy Research Supercomputing Center is solving problems "in silica" that cannot be addressed in the lab. The result has been new discoveries and predictions related to energy, climate, nuclear reactions, and biological systems. Along with these supercomputing capabilities are computational tools for scientific and technology collaborations that will bring the latest findings in labs around the world to investigators in a matter of days.

What skills and knowledge will today's student need?

There have been many reports and studies to answer this question. In brief, students need to work and think like scientists or engineers. I offer the following list with apologies for not fully recognizing these sources or their contributions. The list largely reflects my experiences with undergraduates from universities and colleges across the country, and high school student interns and teacher participants at Berkeley Lab.

1. A solid foundation in the basic concepts, principles, and theories of all fields of science. Ideally, this science literacy level of knowledge would be taught in high school in four years of science courses.

2. Professional level of knowledge and skills in one field of science, engineering, technology, or mathematics. This is the undergraduate preparation provided by community colleges, colleges, and universities.
3. Ability to recognize and make connections between what they are taught in the classroom and real-world applications. It is surprising how frequently undergraduate students miss these connections, and how readily high school students put their knowledge into isolated mental compartments.
4. Understanding of the relationship between science, technology, and societal issues.
5. The nature of scientific inquiry and the ability to apply it to scientific investigations.
6. Math concepts and the ability to use advanced computational tools.
7. Communication and collaboration skills using technology.
8. Willingness to learn and integrate knowledge from areas outside of their own expertise to solve complex interdisciplinary problems.
9. Persistence and willingness to work hard.

Who should we be preparing?

The short answer is that we should be preparing all students, with ongoing support for those students who show an interest in STEM careers. One aspect of our current education system is that we are underserving our most talented and motivated students in the STEM pipeline. Furthermore, we have not extended sufficient effort to reach those groups underrepresented in STEM careers, namely blacks, hispanics, native americans, and women.

It is our experience that programs designed around mentored research experiences using scientific tools can address most of the barriers and challenges to developing the skills and knowledge students will need to contribute to the 21st century science and technology workforce. Furthermore, it is a powerful and effective strategy for capturing and preparing students who have been historically underrepresented. The strategies described below have been built around the principle of mentored research experiences and access to scientific tools. These strategies motivate students to consider STEM careers and advanced degrees. They calibrate students to the skills and knowledge they will need, and provide for their professionalization. These strategies provide teachers and faculty with experiences that update their knowledge and transform their view of teaching and learning.

Strategies for Success

Engineering departments at colleges and universities have long recognized the importance and value of co-ops and internships. Federal science agencies (Energy, NSF, NIH, NASA, Agriculture, and Homeland Security) are increasing their support for internships at the undergraduate level. Minority-serving institutions have utilized mentored internships to provide increased student graduation and graduate school attendance rates.

Following are some strategies we have used at Berkeley Lab to extend the practice of mentored research experience using "real" science and technology tools to more students and further down and earlier in the pipeline:

- Providing a basic framework for student-mentor relationships, and requiring interviews with mentors and writing an abstract that connects the student's assignment to the group's mission-oriented work.
- Effective writing and presentation workshops for undergraduate interns.
- Frontier science lectures by leading Berkeley Lab investigators.
- K–12 outreach opportunities for undergraduate interns.
- Faculty-student teams to develop faculty mentors at community colleges and minority-serving universities to promote scientific collaborations with Berkeley Lab investigators, increase on-campus mentoring, and identify students for internships at Berkeley Lab.
- Summer teacher research internships for secondary science teachers with generous academic year support for materials and professional society meetings.
- Partnerships with local urban school districts to identify and support teacher leaders for internship appointments.
- High school student research participation internships utilizing partnerships with teachers of high minority student populations to identify students to participate along with those who self-identify from high-performing schools.
- Preservice teacher science research and science education immersion internships for K–12 teachers of math and science. Partnerships with California State Universities with NSF-sponsored preservice teacher programs.
- Hands-on science investigations for high schools and college students connected to mission-oriented research activities and professional-level tools at Berkeley Lab with concurrent training of teachers and faculty.

A major factor contributing to our efforts has been a cooperative agreement between the National Science Foundation and the Department of Energy, Office of Science, that allows students and faculty in NSF-sponsored STEM programs on university campuses to receive supplemental support for internships at the DOE labs. Access to mentored research experiences leverages the extensive investment by NSF, especially for underrepresented minorities, and allows DOE to more fully use its Lab based national science and technology investment for STEM education.

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Recommendations

Increase support in federal science and technology agencies for research internships for high school and college students and faculty.

Support programs that recognize mentors and provide additional funding to support long-term follow-up, including tracking participants through graduate school and into careers.

Provide support for minority-serving institutions (MSI's) to obtain state-of-the-art scientific research equipment and technologies to support on-campus mentoring and research for their students. Develop financial and material incentives for faculty training.

Consider some of the successful MSI's strategies to increase minority participation and retention at these institutions as models for major research universities. For example, research clusters with access to advanced tools for lower-division undergraduate students, including non-STEM majors.

Encourage private sector science and technology businesses and industries to partner with schools and colleges, and to participate in outreach to high school and college students and faculty supporting mentored research and student access to science and computational tools.

Fund successful STEM pipeline programs and activities that meet a set of implementation and follow-up criteria for terms longer than five years, provided innovative methods keep pace with scientific technological advances and students' needs and interests.

Encourage all STEM programs to push student mentoring and access to "real science tools and equipment" as far down the educational pipeline as possible.

Encourage public/private/university/school partnerships for mentoring and access to science tools and equipment.